UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

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PJM Interconnection, LLC	)	**Docket No. ER14-_____-000**
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	)	

AFFIDAVIT OF DR. SAMUEL A. NEWELL AND DR. KATHLEEN SPEES ON BEHALF OF PJM INTERCONNECTION, LLC REGARDING PERIODIC REVIEW OF VARIABLE RESOURCE REQUIREMENT CURVE SHAPE AND KEY PARAMETERS

Our names are Dr. Samuel A. Newell and Dr. Kathleen Spees. We are employed by The Brattle Group, as Principal and Senior Associate, respectively. We submit this affidavit on behalf of PJM Interconnection, LLC (PJM) to describe the analysis we conducted on the performance of PJM's Variable Resource Requirement curve (VRR Curve) for procuring capacity in its Reliability Pricing Model (RPM) capacity market. We conducted this analysis as part of PJM's tariff-mandated triennial review of the VRR Curve and its parameters, the results of which have informed PJM's proposed revisions to the VRR Curve in the present filing. The entirety of our review is contained in the attached report, *Third Triennial Review of PJM's Variable Resource Requirement Curve* ("Third Triennial Review").[1] That report was prepared under our supervision and direction.

Our qualifications as experts derive from our extensive experience evaluating capacity markets and alternative market designs for resource adequacy. Our practice in capacity market design with RTOs across North America and internationally has given us a broad perspective on the practical implications of nuanced market design rules under a range of different economic and policy conditions.[2] In PJM, we have worked closely with PJM staff on this and prior assignments to understand RPM at a detailed level.[3] We have also

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[1] Pfeifenberger, Johannes P., Samuel A. Newell, Kathleen Spees, Ann Murray, Ioanna Karkatsouli. *Third Triennial Review of PJM's Variable Resource Requirement Curve.* May 15, 2014.

[2] For example, we have worked with regulators, market operators, and market participants on matters related to resource adequacy and investment incentives in PJM Interconnection, ISO-New England (ISO-NE), New York, Alberta, California, Texas, Midcontinent ISO, Italy, Russia, and Western Australia. A comprehensive description of these engagements is shown in our resumes, which are provided as attachments to this affidavit.

[3] See our 2008 and 2011 triennial RPM reviews respectively, in Pfeifenberger, Johannes, Samuel Newell, Robert Earle, Attila Hajos, and Mariko Geronimo. *Review of PJM's Reliability Pricing Model (RPM).* June 30, 2008; and Pfeifenberger, Johannes, Samuel Newell, Kathleen Spees, Attila Hajos, and Kamen Madjarov. *Second Performance Assessment of PJM's Reliability Pricing Model.* August 26, 2011.

previously worked on a number of assignments with market participants from all sectors operating within the PJM footprint, which has provided us insights on how changes to the capacity market construct may impact the business decisions and other interests of suppliers, customers, utilities, and state regulators in PJM.

A subset of our market design work has focused on the development and improvement of capacity market demand curves designed around different sets of policy objectives. Our experience in capacity demand curve design includes: (1) prior PJM capacity market reviews in 2008 and 2011 to review market performance, including qualitative assessments and statistical simulations of the performance of the VRR Curve;[4] (2) support of ISO-NE in the development of the system demand curve for its capacity market, as filed with and approved by the Commission earlier this year, and of ISO-NE's ongoing development of locational curves, including simulation analyses of candidate curves' performance;[5] (3) Italian capacity demand curve and market design development in 2012, including developing a value-based locational demand curve reflecting the value of capacity to customers; and (4) a study on the economics of reliability for the Commission in 2013, including calculating a value-based capacity demand curve designed to procure an economically optimal quantity of capacity from a risk-neutral societal perspective.[6]

I, Dr. Newell, am an economist and engineer with more than 16 years of experience analyzing and modeling electricity wholesale markets, the transmission system, and market rules. Prior to joining The Brattle Group, I was the Director of the Transmission Service at Cambridge Energy Research Associates and previously a Manager in the Utilities Practice at A.T. Kearney. I earned a Ph.D. in Technology Management and Policy from the Massachusetts Institute of Technology, an M.S. in Materials Science and Engineering from Stanford University, and a B.A. in Chemistry and Physics from Harvard College.

I, Dr. Spees, am an economic consultant with expertise in wholesale electric energy, capacity, and ancillary service market design and analysis. I earned a Ph.D. in Engineering and Public Policy and an M.S. in Electrical and Computer Engineering from Carnegie Mellon University, and a B.S. in Mechanical Engineering and Physics from Iowa State University.

Complete details of our qualifications, publications, reports, and prior experiences are set forth in our resumes, provided as attachments to this affidavit.

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4 See Sections IV and V of our 2008 and 2011 RPM reviews.

5 See the Newell/Spees Testimony in support of ISO New England's April 1, 2014 filing before the Federal Energy Regulatory Commission (FERC) in Docket ER14-1639-000 to implement a downward-sloping system demand curve in their Forward Capacity Market (FCM).

6 See Section IV.B for a derivation and discussion of a value-based capacity demand curve, from Pfeifenberger, Johannes P., Kathleen Spees, Kevin Carden, and Nick Wintermantel. *Resource Adequacy Requirements: Reliability and Economic Implications.* September 2013.

