Defining Reliability for a New Grid

Maintaining Reliability and Resilience through Competitive Markets

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PREPARED BY

Ira Shavel

Michael Kline

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Executive Summary

The past decade has seen significant changes in the composition of electricity generating capacity. The biggest changes have been a significant increase in renewables – primarily wind and solar, which provide fluctuating amount of energy and thereby designated variable energy resources ("VERs") – and a significant increase in natural gas generation. At the same time, coal and nuclear generating capacity is shrinking, with retirements driven by environmental policy (for coal plants in the first half of this decade) and persistent low wholesale market price conditions. These shifts have raised concerns regarding maintaining the reliability and resilience of electricity supply, and promoted debate over the best way to achieve those important objectives. This paper addresses concerns that increased use of natural gas could potentially have a negative impact on reliability and resilience. Drawing from market and policy reforms designed to preserve reliability while integrating larger contributions from VERs, this study articulates principles that should guide the development of electric market rules to address reliability and resilience concerns arising from increased dependence on natural gas generation.

Reliability has always been the cornerstone of electricity system design and operation in both traditionally regulated systems and organized markets operated by Regional Transmission Organizations ("RTOs") or Independent System Operators ("ISOs").[1] RTOs operate markets for energy, capacity and ancillary services, as well as imposing a range of other reliability standards, in order to meet reliability goals of (1) resource adequacy, *i.e.*, ensuring that sufficient operable generation capacity is available to meet instantaneous energy demand at all times and (2) operational reliability, *i.e.*, managing the grid to ensure that electricity is delivered to loads even when significant real-time perturbations threaten grid stability. These goals are achieved by providing sufficient amounts of Essential Reliability Services ("ERS").[2] Resilience is a concept that describes the performance of the grid under severe and/or unprecedented stress conditions, where a resilient grid either avoids a significant customer service disruption or quickly restores power in the event that disruptions cannot be avoided.

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1 Although there are technical differences between RTOs and ISOs, in this paper we use the term RTO to describe both RTOs and ISOs.

2 https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Concept%20Paper.pdf

The introduction of significant amounts of VERs challenged both resource adequacy and operational reliability (primarily the latter) by creating new demands for ERS, from traditional ancillary services such as spinning reserves as well as new services. The RTOs have responded by revising and or defining new ERS and allowing all resources to compete to supply them. The VER integration challenge, therefore, has been met (and continues to be met) through market reforms that compensate resources for providing newly valuable attributes such as rapid ramping and flexibility.

The increased role that natural gas generation plays in the U.S. has prompted reliability and resilience concerns relating to the perceived vulnerability of gas pipelines and/or the assurance of firm gas supply to generators in high gas demand (*e.g.*, extreme cold weather) conditions. Some industry participants and the U.S. Department of Energy ("DOE") have recently attempted to broaden the concept of ERS to encompass attributes or services that have little or no direct relationship to reliability or resilience, and to provide compensation for providing these attributes. A recent proposal by DOE, for example, was based on the premise that "baseload" coal or nuclear plants with 90 days of on-site fuel supply provide essential and unique reliability and resiliency benefits, which justified cost-of-service compensation in selected RTOs. This is an example of starting with a specific reliability solution, and then describing how attributes such as fuel inventories are ERS and therefore justify out-of-market compensation.

However, the historical record and current analysis do not support the claims that these technologies provide unique reliability and resilience benefits. For example, the results of a recent PJM study suggest that even much greater reliance on natural gas in that region does not threaten resilience.[3] Moreover, to the extent that concerns arise regarding the reliability or resilience implications of depending heavily on a single fuel or generating technology, policies that subsidize or mandate other fuels and technologies would likely lead to inefficient outcomes and raise the cost of ensuring reliable electric service. The model of RTO market reforms to meet the challenge of VER integration provides a more productive path forward. These policies began by examining how shifts in the generation mix altered the demands for ERS. RTOs then defined

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3 We discuss the results of the study "PJM's Evolving Resource Mix and System Reliability" in Section III.C. We note that PJM recently announced it has begun another study focusing on the resilience of the electric system under different scenarios involving the disruption of the fuel delivery system.
http://insidelines.pjm.com/new-initiative-continues-pjm-quest-for-better-fuel-security/

products and established markets to ensure that these ERS demands were met with competitive supplies. Reliability and resilience depend on the mix of generating technologies and prevailing market conditions. These factors determine whether a coal plant provides more or less reliability and resiliency benefits to the system than a natural gas plant. All generators, regardless of feedstock, can take measures that improve attributes that contribute to reliability and resilience, *i.e.*, gas plants can add onsite oil storage or contract for firm gas transportation; coal can maintain large inventories at all times; and wind plants can add equipment to provide synthetic inertia. However, not all of these measures are always necessary or cost effective. The task of good policy and market design is to ensure that only the most valuable and cost-effective reliability solutions are pursued. The lesson of VER integration suggests that RTOs should achieve reliability and resilience goals through market signals directed at providing valuable services that are defined in a resource-neutral manner, rather than mandating specific technical measures based on fuel type.

While RTOs have a legitimate interest in performing risk analyses that consider the potential impact of a particular feedstock disruption (*e.g.*, natural gas pipeline failures, coal piles freezing, droughts, multiple nuclear shutdowns, loss of renewables due to calm wind conditions), RTOs should avoid imposing additional fuel-specific technology requirements on certain generating units as a means to provide ERS associated with fuel supply. For example, RTOs should not establish requirements that all natural gas generators have onsite fuel storage or firm natural gas supply. Nor should RTOs require all coal units to have a pre-specified large coal inventory on hand at all times. Preferably, RTOs would establish clear rules related to non-performance to which individual resource owners should determine how best to respond. Economic theory as well as experience shows that it is more efficient to establish penalties for non-performance and let unit owners determine how to manage their fuel supply in light of those penalties.

I. Emerging Reliability and Resilience Issues

Reliability is a function of both resource adequacy and operational reliability. In the past, maintaining reliability focused on ensuring resource adequacy. However, greater reliance on generation from variable energy resources ("VERs") increases the importance of operational reliability needs, particularly in terms of which needs need to be explicitly defined and remunerated. Over the last several years, RTOs have taken steps to create markets for the types of essential reliability services ("ERS") needed to ensure operational reliability while integrating large quantities of VERs. The continued reliable performance of the grid demonstrates that this market approach to VER integration has worked effectively.

In light of the 2014 Polar Vortex and the retirement of coal and nuclear plants, some parties have suggested that increased reliance on natural gas-fired capacity creates unique reliability and resilience issues because natural gas is delivered via pipelines rather than stored as solid fuel onsite. Both PJM and ISO-NE responded to the Polar Vortex by strengthening the performance requirements for resources that clear their capacity markets. These reforms have already been implemented in PJM. A review of generator availability during the Bomb Cyclone compared with the Polar Vortex indicates the measures have improved reliability.[4] As with VER integration, the market approach to obtaining ERS efficiently minimizes the risk that fuel supply issues pose reliability and resilience.

The North American Energy Electric Reliability Corporation ("NERC") develops reliability requirements and the Federal Energy Regulatory Commission ("FERC") approves them. Planners generally try to limit bulk power loss of load events related to generator availability to a single event every 10 years, frequently termed a 1 in 10 Loss of Load Expectation ("LOLE") standard[5]. Grid operators maintain operational reliability – that is the ability to follow load while maintaining frequency – by obtaining ERS to ensure the availability of generators with the

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4 PJM Cold Snap Performance Dec. 28, 2017 to Jan. 7, 2018, page 2. http://www.pjm.com/-/media/library/reports-notices/weather-related/20180226-january-2018-cold-weather-event-report.ashx

5 There are other standards which have been used, but in principle are similar.

necessary reliability attributes.[6] A supply resource's technology determines what ERS a resource can provide.

At the same time, policy makers have begun to focus on a related concept called "resilience." In this paper, "reliability" relates to preventing customer service outages that can occur for predictable reasons and can be protected against (e.g., shortage of generation due to outages of generating units or transmission elements), and "resilience" relates to events that tend to be rare, unexpected, difficult to predict and that have the potential for significant disruption such as physical attacks on infrastructure, cyberattacks, and extreme weather. Reliability criteria are established to prevent service disruptions from occurring (shortage of capacity) or to make sure the events have minimal impact on the system (operating transmission with credible contingencies in mind). Resilience, on the other hand, refers to the "ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event."[7]

Reliability standards exist to mitigate the frequency and severity of power outages, which impose substantial costs on the U.S. economy. Lawrence Berkeley National Labs ("LBNL") estimates the cost of power outages in the U.S. from all causes at $110 billion annually.[8] Beyond the economic costs, extended power outages can also result in loss of life. The disaster left by Hurricane Maria in Puerto Rico demonstrates both the economic and human dangers posed by a lack of electric supply.

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6 Grid operators also maintain transmission system security – the capability of the transmission system to reliably deliver power after the loss of one or more of its elements, although not discussed in this paper.

7 FERC Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures, Docket Nos. RM18-1-000 and AD18-7-000, January 8, 2018, page 13. The focus of this paper is resilience at the level of generation and bulk transmission, not of the distribution system.

8 The National Cost of Power Interruptions to Electricity Customers – An Early Peek at LBNL's 2016 Updated Estimate, Joseph H. Eto, July 19, 2016, p. 11.

Failures in the distribution system cause the vast majority of power outages in the U.S. but transmission outages can affect a larger number of customers and hence a larger amount of load.[9] Distribution outages generally occur because of weather related events. A recent study by the Rhodium Group concluded that between 2012 and 2016 lack of available generation caused only 0.00865% of the major electric supply disruptions. Fuel shortages caused only 0.00007% of the major electric supply disruptions during the period. The Rhodium analysis also notes that the vast majority of the hours of customer outage caused by fuel shortages were associated with a single incident in Minnesota involving a coal plant.[10]

Wholesale supply – or Bulk Power System ("BPS") – related outages occur relatively infrequently. NERC defines BPS reliability as a function of 1) resource adequacy, and 2) operational reliability. NERC defines resource adequacy as "the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components."[11] Resource adequacy standards ensure unexpected generator outages rarely lead to a loss of load. Today, all regions of the U.S. have adequate supply resources. NERC defines operational reliability as "the ability of the electric system to withstand sudden disturbances to system stability or unanticipated loss of system components."[12] While the NERC definition of operational reliability echoes a portion of the resilience definition, the focus of operational reliability is the routine operation of the system rather than response to major disasters. For example, PJM states "[o]perational reliability addresses the grid's day-to-day operational needs

9 "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." Transforming the Nation's Electricity Sector: The Second Installment of the QER, January 2017, Page 4-31.

10 Trevor Houser, John Larsen, and Peter Marsters, The Rhodium Group, "*The Real Electricity Reliability Crisis*" October 3, 2017.

11 Gerry Cauley (president and CEO, North American Electric Reliability Corporation), letter to Energy Secretary Rick Perry, May 9, 2017.

http://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Comments%20of%20NERC%20re%20Proposed%20Grid%20Reliability%20and%20Resilience%20Pricing.pdf.

12 Gerry Cauley (president and CEO, North American Electric Reliability Corporation), letter to Energy Secretary Rick Perry, May 9, 2017.

http://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Comments%20of%20NERC%20re%20Proposed%20Grid%20Reliability%20and%20Resilience%20Pricing.pdf.

and is measured by a portfolio's capability to provide the defined key generator reliability attributes."[13]

Both reliability and resiliency are functions of the grid as a whole and the mix of resources used to meet load. In a system with very little dependence on VERs and relatively stable load, the need for frequency response is much less and the supply of inertia is much greater than in a system with fast moving net load and a high degree of VER integration. An individual resource's contribution to reliability and resilience is not simply a function of its average availability. It is a function of many factors including its expected availability during system peaks, the correlation of its forced outages with other system resources, and its ability to provide ERS. Thus, a resource's contribution to reliability and resilience may change as demand patterns change and as the composition of the supply stack changes.

For example, as the penetration of VERs continues to increase, they can shift peak net load to hours when VERs have a lower expected output. This can decreases the contribution VERs make to resource adequacy. VERs also increases the volatility of net load, which can increase the need for ERS. Moreover, the output of wind and solar units in a particular region tends to be highly correlated. As the penetration of a particular VER technology (i.e. wind or solar PV) increases, the possibility of a generation shortfall due to an unexpected drop in wind speed or solar insolation also increases. Thus, the contribution VERs makes to resilience decreases as penetration increases and may even become negative on the margins.

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13 PJM's Evolving Resource Mix and System Reliability, March 30, 2017, page 4.
http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

II. Market-Based Approaches Maintain Reliability Despite Greater Reliance on VER Generation

In the past, reliability efforts focused on resource adequacy, but increased contributions from VERs has increased the importance of operational reliability. Going forward, economic, environmental, and policy indicators all suggest the share of VERs in the generation mix will increase further. While VERs provide some reliability benefits, they can increase a system's aggregate need for ERS by increasing the variability of net load (i.e., customer demand minus VER output).[14][15]

Recent studies examining the importance of operational reliability have generally concluded that VERs can provide a significant share of system energy supply without compromising reliability. These studies also indicate that integrating high levels of VERs requires flexible resources that can provide ERS to stabilize frequency, provide inertia, ramp, and provide voltage control.[16] For that reason, the increased penetration of VERs has created new operational reliability requirements that the FERC and the RTOs have begun to address. Increased reliance on VERs has led NERC to expand its definition of balancing to include a time dimension (ramping) that reflects the new reality that VER integration requires operationally flexible resources that provide ERS.