TABLE OF CONTENTS

I. SUMMARY

We were asked by PJM to evaluate the parameters and shape of the administrative VRR Curve used to procure capacity under RPM, as required periodically under the PJM Tariff.[7] Consistent with the review scope specified in PJM's Tariff, we evaluated three key elements of RPM: (1) the gross Cost of New Entry (CONE) parameter; (2) the methodology for determining the Net Energy and Ancillary Services (E&AS) Revenue Offset; and (3) the shape of the VRR Curve.

On the first of these, the CONE parameter, we conducted an engineering cost estimate as summarized in the concurrently-filed affidavit of Dr. Newell and Mr. Christopher Ungate of Sargent & Lundy (Newell/Ungate affidavit), and described in detail in the attached report, *Cost of New Entry Estimates for Combustion Turbine and Combined Cycle Plants in PJM* ("2014 CONE Study").[8] We also authored a second attached study, *Third Triennial Review of PJM's Variable Resource Requirement Curve* ("Third Triennial Review") to quantitatively and qualitatively evaluate all other parameters of the VRR Curve, and conduct a probabilistic simulation analysis of the curve's performance as required under the Tariff.[9]

This affidavit summarizes how the findings of this second report have informed PJM's proposed changes to the VRR Curve. With respect to the Net CONE parameter, our analysis informed PJM's proposals to: (a) eliminate the Dominion CONE Area, (b) revise the indices used for annual updates to gross CONE, (c) revise the mapping of CONE and E&AS offsets such that these components of administrative Net CONE will be aligned as closely as possible to each Locational Deliverability Area (LDA) modeled in RPM, and (d) apply a minimum on locational Net CONE values so that no sub-LDA will have a lower Net CONE than its parent LDA.

With respect to the shape of the VRR Curve, our qualitative assessment and probabilistic simulation analyses informed PJM's decision to propose the revised VRR Curve shape shown in Figure 1 in comparison with the current VRR Curve. This revised curve addresses three performance concerns that we identified in the current VRR Curve. First, point "a" in the current curve does not reach the price cap until a relatively low quantity that is below PJM's backstop procurement threshold. Second, we estimate that in the long-term after current capacity surpluses are exhausted, the current VRR Curve is not likely to procure enough capacity to achieve average reliability at the 1-day-in-10-years (1-in-10 or 0.1) loss of load event (LOLE) reliability standard of RPM. And third, the concave shape of the VRR

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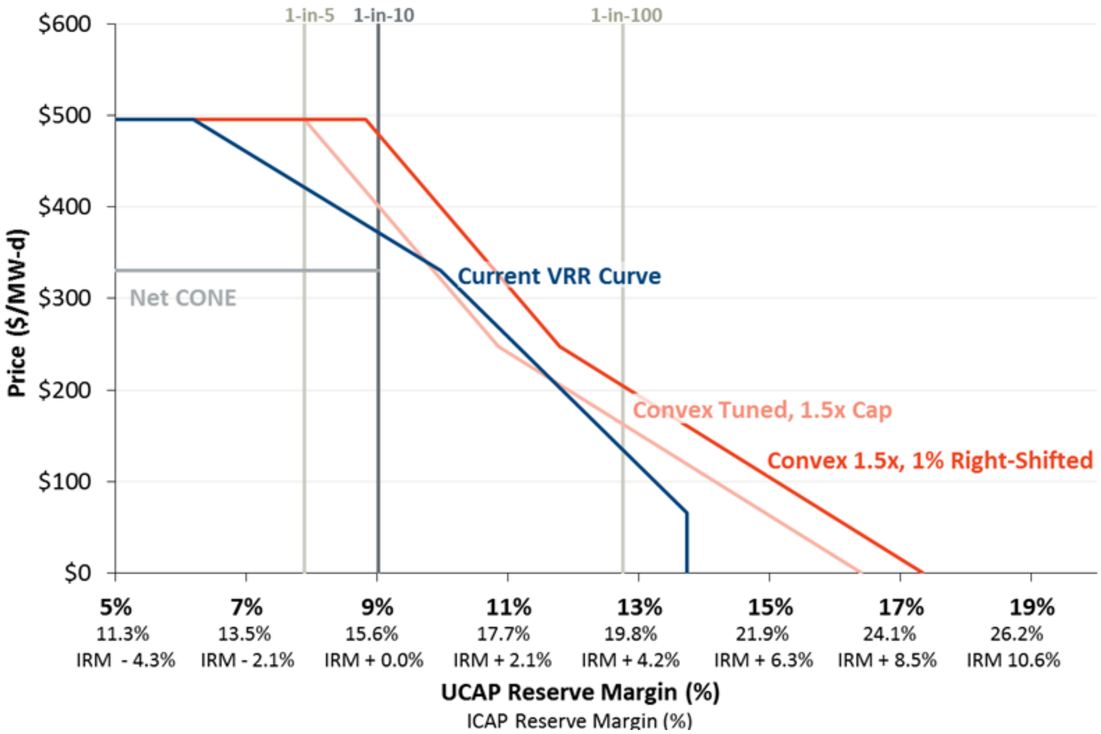
7 To date, PJM has required a triennial review of these parameters; in the future the review will be required only once every four years. See Section 5.10.a.iii of the *PJM Open Access Transmission Tariff*. Effective April 23, 2014. Retrieved from: http://www.pjm.com/~/media/documents/agreements/tariff.ashx

8 Newell, Samuel A., Michael Hagerty, Kathleen Spees, Johannes P. Pfeifenberger, Quincy Liao, Christopher D. Ungate, and John Wroble, *Cost of New Entry Estimates for Combustion Turbine and Combined Cycle Plants in PJM*, May 15, 2014.