As an example of the challenge posed by VER integration, CAISO, ERCOT and the U.S. Department of Energy ("DOE") have expressed concern that greater reliance on renewables combined with the loss of coal and nuclear units will lead to less inertia, which helps maintain

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14 http://www.brattle.com/news-and-knowledge/news/brattle-economists-identify-key-attributes-for-ensuring-electric-grid-reliability-with-increased-variable-energy

15 http://files.brattle.com/files/6106_exploring_natural_gas_and_renewables_in_ercot-future_generation_scenarios_for_texas.pdf

http://files.brattle.com/files/6065_exploring_natural_gas_and_renewables_in_ercot_part_iii_shavel_weiss_fox-pennerf.pdf

16 http://files.brattle.com/files/7760_exploring_natural_gas_and_renewables_in_ercot_-_future_generation_scenarios_for_texas.pdf

See Appendix B for a description of the PSO modeling of net load uncertainty. Further detail about the modeling of ancillary services can be found in

http://www.ercot.com/content/meetings/lts/keydocs/2014/0113/5._ERCOT_01_13_14_shavel.pdf frequency.[17] FERC also raised concerns that increased reliance on wind and solar has led to a decline in total system inertia, leading to larger and more rapid variations in frequency.[18] Similarly, NERC has stated, "[w]ind, solar, and other variable energy resources that are an increasingly greater share of the BPS provide a lower level of ERS than conventional generation."[19]

To address such challenges, market rules will need to attract resources that provide the ERS needed to integrate VERs. Although markets already pay resources that provide ERS, the amount and types of ERS needed to integrate the planned levels of VERs will challenge the current market structures. For that reason, both FERC and the RTOs have already started to take action to adapt to the changing resource mix.

A. FERC Order 755

One of the most critical ERS needed to integrate additional VERs into the system is the frequency regulation needed to maintain 60 Hz AC. In Order 755 FERC recognized RTOs were not fairly compensating all fast ramping resources for providing frequency regulation. FERC expressed concerns that as a result of existing policies "slower-responding resources are compensated as if they are providing the same amount of service when, in reality, they are not."[20] As a remedy, FERC ordered the RTOs to develop performance payment systems to ensure that payments for frequency regulation are not unduly discriminatory or preferential.[21]

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17 https://www.caiso.com/Documents/Presentation-FrequencyResponseStudy_Dec132011.pdf
http://ercot.com/content/gridinfo/etts/keydocs/System_Inertial_Frequency_Response_Estimation_and_Impact_of_.pdf

Staff Report to the Secretary on Electricity Markets and Reliability, August 2017.

https://energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf

18 https://www.ferc.gov/whats-new/comm-meet/2016/021816/E-2.pdf

19 Written Statement of Gerry Cauley, President and CEO North American Electric Reliability Corporation to the Quadrennial Energy Review Task Force, February 4, 2016, page 4.

https://www.nerc.com/news/testimony/Testimony%20and%20Speeches/Cauley%20Testimony%20-%20QER.pdf

20 18 CFR Part 35, Docket Nos. RM11-7-000 and AD10-11-000; Order No. 755, ¶ 17.

https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

21 18 CFR Part 35, Docket Nos. RM11-7-000 and AD10-11-000; Order No. 755, ¶ 60-63.

Continued on next page

Additionally, FERC expressly stated that its Order is technology neutral and intended to ensure that all eligible resources providing frequency regulation receive just and reasonable compensation.[22]

B. ERCOT Future Ancillary Services Reform

ERCOT has integrated large amounts of VERs (primarily wind) into its system over the last decade. In 2013, recognizing the important role of ERS for operational reliability, ERCOT proposed reforms to its ancillary service markets, collectively referred to as "Future Ancillary Services" ("FAS").[23] ERCOT noted that the set of ancillary services previously used had been developed in a period two decades earlier when VERs were not a significant part of their system.

The value of ERS depends on the overall make-up of an RTO's resources and the grid's topology.[24] FAS reforms recognized that the changing generation mix, driven by VERs (mostly wind at the time), created the need to re-think the set of ERS embodied in the existing ancillary service requirements. Notably, ERCOT planned to divide Responsive Reserve Service ("RRS"), a type of spinning reserve, and non-spinning reserve into eight products, and anticipated that one of them would be a new "Synchronous Inertial Response" product, which is not priced in other RTOs. Ultimately, stakeholders rejected the ERCOT reforms, but the proposal suggests that as VER integration precedes ancillary service reforms – including new product definitions and markets - will need to occur. [25]

Continued from previous page

https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

22 18 CFR Part 35, Docket Nos. RM11-7-000 and AD10-11-000; Order No. 755, ¶ 194. https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

23 - ERCOT (2013). ERCOT Concept Paper: Future Ancillary Services in ERCOT. Posted at https://www.ferc.gov/CalendarFiles/20140421084800-ERCOT-ConceptPaper.pdf

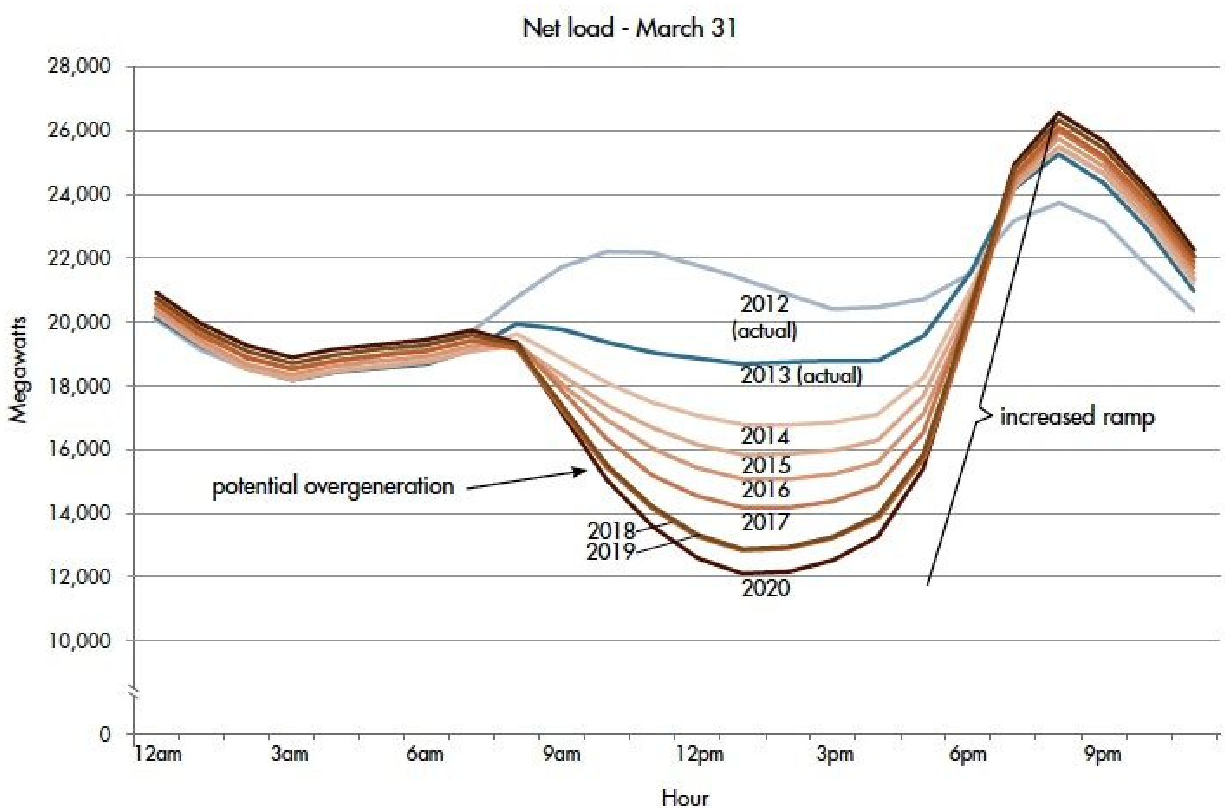
24 http://www.ercot.com/content/gridinfo/resource/2015/mktanalysis/Brattle_ERCOT_Resource_Adequacy_Review_2012-06-01.pdf