9 See Pfeifenberger, Johannes P., Samuel A. Newell, Kathleen Spees, Ann Murray, and Ioanna Karkatsouli, *Third Triennial Review of PJM's Variable Resource Requirement Curve,* May 15, 2014.

Curve is less economically rational and more susceptible to reliability risks in the presence of administrative errors in Net CONE than the revised convex shape proposed by PJM.

Figure 1
PJM Proposed VRR Curve Compared to Current Curve



Sources and Notes:

Current VRR Curve reflects the system VRR curve in the 2016/2017 PJM Planning Parameters, calculated relative to the full Reliability Requirement without applying the 2.5% holdback for short-term procurements. See "2016/2017 Planning Parameters," April 30, 2013, posted at: http://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2016-2017-planning-period-parameters.ashx.

Our findings are supported by probabilistic simulation analyses of RPM mechanics, and with parameters that are grounded in empirical data on supply curve shapes and supply/demand variations from the first ten Base Residual Auctions (BRAs) conducted under RPM. Our probabilistic market simulations are also grounded in the rational economic expectation that capacity prices must equal the long-run marginal cost of supply (or Net CONE) on a long-run average basis, and we adjust the amount of entry until this condition is satisfied. This approach reflects the fact that in PJM, as in other restructured markets, the system will meet resource adequacy needs only if the market can attract new investments made by merchant suppliers. Such private investors will only build new generation if they expect to earn a competitive return on investment through the capacity, energy, and ancillary service markets. In other words, capacity prices will converge to Net CONE in expectation. However, prices will not equal Net CONE in every year, but rather reflect a distribution around that expected value based on the shape of the VRR Curve and year-to-year variations in supply and demand. We estimate this distribution of realized price, quantity, and reliability outcomes that would be realized under long-run equilibrium conditions using a Monte Carlo simulation model that incorporates historical data on the magnitude of these variations.

Details on these other topics are available in the full body of our attached report.

II. NET COST OF NEW ENTRY (CONE) PARAMETER

Here we summarize our analysis and findings with respect to PJM's administrative Net CONE estimates, and how they have informed PJM's proposals to: (a) eliminate the Dominion CONE Area, (b) revise the indices used for annual updates to gross CONE, (c) revise the mapping of CONE and E&AS offsets such that these components of administrative Net CONE will be aligned as closely as possible to each Locational Deliverability Area (LDA) modeled in RPM, and (d) apply a minimum to locational Net CONE values so that no sub-LDA will have a lower Net CONE than its parent LDA.[10]

A. Elimination of Dominion CONE Area

Currently, PJM's Tariff defines five CONE Areas for which the gross CONE parameter must be separately estimated: (1) Eastern Mid-Atlantic Area Council (Eastern MAAC), (2) Southwest Mid-Atlantic Area Council (Southwest MAAC), (3) Rest of Regional Transmission Organization (Rest of RTO), (4) Western Mid-Atlantic Area Council (Western MAAC), and (5) Dominion. These five CONE estimates are then used in calculating the Net CONE parameter for each CONE Area and the Net CONE for use in any LDA for which PJM must establish a separate VRR Curve.

However, the CONE estimate for CONE Area 5: Dominion has not been used for developing any locational Net CONE parameters because Dominion has never been a modeled LDA within RPM. Therefore, we recommend that the Dominion CONE Area be combined into CONE Area 3: Rest of RTO, which is the broader region within which Dominion is modeled for the purposes of pricing and procurements in RPM. The remaining four CONE Areas will then be consistent with the four permanently-modeled regions in RPM auctions.[11]

Combining CONE Area 5: Dominion into CONE Area 3: Rest of RTO would not affect our estimate of gross CONE in Area 3 as summarized in the Newell/Ungate Affidavit. This is because, based on the relatively few reference projects in Dominion, we would not have used the Dominion zone as one of the most representative locations for developing a CONE estimate in the larger combined area. Further, the two estimates are relatively similar in any case, with the Dominion CONE estimate being 2% below the Rest of RTO estimate for a gas Combustion Turbine (CT).[12]

B. Adopting Different Indices for Annual CONE Escalation

PJM updates its gross CONE parameter annually for each year between the periodic CONE studies by applying the Handy-Whitman "Total Other Production Plant" index for the

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[10] See the more detailed discussion and analysis in our attached Third Triennial Review, Section III.

[11] A more detailed discussion of our review of how gross CONE is mapped between the CONE Areas into each LDA VRR curve is contained in Section III.C.1 of our attached Third Triennial Review.