25 ERCOT stakeholders voted not to proceed with ancillary services reforms in 2016. https://www.rtoinsider.com/ercot-ancillary-service-revisions-27118/

C. THE CALIFORNIA "DUCK CURVE"

California, which has pursued an agenda designed to reduce greenhouse gas emissions, provides an early example of emerging operational reliability issues. The state has a very ambitious Renewable Portfolio Standard ("RPS") policy, as well as policies and rates designed to foster rooftop solar. VER generation, particularly from solar PV, has increased significantly. While ample generating capacity ensures resource adequacy, the increased variation in net load has created operational reliability risks.

The California "duck curve," which shows net load for a spring day, graphically explains the operational issue. During the morning hours when solar output increases rapidly, the demand for non-solar generation drops sharply, but when the sun sets in the evening the demand for non-solar generation increases steeply. This new, more variable net load pattern requires flexible resources that can start and change output, or "ramp," quickly.



Source: Confronting the Duck Curve: How to Address Over-Generation of Solar Energy, US Department of Energy, October 2017.

For that reason, CAISO has redesigned its markets to include a flexible capacity product to ensure the system has access to resources with the characteristics needed to meet the highly varying net load of customers.[26]

D. MISO Ramp Products

In 2016, MISO added two new ancillary services (up and down ramp) to manage the challenge of rising variability and uncertainty in net load due to increasing levels of renewables.[27] These ramp capability products allow the real-time dispatch algorithm to deploy resources in a way that reduces the likelihood of scarcity events. The products are designed to strike a balance between the higher operating costs required to provide additional ramp capability and the high costs of scarcity events.

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26 California ISO, Flexible Ramping Product, Revised Draft Final Proposal, December 17, 2015. https://www.caiso.com/Documents/RevisedDraftFinalProposal-FlexibleRampingProduct-2015.pdf.

27 See https://www.misoenergy.org/Library/Repository/Communication%20Material/Key%20Presentations%20and%20Whitepapers/Ramp%20Capability%20for%20Load%20Following%20in%20MISO%20Markets%20White%20Paper.pdf.

III. The Rationale for Using First-Principles Approaches to Defining Reliability Needs

Some policy makers have proposed paying for generator attributes that may not directly translate into reliability or resilience. Recent examples include out-of-market payments to so-called “baseload” coal and nuclear generators, and proposals to require natural gas generators to obtain either firm delivery service or build onsite oil storage (or both).

These proposals portray the possibilities of pipeline failure and non-delivery due to high heating demand as unique reliability and resilience issues for natural gas fired plants. While a massive natural gas pipeline failure has never resulted in an outage in the U.S., it hypothetically could happen in the future. However, every resource type and fuel source creates unique reliability challenges. Prolonged droughts and floods can reduce barge delivery and floods can damage railways enough to interrupt coal delivery. Drought can dramatically reduce the availability of hydro generation. Unexpected drops in wind speed or loss of insolation can result in threats to operational reliability. The discovery of a previously unrecognized safety flaw in nuclear technology could require the shutdown of all or part of the nuclear fleet. This happened in Japan after the Fukushima Daiichi disaster. However, none of these idiosyncratic reliability challenges eliminates any one resource type from making contributions to system reliability, and none necessarily justifies a change to reliability definitions.

The true nature of the reliability or resilience need that arises in the context of increasing reliance on natural gas must be understood and defined properly in order to design market mechanisms to cost-effectively meet that need. Electricity system reliability may not necessarily require every gas plant to have firm fuel or limit the maximum quantity of gas resources that can be built. Instead, in many systems the need can more accurately be defined as a need to meet winter resource adequacy (i.e. a winter reserve margin above peak load). When defined in this reliability-driven, resource neutral way, it becomes possible to measure the current ability of a particular system to meet that need and evaluate whether a revised definition of the need is warranted.

While the data indicate that inability to deliver natural gas rarely results in electricity customer outages, policy makers have increasingly scrutinized the reliability of natural gas fired power plants during high demand, cold weather events. Based on our review of the available evidence, however, increasing the share of electricity generated by natural gas is unlikely to decrease reliability or resilience in properly designed markets. To date, interruption of the natural gas supply has caused very few outages in the U.S., even under emergency conditions. Moreover, a PJM study demonstrates that a substantial increase in reliance on natural gas will not threaten reliability or resilience. While any major change in the composition of the generation mix should result in careful analysis by the FERC and the RTOs, actual recent performance and careful analysis all demonstrate that well-designed markets can achieve reliability and resilience even if the reliability challenges are significant. As seen in the case of VERs, RTOs can meet new reliability or resiliency challenges by creating market rules that compensate resources for providing ERS the system needs.

A. Reasons for the Shift to Natural Gas

The revenues that coal and nuclear units earn in organized wholesale markets has been has impaired substantially in the current environment of sustained low natural gas prices, increased penetration of renewables, and stagnant/negative load growth. Even after a wave of coal retirements that coincided with the compliance deadlines with the Mercury and Air Toxic Standard ("MATS") in 2015, both coal and nuclear retirements and announced retirements have continued. At the same time, developers have made significant investments in new natural gas capacity.

Some owners of existing coal and nuclear generators cannot operate profitably in competitive markets. As an example, prior to filing for bankruptcy protection on Match 3l, 2018, on March 28, 2018 FirstEnergy Solutions Corp., the competitive generation subsidiary of FirstEnergy, announced plans to close three nuclear reactors between 2020 and 2021. It followed this announcement with a request that the DOE issue an emergency order requiring PJM to compensate at-risk coal and nuclear plants for "the full benefits they provide to energy markets and the public at large."[28]

Continued low natural gas prices and new environmental regulations have reduced earnings at coal and nuclear plants throughout the country. As a result, 60 GW of coal and 5 GW of nuclear capacity have retired since the beginning of 2012.[29] [30] We expect additional coal and nuclear

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28 Dan Testa, SNL, FirstEnergy competitive generation subsidiary files for bankruptcy, April 1, 2018.

29 Energy Velocity.

retirements going forward, though we expect these retirements will occur gradually over the next decade and beyond.

As coal and nuclear plants retire, natural gas-fired capacity will likely constitute the bulk of the replacement power. Environmental regulations for new coal plants make them prohibitively expensive and potentially even technically infeasible. Nuclear power also faces severe economic and technical challenges, as demonstrated by the problems facing the under construction units at VC Summer and Vogtle. VERs will also replace some of the retiring generating capacity, but relatively low capacity values, grid integration costs, and limits on dispatchability will limit the degree to which VERs can serve as replacements for these resources. For these reasons, the percentage of U.S. electricity provided by natural gas-fired generators will continue to rise.

B. The DOE NOPR

Motivated, at least in part, by the retirement of coal and nuclear plants, in September 2017 the DOE issued a Notice of Proposed Rulemaking ("NOPR") directing FERC to consider establishing market rules that would ensure that generators with a 90-day supply of onsite fuel would earn "recovery of costs and a fair rate of return."[31] As written, the rule would have applied primarily to coal and nuclear facilities because most other generators lack the ability to store 90 days of fuel onsite. The rule was widely criticized for its high potential cost and adverse impact on the operation of competitive wholesale electricity markets. [32]

On January 8, 2018, the FERC issued an order closing the FERC proceeding regarding DOE's Proposed Rule noting that in order to implement the requested tariff changes "*there must first be a showing that the existing RTO/ISO tariffs are unjust, unreasonable, unduly discriminatory or preferential. Then, any remedy proposed under FPA section 206 must be shown to be just, reasonable.*[33] The FERC found that neither requirement had been satisfied.

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30 Low natural gas prices can play a role in the decision to retire regulated coal and nuclear facilities. This occurs because the utility considers the cost of alternatives to its existing fleet when making retirement decisions.

31 DOE NOPR on Grid Resiliency Pricing Rule, September 28, 2017.

32 http://files.brattle.com/files/11635_evaluation_of_the_does_proposed_grid_resiliency_pricing_rule.pdf

33 https://www.ferc.gov/media/news-releases/2018/2018-1/01-08-18.asp#.WlgpRa6nEz0

At this point, no evidence has been presented to demonstrate that maintaining 90-day stockpiles of onsite fuel provides significant reliability or resilience benefits to the system. It is true that some natural gas plants have failed to perform due to fuel deliverability issues, notably in ERCOT in February 2011 and during the 2014 Polar Vortex in the Northeast, and that the New England region has experienced infrequent, but material, reliability challenges during winter peak periods. A number of other issues also drove the majority of generator failures during both events. However, these challenges have been largely addressed by a range of reliability and operational enhancements by the RTOs, including enhanced energy market scarcity pricing, improved gas-electric coordination, and new market rules that impose penalties on non-performing capacity resources. Additionally, the diversification of the gas supply and increased pipeline infrastructure in recent years has further reduced the risk that a gas supply interruption will lead to an electric customer outage.[34] If some regions (such as New England) continue to face winter resource adequacy challenges it would be most efficient to meet these challenges through explicitly defined winter reliability or resource adequacy standards that can be met through resource-neutral, market-based mechanisms.

C. PJM Fuel Diversity Study

The current U.S. resource mix is actually quite diverse. For example, in the largest electric market in the country, PJM, natural gas and coal each provide slightly more than one third of the installed capacity, with nuclear, hydroelectric, oil, and renewables providing the remaining capacity. Based on capacity auction results, the share of natural gas will increase, but it will remain under 50% of total installed capacity through at least 2020.[35] Policy makers had time to respond to the shift in the generation mix with market rules to ensure reliability. Figure 1 shows the PJM resource mix over time.

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[34] A recent NERC study that found "natural gas supply sources have become more diversified, reducing the likelihood of natural gas infrastructure outages affecting electric generation."

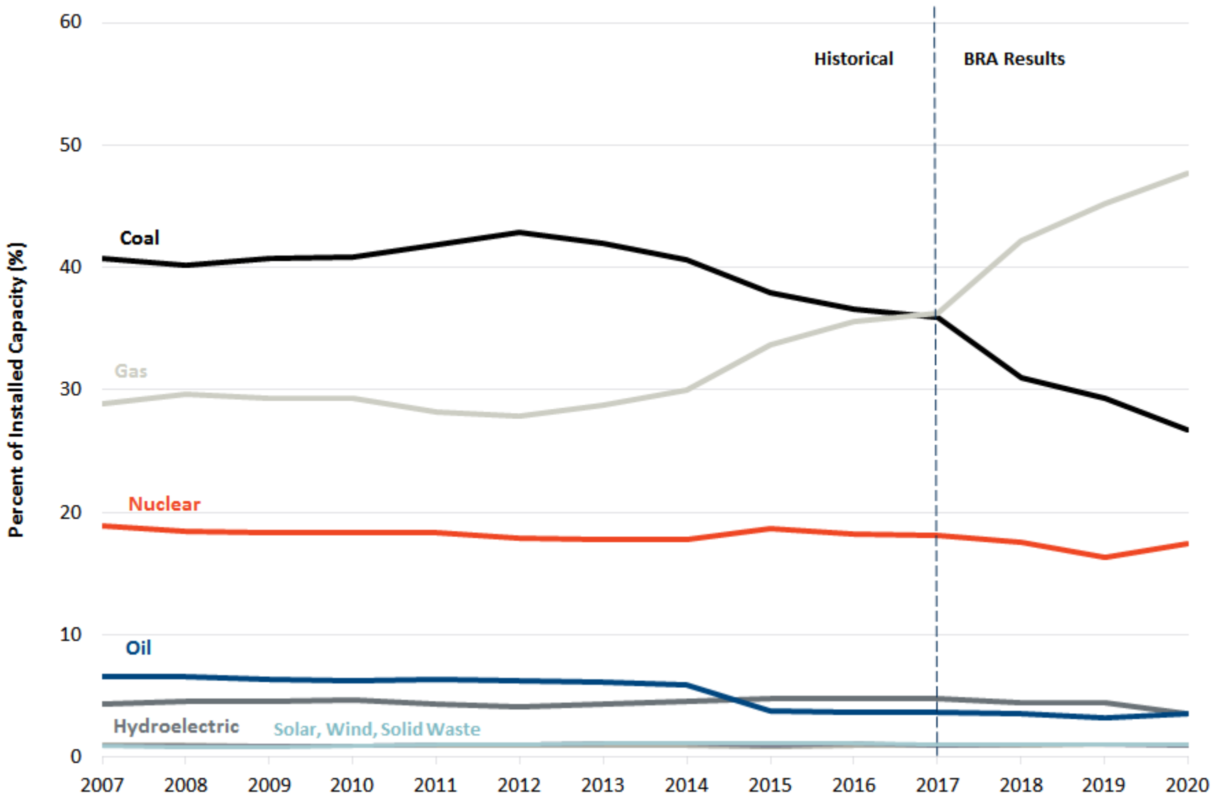
NERC Special Reliability Assessment: Potential Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System, November 2017, page viii.