[12] See Newell/Ungate affidavit.

appropriate location.[13] However, we found that this index has escalated more quickly than the rate of cost increases suggested by recent CONE studies.[14]

We therefore explored alternative updating methodologies, and we recommend that PJM adopt a revised annual escalation methodology based on a weighted average of three indices from the Bureau of Labor Statistics (BLS). These three indices track wages in utility system construction by location, construction materials costs, and turbine costs.[15] The weightings on each of the three indices would be equal to the relevant proportion of capital costs from the 2014 CONE Study.[16] As shown in the Third Triennial Review, we "backcasted" the resulting composite index over the 2004 to 2014 against the changes in CONE from the "bottom-up" comprehensive estimates of CONE studies, showing that the index more closely tracks the results of the CONE studies than does the Handy-Whitman Index.[17]

C. Single-Zone and Multi-Zone Calculation of Net CONE

Each modeled LDA must have a defined Net CONE parameter from which the price points on the locational VRR Curve is derived. Currently, PJM's Tariff specifies that Net CONE will be calculated for each CONE Area based on the gross CONE for that CONE Area, and the E&AS offset for a specific energy zone within that area. However, because the CONE Areas do not exactly align with the modeled LDAs, the Tariff also specifies how these Net CONE estimates are then mapped to each LDA.

The consequence of these mappings is that many single-zone LDAs have a Net CONE parameter based on the energy prices in a different (sometimes distant) location. In larger LDAs that cover many zones, the Net CONE reflects the energy prices in only one sub-zone and may not be reflective of other zones in the LDA.

To improve the accuracy of its Net CONE parameter, we recommend that PJM more closely align the Net CONE estimates to the LDAs as modeled in RPM. PJM's proposed Tariff revisions will accomplish that goal by calculating Net CONE individually for each

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13 See p. 27 of PJM's *Manual 18: PJM Capacity Market*. Revision 22, Effective April 24, 2014. Retrieved from: http://www.pjm.com/~/media/documents/manuals/m18.ashx

14 See Section III.A.3 of our Third Triennial Review.

15 The specific indices reflected in the composite index for the example of Eastern MAAC are: (1) BLS Quarterly Census of Employment and Wages: 2371 Utility System Construction for the appropriate state in each CONE Area; (2) BLS Producer Price Index Commodity Data: SOP Stage of Processing: 2200 Materials and Components for Construction; and (3) BLS Producer Price Index Commodity Data: 11 Machinery and Equipment: 97 Turbines and Turbine generator Sets. These indices weighted at 28%, 47%, and 25% for the CT, and 37%, 51% and 12% for the CC, consistent with our estimate of the relevant contribution to plant capital costs in each case, see Bureau of Labor Statistics. *Quarterly Census of Employment and Wages – Industry*. Available at http://data.bls.gov/cgi-bin/dsrv?en

16 We assign each capital cost line item to one of the three cost indices for calculating this ratio, even though in some cases these assignments are inexact.

17 See additional detail in our attached 2014 CONE Study, as well as in Section III.A.3 of our attached Third Triennial Review.

energy zone based on the energy prices for that zone. Each LDA's Net CONE will then be defined: (a) for LDAs that cover a single zone, as the Net CONE for that zone; and (b) for LDAs that cover multiple zones, as the average of the zonal Net CONEs for all zones in that LDA.[18]

D. Minimum Net CONE at Parent LDA Value

PJM also proposes to adopt our recommendation to prevent the Net CONE of a sub-LDA (*i.e.*, an LDA wholly encompassed within a larger LDA) from falling below the Net CONE of its parent LDA. We made this recommendation as a safeguard against under-estimating locational Net CONE and the consequential under-procurement that could occur in small LDAs. Net CONE estimation errors are more likely in small LDAs, such as Southwest MAAC, which may have idiosyncratic estimation uncertainties as well as small sample sizes for estimating gross CONE and calibrating E&AS estimates. Capacity under-procurement that can result from Net CONE underestimates would also have disproportionately high reliability consequences in small LDAs, as explained in our Third Triennial Review.[19] Consequently, there are substantial reliability benefits from subjecting sub-LDA Net CONE values to a minimum at the parent LDA's Net CONE value.

There is little cost from imposing the parent Net CONE as a minimum for the sub-LDA. If Net CONE is truly lower in the sub-LDA than in the parent LDA, developers considering locating somewhere in the parent LDA should preferentially site their new entry plants in the sub-LDA, given its lower net cost (and potential for higher capacity prices). That cost advantage indicates that the sub-LDA would attract sufficient capacity to avoid price-separating from the parent LDA in RPM auctions. If the sub-LDA does not price-separate, then the theoretically lower Net CONE in the sub-LDA will never find any practical expression. Even if a separate VRR Curve is established for the sub-LDA, the VRR Curve for the parent LDA will continue to set clearing prices in the sub-LDA.

In fact, the attractiveness of investing in locations with the lowest Net CONE is the reason that we would not expect Net CONE to be lower in a sub-LDA for any extended period of time. If we observe the opposite, with a location being persistently import-constrained and lacking investment despite a low administrative Net CONE estimate, then it seems likely that the low Net CONE estimate is a consequence of administrative estimation error rather than of developers failing to identify the low-cost, high-value investment opportunity.

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18 See Section III.C.2 of our Third Triennial Review for a more detailed discussion of locational E&AS offset and Net CONE mapping.

19 See our Third Triennial Review, Section III.C.3 for a more detailed conceptual discussion of this topic, Section III.B.1 for additional detail on Southwest MAAC, and Section VI.B.3 for simulation results illustrating the large reliability impacts from under-estimation errors in Net CONE in small LDAs.