https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SPOD_11142017_Final.pdf

[35] 2017 Quarterly State of the Market Report for PJM: January through September, Table 5-3, page 237.

http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2017/2017q3-som-pjm.pdf

Figure 1
PJM Capacity Mix Over Time



Source: 2017 Quarterly State of the Market Report for PJM: January through September, Figure 5-1, page 237

Based on a recent study by PJM, the RTO could incorporate even more natural gas without endangering reliability.[36] In the study, PJM considered reliability in 2021 under a variety of portfolios, starting with a baseline scenario based on recent trends in new capacity and retirements. The baseline scenario is designed to meet the "one day in 10 year" LOLE. From there, PJM developed portfolios with the same LOLE that included different levels of coal, nuclear, gas, and renewables. Alternative portfolios were designed to maintain the same level of Loss of Load Expectation. PJM then evaluated the reliability of each portfolio and identified 98

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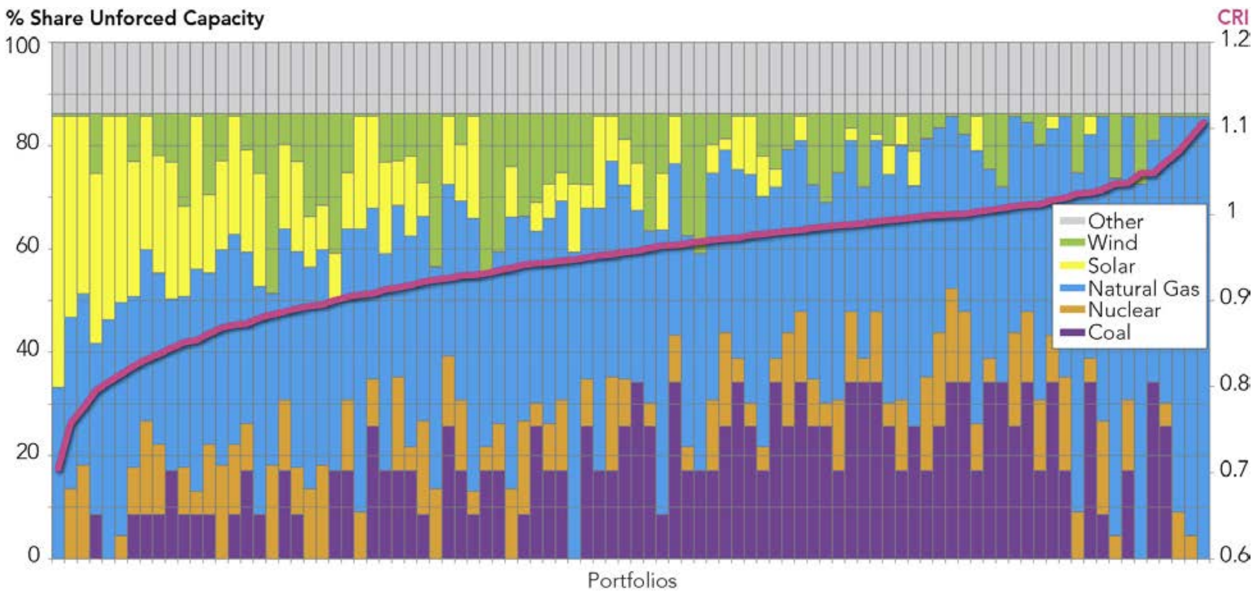
[36] PJM's Evolving Resource Mix and System Reliability, March 30, 2017 http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

“desirable” portfolios that met a minimum threshold for the composite reliability index in all operating states. PJM found that portfolios with greater dependence on renewables generally had lower reliability, while portfolios with more coal and gas capacity had higher reliability.[37] The report also found that portfolios with as much as 86% natural gas (the highest level evaluated) maintained acceptable reliability.[38] Figure 2 shows the reliability for the 98 desirable portfolios as defined by a Composite Reliability Index (the red line) that is based on a weighting of 13 reliability attributes. There is a clear positive correlation between reliability and reliance on natural gas and coal generation, just as there is an equally clear negative correlation between reliability and reliance on VERs.

Figure 2
PJM Portfolio Composition and Associated Composite Reliability Index



Source: PJM’s Evolving Resource Mix and System Reliability, March 30, 2017, Figure 10.

PJM also considered whether the desirable portfolios had the resilience to withstand a Polar Vortex event. To simulate a future Polar Vortex, PJM lowered availability rates of natural gas, coal, and solar plants based on performance data from high load days during Winter 2014/2015

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37 PJM’s Evolving Resource Mix and System Reliability, March 30, 2017, page 28. http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

38 PJM’s Evolving Resource Mix and System Reliability, March 30, 2017, page 5. http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

and Winter 2015/2016. Using these lower availability rates, portfolios that provided the same level of reliability as the baseline, as measured across four reliability indices, were deemed resilient to a Polar Vortex event. Even under Polar Vortex conditions, the study concluded natural gas could contribute up to 66% of the portfolio without endangering reliability.[39]

In addition, the study found that fuel diversity *per se* was not correlated with reliability. PJM used a measure of diversity called the Shannon-Wiener diversity index.[40] The index, originally developed for the field of information theory, measures how many different types of fuels comprise a portfolio and also the preponderance of each fuel. For example a portfolio with many fuels but a few dominant fuels would have a relatively low index relative to one that had fewer fuels but a more balanced portfolio. PJM found that high diversity portfolios with high VER levels performed less well than gas dominant portfolios that had lower diversity indices. Thus, simply measuring the diversity of the fuel mix did not indicate the reliability of a portfolio. The results of PJM's study are supported by previous studies that have also found fuel diversification for its own sake does not necessarily result in economically optimal outcomes.[41]

D. Historical Performance of Natural Gas During Extreme Weather Events

During the February 2011 emergency event in ERCOT, natural gas fuel curtailment accounted for only 4% of the generator capacity outages,[42] while freezing equipment accounted for over half the outages of capacity.[43] Natural gas fuel deliverability issues had a greater impact during

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39 Appendix to PJM's Evolving Resource Mix and System Reliability, March 30, 2017 http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-appendix-to-pjms-evolving-resource-mix-and-system-reliability.ashx

40 Appendix to PJM's Evolving Resource Mix and System Reliability, March 30, 2017 http://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-appendix-to-pjms-evolving-resource-mix-and-system-reliability.ashx

41 Phil Hanser and Frank Graves, The Electricity Journal, Utility Supply Portfolio Diversity Requirements, 2007.

42 Texas Reliability Entity Event Analysis Event: February 2, 2011 EEA-3 Event Public Report, https://www.texasre.org/CPDL/2011-02-02%20EEA3%20Event%20Analysis-public_final.pdf, page 28.