III. DESCRIPTION OF PROBABILISTIC SIMULATION APPROACH USED TO EVALUATE VRR CURVE PERFORMANCE

One component of the Triennial review required by PJM's tariff is a probabilistic simulation analysis of the VRR Curve's performance. To conduct that probabilistic analysis, we developed a Monte Carlo simulation model that estimates the likely distribution of price, quantity, and reliability outcomes in PJM on both a system-wide and a locational basis under each analyzed demand curve. We present simulated results from 1,000 draws of potential market outcomes based on uncertainty distributions around year-to-year variations in: (a) total supply offers in the market and in each LDA, (b) different supply curve shapes, (c) the reliability requirement, (d) administrative Net CONE, and (e) capacity import limit parameters. For each variable, we developed estimates of the typical magnitude of such variations based on historical data.[20]

As we explained previously, the model assumes economically rational new entry, with new supply added infra-marginally until the long-term average price equals Net CONE. As such, our simulations reflect long-term equilibrium conditions in a market environment where prices must be high enough to support merchant investment.

Our simulation modeling approach is very similar to the one that we used when assisting ISO-NE in developing its downward-sloping demand curve, as recently approved by the Commission.[21] This approach also has a number of conceptual similarities to the model developed by Professor Benjamin Hobbs and previously used to evaluate the PJM VRR Curve.[22] Our approach differs from Professor Hobbs's approach primarily because we: (i) incorporate a substantial body of empirical data (covering ten BRAs) to develop estimates of realistic variations in supply, demand, and transmission for use in the Monte Carlo draws; (ii) assume a sloped capacity supply curve reflective of historical offer curve shapes; and (iii) apply RPM's locational auction clearing mechanism.

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[20] See Section IV and Appendix A of our Third Triennial Review for a detailed description of each uncertainty that we model and the underlying data we used to support our estimate of the magnitude of variations.

[21] See Newell, Samuel A. and Kathleen Spees. "Testimony of Dr. Samuel A. Newell and Dr. Kathleen Spees on Behalf of ISO New England Inc. Regarding a Forward Capacity Market Demand Curve," Attachment to ISO New England and New England Power Pool submission before the Federal Energy Regulatory Commission, April 1, 2014. Docket ER14-1639-000.

[22] See Hobbs, Benjamin F. "Affidavit of Benjamin F. Hobbs on Behalf of PJM Interconnection, LLC," Filed before the Federal Energy Regulatory Commission, August 5, 2005. Docket Nos. ER05-1440-000, EL05-148-000; and Hobbs, Benjamin F., Ming-Che Hu, Javier G. Iñón, Steven E. Stoft, and Murty P. Bhavaraju, "A Dynamic Analysis of a Demand Curve-Based Capacity Market Proposal: The PJM Reliability Pricing Model," IEEE Transactions on Power Systems, Vol. 22, No. 1. February 2007.

IV. REVIEW OF THE VARIABLE RESOURCE REQUIREMENT CURVE

We qualitatively and quantitatively evaluated the VRR Curve, to evaluate its likely performance and consistency with the RPM design objectives. The primary objective of the VRR Curve, and of RPM itself, is to achieve the 1-event-in-10-years (1-in-10) Loss of Load Expectation (LOLE) reliability standard on a long-term average basis (although not necessarily in every individual year). Other objectives include mitigating price volatility, reducing exposure to the exercise of market power, producing prices reflective of market conditions, minimizing complexity, and producing capacity prices that are reflective of reliability value (if possible). While not all of these objectives can be fully met simultaneously, a well-designed capacity demand curve will reflect a balance among these conflicting objectives.

In evaluating the current VRR Curve, we identified three performance concerns that PJM's revised curve would ameliorate: (1) the point "a" quantity at the VRR Curve cap is below PJM's backstop procurement trigger threshold, (2) based on our probabilistic market simulations we find that the current curve is not likely to achieve the 1-in-10 reliability standard on a long-run average basis, and (3) the concave shape of the curve is less economically rational than a convex curve and is more vulnerable to Net CONE estimation errors. In the following discussion, we qualitatively discuss how PJM's proposal to revise the shape of the VRR Curve addresses the first and third of these performance concerns. We then present a summary of our probabilistic analysis of PJM's proposed curve, showing that, unlike the current curve shape, the revised curve shape will meet or exceed the reliability standard at the PJM Region-wide level and in each modeled LDA under base assumptions.

A. Point "a" Quantity is Below Backstop Threshold

Point "a" on the current VRR Curve is where the curve reaches the price cap, at a quantity of Installed Reserve Margin (IRM) – 3%. Reliability is relatively poor at this point, corresponding to an average LOLE of 0.42 events/year (this LOLE can alternatively be described as a "reliability index" of 1 load loss event in 2.4 years). This point is also below PJM's defined backstop threshold of IRM – 1%, consistent with an LOLE of approximately 0.18 events/year (reliability index of 1-in-5.6). If procured quantities in the BRA fell below this threshold for three consecutive years, PJM would initiate a backstop procurement.[23]

To make the shape of the VRR Curve more consistent with design objectives, we recommended that PJM consider increasing the quantity at point "a" to a level equal to or greater than this IRM – 1% backstop procurement threshold. This change would: (a) reduce the likelihood of realizing very low reliability events in any one year, (b) produce stronger price signals more reflective of the low reliability conditions that would be realized at lower margins, and (c) ensure that PJM has exhausted all opportunities to procure capacity within the normal BRA structure before any backstop mechanism could be triggered. PJM's proposed VRR Curve incorporates this recommendation.

[23] See additional discussion of the point "a" quantity and the backstop threshold in our Third Triennial Review, Section V.A.3.

B. Concave Shape is Less Economically Rational

Another, potentially less significant, limitation of the current VRR Curve is its concave shape that points away from the origin. Moving to a convex shape that points toward the origin would be more economically rational and somewhat more reflective of the incremental reliability and economic value of capacity. We therefore recommend that PJM consider adopting a convex curve, although we acknowledge that aligning the curve shape with marginal economic or reliability value is a secondary objective of the VRR Curve. We did not recommend developing a curve that is exactly reflective of marginal reliability value, because such a curve would be relatively steep compared to the current VRR Curve and therefore would not achieve the price volatility mitigation benefits of a more sloped curve.[24] PJM's proposed curve does reflect a slightly convex shape.

This revised convex shape also demonstrates more robust performance than the current concave shape in the stress scenario in which administrative Net CONE is systematically under-estimated. This is because the convex curve has a steeper shape in the high-price region, so an under-estimate of Net CONE will result in a relatively smaller reduction in average quantity and a relatively smaller degradation in reliability as compared to the current VRR Curve. In the case of an over-estimate of Net CONE, the convex curve will produce a relatively lower amount of over-procurement.[25]

C. Simulated System-Wide Performance of the Current and Proposed VRR Curves

Using the probabilistic simulation analysis described above, we evaluated the performance of the current VRR Curve as well as a variety of alternative curves under base case assumptions and a range of sensitivity assumptions.[26] We present in Figure 2 and Table 1 a comparison of the shapes and simulated performance of: (1) a vertical demand curve, (2) the current VRR Curve, (3) a convex-shaped curve tuned to exactly achieve the 0.1 LOLE standard, and (4) the convex curve right-shifted by 1%, consistent with PJM's proposal.

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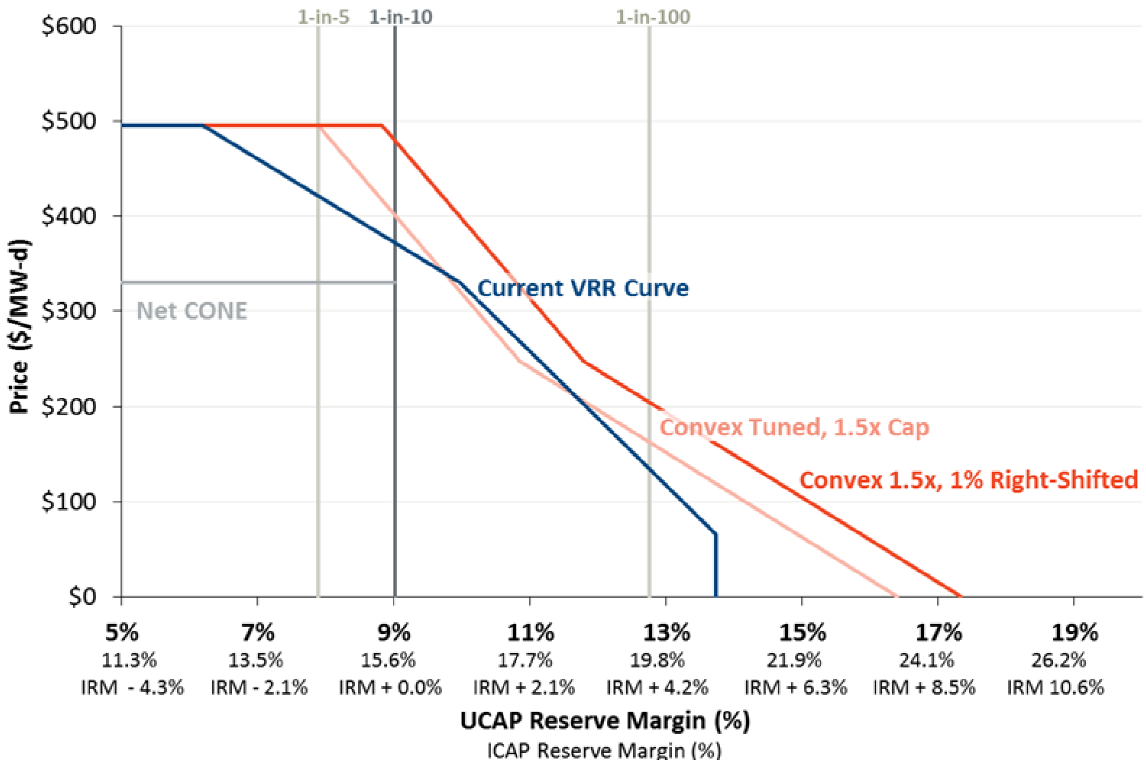
[24] See additional discussion of the VRR curve's concave shape and a convex alternative in our Third Triennial Review, Section V.A.2.

[25] See section V.C.4 of our Third Triennial Review for additional discussion of the robustness of each curve in our sensitivity analyses.

[26] See our Third Triennial Review, Sections V.B-C for a detailed description and the results of this analysis.