43 Texas Reliability Entity Event Analysis Event: February 2, 2011 EEA-3 Event Public Report, https://www.texasre.org/CPDL/2011-02-02%20EEA3%20Event%20Analysis-public_final.pdf, Figure 11, page 27.

the Polar Vortex, but even there other problems also drove outages. In PJM other issues caused over 75% of the generator outages during the time period the grid suffered the greatest stress.[44] In New England, which suffered the highest level of gas-delivery related outages, issues unrelated to fuel delivery caused over half of the generator outages at the time.[45] During the Polar Vortex event, however, the system remained remarkably resilient. Only one balancing authority – South Carolina Energy and Gas ("SCE&G") needed to shed load during the emergency.[46] Of note, SCE&G's outages related to frozen equipment and record high demand – not a failure to deliver natural gas to power plants.[47]

In response to the Polar Vortex, both PJM and ISO-NE adopted penalties for non-performance that provide a financial incentive for generators to ensure they can perform during peak system conditions.[48] PJM describes the purpose of its Capacity Performance Standards stating that under the "requirement, generators may receive higher capacity payments in exchange for modernizing equipment, firming up fuel supplies and/or adapting to use an alternative fuel."[49] Notably, the rules do not require resource owners to take specific actions (such as obtaining an alternative fuel supply or constructing on-site fuel storage). Instead they provide a financial benefit for performance combined with a financial penalty for non-performance that incentivizes capacity

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44 Analysis of Operational Events and Market Impacts During the January 2014 Cold Weather Events, http://www.pjm.com/~/media/library/reports-notices/weather-related/20140509-analysis-of-operational-events-and-market-impacts-during-the-jan-2014-cold-weather-events.ashx, Figure 17, page 26.

45 NERC Polar Vortex Review September 2014, http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf, Figure 8, page 8.

46 NERC Polar Vortex Review September 2014, http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf, page iii, 2.

47 Joey Holleman, Greenville News, *SCE&G's rolling blackouts compound freeze*, January 8, 2014.

48 FCM Pay for Performance Evaluations https://www.iso-ne.com/static-assets/documents/2017/11/20171023-14-fcm101-pfp.pdf

PJM – Capacity Performance at a Glance https://www.pjm.com/-/media/library/reports-notices/capacity-performance/20150720-capacity-performance-at-a-glance.ashx?la=en

49 http://www.pjm.com/-/media/about-pjm/newsroom/fact-sheets/20161019-view-point-capacity-markets.ashx

resources to improve their performance. Electricity markets work most efficiently when the rules pay resources for desired ERS directly.

Access to large onsite fuel supplies does not necessarily prevent generator outages during extreme weather conditions. During the February 2011 cold snap in ERCOT, coal capacity experienced outage rates similar to simple cycle turbines and higher than either natural gas combined cycles or Gas Steam Boilers.[50] Coal, while experiencing lower outage rates than natural gas, still accounted for 26% of the capacity on outage during the Polar Vortex.[51] NERC specifically noted that frozen coal piles contributed to the high outages and that a majority of the outages were unrelated to the interruption of fuel delivery.[52] More recently, NRG switched from coal to natural gas at its W.A. Parish Units 5 & 6 when Hurricane Harvey saturated the plant's coal piles.[53]

An even more recent event demonstrates the system can operate reliably even during emergency conditions with significant reliance on natural gas. The January 2018 "Bomb Cyclone" extremely cold weather rocked the Eastern US, but did not result in any customer outages caused by generation shortages. New England has the most significant natural gas pipeline constraint, and it suffered the outage of the Pilgrim nuclear plant during this time. However, no reliability problems were reported, even though this event preceded the implementation of capacity performance policies introduced in response to the stresses of the 2014 Polar Vortex event.[54] It should be noted that ISO New England continues to study fuel security and found in a recent report that certain hypothetical events could present fuel supply problems in the winter of

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50 Texas Reliability Entity Event Analysis Event: February 2, 2011 EEA-3 Event Public Report, https://www.texasre.org/CPDL/2011-02-02%20EEA3%20Event%20Analysis-public_final.pdf, Figure 6, page 22.

51 NERC Polar Vortex Review September 2014, http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf, page 13.

52 NERC Polar Vortex Review September 2014, http://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf, page 3.

53 Watson, Mark. "Harvey's rain forced NRG to switch Texas coal plants to gas." *SNL Global*, September 27, 2017.

54 https://www.ferc.gov/CalendarFiles/20180123092917-McIntyre-Testimony.pdf

2024/25 absent new infrastructure (gas pipeline, electric transmission and oil backup).[55] The ISO has noted that expanding natural gas pipeline infrastructure would improve reliability, provide environmental benefits, and reduce wholesale electric price volatility.[56]

Finally, it is worth noting that a plant's fuel type by itself provides little information about its reliability. Although they rarely lack onsite fuel, coal plants have suffered failures during low temperatures because of equipment failure and frozen coal piles. Wet coal has also caused failures during intense storms. While natural gas units have also experienced supply interruptions, they have operated when coal units failed and when wind, solar, and hydro units were unavailable. Gas generators have multiple options to increase reliability. They can purchase fuel from multiple gas supply sources, opt for firm gas supply, or build dual-fuel capability with onsite oil storage. However, as we discuss in Section IV the resource owner – not the RTO – remains in the best position to determine what options, if any, should be taken in response to a fuel - and technology - neutral capacity performance incentives.

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55 https://www.iso-ne.com/static-assets/documents/2018/01/20180117_operational_fuel-security_analysis.pdf

56 https://www.iso-ne.com/about/regional-electricity-outlook/grid-in-transition-opportunities-and-challenges/natural-gas-infrastructure-constraints

IV. Meeting Reliability Needs through Competitive Markets

A. Impact of Markets on the Cost of Serving Load

Competition in electric generation has the potential to reduce customer costs through market design that rewards efforts to minimize the cost of serving load. Regulated utilities pass operating costs on to customers and earn a regulated return on invested capital. While state commissions oversee spending by regulated utilities, proponents of restructuring argued the economic incentives provided by markets more effectively incentivizes cost reduction. In restructured markets, owners of merchant generation have an economic incentive to maintain and dispatch their units efficiently and to reduce plant costs.

In general, free markets for commodities have the potential to drive down costs, relative to central planning, for two reasons. First, markets incentivize suppliers to reduce their costs. By reducing the cost of operating, maintaining, and developing resources market participants have the opportunity to sell a greater volume and to earn a higher margin on each sale. Thus, restructured electricity markets have the potential to drive down costs by improving the incentives facing market participants.

Second, markets have the potential to reduce costs by decentralizing decision making and creating incentives for a broad suite of players to identify innovative lower-cost solutions. Even the best-intentioned central planner lacks the "on the ground" knowledge of market participants directly involved in production and commerce. Well-designed market rules that allow all resources to compete on a level playing field are needed to ensure resources providing necessary ERS come online and operate profitably.