Figure 2
PJM Proposed VRR Curve Compared to Current Curve



Sources and Notes:

Current VRR Curve reflects the system VRR curve in the 2016/2017 PJM Planning Parameters, calculated relative to the full Reliability Requirement without applying the 2.5% holdback for short-term procurements. See “2016/2017 Planning Parameters,” April 30, 2013, posted at: http://www.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2016-2017-planning-period-parameters.ashx.

The most important result from our simulation analysis is that the current VRR Curve produces an average LOLE of 0.121 events/year, which does not achieve the primary RPM design objective. We also note that the curve produces a relatively high 20% frequency of events below the 1-in-5 (0.2 events/year) reliability level, which is approximately consistent with the IRM – 1% backstop threshold discussed in the prior section. These performance results are consistent with our qualitative observations that the quantity at the price cap is lower than desirable, and that the relatively flatter convex shape of the curve at low quantities contributes to these reliability concerns.

We tested a number of options for addressing these performance concerns in the VRR Curve, including developing a revised convex curve with the cap quantity at 1-in-5 and with the shape tuned such that the curve would exactly achieve the 0.1 LOLE standard on a long-term average basis. Our simulations demonstrate that this curve improves performance, meeting the 0.1 LOLE standard on average and reducing the frequency of falling below 0.2 LOLE to 13% of all years. However, this revised convex curve does not have uniformly superior performance in all dimensions, in that it produces somewhat higher price volatility (increasing from a standard deviation of $95/MW-day to $107/MW-day), and a higher frequency at the price cap (increasing from 6% to 13%). This somewhat higher price volatility is driven by the steeper shape of the curve in the high-price region, which is the region that has the greatest impact on price volatility due to the interaction with the steep portion of the upward-sloping capacity supply curve. Under the current VRR Curve, the flatter shape in the high price region mitigates this upside price volatility substantially, but at the expense of introducing more frequent and more severe shortage events.

PJM's proposed curve has the same convex shape, but is right-shifted by 1% IRM. Because PJM's proposed curve has the same shape and slope as the convex curve tuned to 0.1 LOLE, it produces the same price volatility results, but it supports 1% higher quantity in the market. The right-shifted curve therefore produces higher reliability with an LOLE of 0.060, and only 7% frequency below 1-in-5. The right-shifted curve also maintains the reliability standard under the stress scenario we analyzed where supply/demand fluctuations are 33% higher, whereas the non-shifted curve does not.[27] In a scenario where Net CONE is systematically underestimated by 20%, the right-shifted curve achieves an LOLE of 0.18 compared to 0.28 for the non-shifted curve.

However, the higher quantity that the right-shifted curve procures would come at a slight increase in long-term average capacity procurement costs. System-wide long-term average costs increase by about 1%, or approximately $170 million per year, relative to the similarly shaped curve that is not right-shifted. Note that this cost magnitude is indicative only, and does not account for the partially offsetting effects of higher reserve margins on net system costs and customer costs.[28]

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27 In this scenario, the convex tuned curve produced an LOLE of 0.156, while PJM's proposed convex + 1% curve produced an LOLE of 0.099 events/year or nearly the reliability standard. See Section V.C.4 of our Third Triennial Review.

28 This cost estimate accounts for only the difference in cleared capacity prices and quantities among 1,000 draws, assuming Net CONE remains the same. A more comprehensive cost-benefit analysis would account for a number of factors that we have not considered, that would change with a higher reserve margin including: lower energy prices, higher Net CONE, and fewer scarcity and other emergency event costs.

Table 1
System-Wide Performance of Vertical, Current, Convex Tuned, and PJM Proposed VRR Curves

	Price			Reliability					Procurement Costs		
	Average	Standard Deviation	Freq. at Cap	Average LOLE	Average Excess (Deficit)	Reserve Margin St. Dev.	Freq. Below Rel. Req.	Freq. Below 1-in-5	Average	Average of Bottom 20%	Average of Top 20%
	($/MW-d)	*($/MW-d)*	*(%)*	*(Ev/Yr)*	*(IRM + X%)*	*(% ICAP)*	*(%)*	*(%)*	*($mil)*	*($mil)*	*($mil)*
Vertical Curve	$331	$147	69%	0.175	-0.8%	1.4%	36%	24%	$19,980	$8,030	$31,531
Current VRR Curve	$331	$95	6%	0.121	0.4%	2.0%	35%	20%	$20,167	$12,672	$28,094
Convex Tuned to 1-in-10	$331	$107	13%	0.100	0.7%	1.9%	29%	13%	$20,210	$12,379	$29,631
PJM Proposal (Convex + 1%)	**$331**	**$107**	**13%**	**0.060**	**1.7%**	**1.9%**	**16%**	**7%**	**$20,383**	**$12,461**	**$29,859**

Note: Capacity procurement costs account for price premiums in import-constrained sub-LDAs.

D. Simulated Performance at the Local Level

We also evaluated the performance of PJM's current and revised VRR Curves at the LDA level, evaluating the distribution of price, quantity, and reliability results under base and sensitivity assumptions.[29] When testing the performance of VRR Curves at the local level, we focused primarily on cases where each successive import-constrained sub-LDA has a Net CONE 5% higher than the parent LDA (with administrative Net CONE accurately reflecting true Net CONE on average in each location). This Net CONE assumption allows us to test the curve performance under a modest locational net cost differential, although the Net CONE values for most LDAs do not exactly match historical PJM Net CONE parameters.

In evaluating the locational performance of the current VRR Curve, we found even more reliability concerns in some LDAs than at the system level.[30] As shown in Table 2 summarizing our simulation results, four of the nine modeled LDAs experience poorer local reliability than the standard, at conditional LOLE values of 0.042 to 0.064 events/year compared to the 0.040 events/year (or 1-in-25) local reliability standard. Three of the LDAs also have a relatively high frequency of events below 1-in-15, at 11% to 17%.[31] We also found that the reliability performance of the VRR Curve in the LDAs is relatively vulnerable to sensitivity assumptions such as administrative under-estimates in Net CONE and an LDA having a Net CONE that is substantially above the parent Net CONE. The smallest and most import-dependent zones demonstrated the most vulnerability under these sensitivity tests.

PJM's proposed VRR Curve shape substantially mitigates these reliability concerns. Under the same assumptions, all LDAs meet or exceed the conditional 0.4 events/year LOLE

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29 See Third Triennial Review, Sections VI.B-C to review the entirety of this analysis of the VRR curve as implemented on a locational basis.

30 One LDA shows LOLE further in excess of the standard than the system results, and several LDAs show greater vulnerability to low reliability events under similar sensitivity assumptions compared to the system.

31 We use the 1-in-15 threshold as a measure of very poor reliability performance at the LDA level, similar to the 1-in-5 threshold that we used at the system level.

standard and no LDA shows a frequency below 1-in-15 above 9%. However, as at the system level, we observe a moderate increase in price volatility under the revised convex shape, and somewhat higher locational procurement costs associated with the right-shifted curve.

Table 2
Locational Performance of the Current and Proposed VRR Curves

	Price				Reliability								Procurement Costs		
	Average	St. Dev	Freq. at Cap	Freq. of Price Separation	Conditional Average LOLE	Conditional Average LOLE (Additive)	Average Excess (Deficit) Above Rel. Req.	St. Dev.	Average Quantity as % of Rel. Req.	St. Dev. as % of Rel. Req.	Freq. Below Rel. Req.	Freq. Below 1-in-15	Average	Average of Bottom 20%	Average of Top 20%
	($/MW-d)	*($/MW-d)*	*(%)*	*(%)*	*(Ev/Yr)*	*(Ev/Yr)*	*(MW)*	*(MW)*	*(%)*	*(%)*	*(%)*	*(%)*	*($mil)*	*($mil)*	*($mil)*
Current VRR Curve															
MAAC	$277	$89	12%	33%	0.053	0.160	1,389	2,356	102%	3%	27%	17%	$7,082	$4,257	$10,146
EMAAC	$291	$98	8%	25%	0.033	0.193	1,349	1,706	103%	4%	22%	15%	$3,903	$2,259	$5,683
SWMAAC	$291	$96	6%	17%	0.042	0.202	1,215	1,163	107%	7%	14%	8%	$1,621	$965	$2,328
ATSI	$277	$87	11%	18%	0.035	0.143	1,152	1,121	107%	7%	14%	11%	$1,451	$901	$2,046
PSEG	$305	$105	5%	15%	0.022	0.215	1,036	886	108%	7%	13%	9%	$1,281	$722	$1,859
PEPCO	$305	$104	25%	14%	0.064	0.266	1,099	923	112%	10%	11%	10%	$791	$462	$1,135
PS-N	$321	$116	31%	15%	0.023	0.238	503	442	108%	7%	12%	8%	$633	$352	$929
ATSI-C	$291	$95	10%	12%	0.059	0.202	906	694	115%	11%	9%	8%	$504	$311	$707
DPL-S	$305	$105	13%	15%	0.027	0.220	309	259	110%	8%	12%	7%	$289	$164	$421
Convex 1.5x, Right-Shifted															
MAAC	$277	$97	14%	31%	0.028	0.080	2,237	2,314	103%	3%	15%	9%	$7,167	$4,175	$10,602
EMAAC	$291	$107	13%	23%	0.020	0.100	1,879	1,694	105%	4%	14%	8%	$3,948	$2,200	$5,930
SWMAAC	$291	$104	8%	16%	0.024	0.105	1,460	1,159	108%	7%	8%	6%	$1,640	$935	$2,433
ATSI	$277	$95	9%	17%	0.022	0.074	1,373	1,118	108%	7%	10%	7%	$1,468	$884	$2,155
PSEG	$305	$114	8%	14%	0.014	0.114	1,218	885	109%	7%	9%	5%	$1,297	$700	$1,934
PEPCO	$305	$111	9%	14%	0.040	0.144	1,224	922	114%	10%	9%	7%	$801	$452	$1,187
PS-N	$321	$123	8%	14%	0.015	0.129	593	443	109%	7%	8%	5%	$640	$340	$962
ATSI-C	$291	$102	7%	11%	0.036	0.110	999	695	116%	11%	8%	6%	$510	$304	$744
DPL-S	$305	$113	7%	14%	0.018	0.118	351	259	111%	8%	7%	5%	$292	$161	$438

Notes:

Procurement cost estimates differ slightly from our Triennial Review, reflecting a more accurate allocation of customer costs in each LDA.
Capacity procurement costs are inclusive of higher-cost procurement in import-constrained sub-LDAs.