RTOs have less information on the operational issues facing individual resources than the resources' owners. Ideally, market design should empower the RTOs to define product specifications along with penalties for non-performance, but leave resource owners the maximum level of flexibility to provide those products according to their best business judgement. With the appropriate financial incentives for both performance and penalties for non-performance, resource owners are in a better position than the RTOs to determine the most cost-effective way to provide products (including energy, capacity, ERS, and other ancillary services) to the grid.

While market rules vary across RTOs, all restructured markets share common policy goals of reliability and cost minimization. Maintaining a high reliability level is an absolutely critical requirement for restructured markets (and regulated regions) because of the high value of lost load ("VOLL").[57] If restructured markets cannot provide the same level of reliability as vertically integrated utilities, almost no level of cost savings would justify their continued existence. For that reason, much of the work in market design focuses on identifying efficient ways to ensure the market attracts the appropriate mix of resources to maintain a high level of reliability. To ensure resource adequacy, several RTOs developed capacity markets intended to supplement energy markets. As VER penetration increases, RTOs need to develop new ancillary service markets to attract resources that provide the ERS that ensure operational reliability. If market design fails to attract these resources, operational reliability will suffer. Because of the high VOLL, this could likely result in a great deal of economic harm to consumers.

B. Principles for Ensuring Reliability Through Market Mechanisms

Several principles should guide the design of markets for ERS. First, the types and quantities of ERS the market procures should be functions of each RTO's current and expected resource mix. Different RTOs have different mixes of resources that require different types of ERS. With its substantial wind capacity, ERCOT needs resources that can quickly respond to wide and unexpected swings in net load. CAISO, which has substantial installed rooftop solar capacity, needs resources that can respond to the dramatic uptick in net load that occurs when the sun sets. As CAISO incorporates more VERs and relies less on traditional turbine capacity to meet its energy needs, it will also need more resources that can provide inertia and primary frequency response. These regions have already moved to begin addressing these needs. In some of the northeastern markets, there may be a need to define explicitly winter resource adequacy standards (if any of the system operators identifies a concern that winter adequacy might otherwise not be met).

Second, rules for procuring ERS and resource adequacy should be technology neutral; any technology that meets the RTO-performance standards should be allowed to sell into the market.

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57 Julia Frayer, Sheila Keane, and Jimmy Ng, "Estimating the Value of Lost Load," June 7, 2013, page 66. http://www.ercot.com/content/gridinfo/resource/2015/mktanalysis/ERCOT_ValueofLostLoad_LiteratureReviewandMacroeconomic.pdf

Batteries, flywheels, VERs, demand response, distributed resources, imports, and thermal generators can all provide ERS and resource adequacy, to greater or lesser degrees. RTO rules should not preclude certain resources from providing services, nor should the rules discriminate for or against certain technologies. This is both a sound economic principles and it is consistent with FERC Order 755.

Third, RTOs should ensure resource adequacy and operational reliability by establishing reliability-based standards and using competitive market forces to determine the most effective means for supplying those services (as well as the payment levels needed to procure those services). In some cases, VOLL can be used to establish the appropriate willingness to pay for certain types of reliability services, or the appropriate penalties for non-performance. Allowing resource owners the flexibility to determine how to provide ERS and available capacity furthers the goal of efficiency. Resource owners have financial incentives to earn revenue for performance and avoid penalties for non-performance. They are better situated than RTOs to determine the best method for ensuring they can perform when needed.

In light of recent events, this third point deserves additional attention. DOE has raised concerns about the impact of increased reliance on natural gas-fired generation.[58] The appropriate way to address concerns about over-reliance on non-firm natural gas contracts and lack of onsite storage is through economic carrots and sticks related to individual unit performance, not equipment or operational mandates. Treating onsite fuel storage as a proxy for reliability or resilience, as proposed by the DOE, would result in higher consumer costs because it does not directly pay for reliability or resilience.[59] A market approach that provides payments to resources for performance and penalizes resources for non-performance will ensure greater reliability at a lower cost for consumers than an approach that simply pays resources for maintaining a particular level of onsite fuel storage or firm delivery contracts.

Because fuel security, reliability, and resilience depend on many complicated and frequently resource-specific factors, resource owners “on the ground” are better suited than regulators to determine the best technical solutions for improving the contribution individual resources make

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58 DOE NOPR on Grid Resiliency Pricing Rule, September 28, 2017.

59 http://www.rff.org/blog/2018/projecting-impacts-doe-s-grid-resiliency-pricing-proposal
http://files.brattle.com/files/11635_evaluation_of_the_does_proposed_grid_resiliency_pricing_rule.pdf

to reliability. Generator performance during recent scarcity events, and RTOs responses to those events, demonstrate that effective market design effectively mitigates the risk posed by fuel security during extreme weather conditions.

V. Conclusions

In order to meet the reliability or resilience challenges posed by shifting resources, we recommend a framework that begins with a clear definition of the reliability need. Once defined in a resource-neutral way, a competitive market can be defined to procure the needed reliability services at least cost. This market-based approach will incentivize competitive players to identify innovative, low-cost solutions to any identified reliability challenge. In the environment of low wholesale electricity and natural gas prices, policy makers have raised concerns about the impact of natural gas generators on reliability and resilience. This has led to a situation in which some have called for rules that reward certain resources (and penalize others) under the guise of improving reliability. However, no evidence suggests that maintaining several months of fuel onsite improves system reliability. At the same time, the historical record and analysis by PJM demonstrate that with properly designed market rules, increased use of natural gas can actually increase the operational and bulk power reliability of the system. No credible evidence suggests that increasing the electric sector reliance on natural gas past current levels threatens reliability or resilience.

Markets designed to compensate resources for reliability services directly, rather than to pay resources for taking specific actions such as contracting for firm natural gas supply, will maintain the desired level of reliability at a lower cost. The fundamental purpose of electricity markets is cost reduction. To reduce costs, market operators should establish the desired level of ERS, but allow resource owners to determine the best way to provide those ERS. Properly designed payments for performance, and penalties for non-performance, ensure reliability more efficiently than mandates by an RTO. For example, owners of natural gas generators are in the best position to determine whether they need to obtain firm natural gas contracts or to construct on-site fuel storage.

If RTOs mandate resources adopt specific fuel contracts, or construct large on-site fuel storage facilities, they will undermine the purpose of electricity markets. Electricity markets are premised on the idea that individual resource owners will minimize the cost of achieving reliability objectives when left to their own devices. For that reason, market rules should focus on obtaining the ERS necessary to integrate VERs and on penalizing generators for non-performance. Developing the right price signals to achieve the desired level of reliability is critical. RTOs mandating fuel contracting or inventory requirements would undermine the purpose of electricity markets, raise electricity costs, and would not result in better reliability and resilience outcomes.

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