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NORTH CAROLINA UTILITIES COMMISSION

APPEARANCE SLIP

DATE: 1/8/20 DOCKET NO.: G-100, Sub 157

ATTORNEY NAME and TITLE: Lawrence B. "Bo" Somers, Deputy General Counsel

FIRM NAME: Duke Energy Corp.

ADDRESS: ______

CITY: ______ STATE: ______ ZIP CODE: ______

APPEARING FOR: Duke Energy Carolinas + Duke Energy Progress

APPLICANT: ✓ COMPLAINANT: ___ INTERVENOR: ___

PROTESTANT: ___ RESPONDENT: ___ DEFENDANT: ___

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APPEARANCE SLIP

DATE: 1/8/20 DOCKET NO.: E-100, Sub 157

ATTORNEY NAME and TITLE: Gudrun Thompson

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APPLICANT: ___ COMPLAINANT: ___ INTERVENOR: ✓

PROTESTANT: ___ RESPONDENT: ___ DEFENDANT: ___

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NORTH CAROLINA UTILITIES COMMISSION

APPEARANCE SLIP

DATE: Jan. 8, 2020 DOCKET NO.: E-100 Sub 157

ATTORNEY NAME and TITLE: Peter Ledford, General Counsel

FIRM NAME: NC Sustainable Energy Association

ADDRESS: 4800 Six Forks Rd Suite 300

CITY: Raleigh STATE: NC ZIP CODE: 27609

APPEARING FOR: NC Sustainable Energy Association

APPLICANT: ___ COMPLAINANT: ___ INTERVENOR: X

PROTESTANT: ___ RESPONDENT: ___ DEFENDANT: ___

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NORTH CAROLINA UTILITIES COMMISSION

APPEARANCE SLIP

DATE: 1/8/2020 DOCKET NO.: E-100, Sub 157

ATTORNEY NAME and TITLE: Benjamin Smith, Regulatory Counsel

FIRM NAME: NA

ADDRESS: 4800 Six Forks Rd, Ste 300

CITY: Raleigh STATE: NC ZIP CODE: 27609

APPEARING FOR: NCSEA

APPLICANT: ___ COMPLAINANT: ___ INTERVENOR: ✓

PROTESTANT: ___ RESPONDENT: ___ DEFENDANT: ___

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PUBLIC STAFF - APPEARANCE SLIP

DATE 01/08/20 DOCKET # : E-100 Sub 157

PUBLIC STAFF MEMBER Tim Dodge & Lucy Edmondson

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Comment Materials
James F. Wilson --/A

Responses to Commission Questions in Docket No. E-100, SUB 157 (Duke IRP)

James F. Wilson
Principal, Wilson Energy Economics
on behalf of Southern Alliance for Clean Energy (SACE), Natural Resources Defense Council (NRDC) and Sierra Club

North Carolina Utilities Commission
January 8, 2020

About the Speaker

- Reports on resource adequacy and load forecast issues in last two Duke Company IRPs
- Economist involved in resource adequacy for many years
- My Public Utilities Fortnightly articles in 2010 questioned the "One Day in Ten Years" resource adequacy approach; were followed by attention to the subject by FERC, ERCOT, others
- Other related work listed in last slide and at www.wilsonenec.com

Scope of Comments
(referencing questions in 8/27/19 Order Appendix A)

Topic 1: Resource adequacy analysis and metrics/criteria (LOLE, LOLH, EUE, EORM….) (Q1; and 12/23/19 order)

Topic 2: Load forecasting and peak load mitigation (Q2)

Topic 3: Process and stakeholder involvement (Q1h)

"Reliability" – Broad Categories

1. **Distribution systems** (equipment replacement, tree trimming..)
2. **Transmission system** planning and operation for reliable bulk power system operation
3. **System operation** (balancing supply and demand at all locations in real time)

and commonly also considered "reliability":

4. **"Resource adequacy":** "enough" resources at peak times

The focus today: #4, resource adequacy

Outage Frequency and Impact by Cause

Category of "Reliability"	Frequency of Outages	Impacts of Outages		
		# customers affected	*Total $$ Impact*	*Impact per customer or per KWh (VOLL)*
#1 Distribution System	Frequent	Few: very local	Large (many incidents)	Can be high (events are unexpected, duration is unknown, can be long)
#2 Transmission System	Very rare	Many if widespread	Can be very large	
#3 System Operational	Rare	Likely brief, local	Low (few MWh)	Low? (brief)
#4 Resource Adequacy	Very rare	Few (only the "peak" demand)	Low: Few customers, MWh	**Low: Likely a controlled, rotating outage, noticed in advance, avoids high-impact customers**

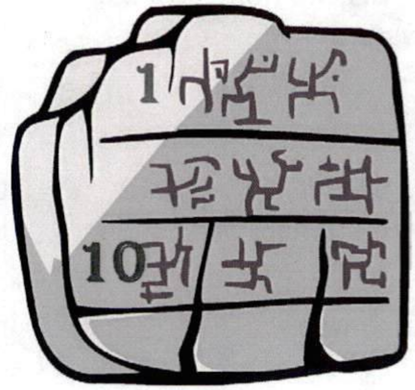
Value of Lost Load ("VOLL") for resource adequacy

- The assumption used for the cost of unserved energy for resource adequacy analysis should be much lower than for other types of reliability analysis (distribution, transmission, resilience)
  - Extreme weather, low reserve margins likely foreseen days in advance
  - Need for rotating outage likely warned and noticed in advance
  - Rotating outages are imposed on lower-impact circuits (likely residential), avoiding essential needs customers (hospitals, etc.)
  - Rotating outages of fixed, short duration (perhaps 30 or 60 minutes)

"One Day in Ten Years" Resource Adequacy

- "One Day in Ten Years:" Capacity is planned such that a loss of firm load is expected to occur no more often than one event every ten years (Loss of Load Expectation, "LOLE" = 1 event/10 years = 0.1/year).
- Origin of 1-in-10? Unknown (probably early twentieth century).
- Current "status"? A common metric. 1-in-10 is <u>not</u> a NERC or FERC planning requirement. (in RFC, a standard requires it for a *study*)
- Use, role of such criteria? Varies by region.

"1 in 10"



"One Day in Ten Years" Is Very Conservative

- 1-in-10 does not balance the marginal cost of incremental capacity against its benefit (economically optimal reserve margins are considerably lower)
- 1-in-10 provides roughly two orders of magnitude more delivered reliability than provided by distributions systems
- Approaches to calculating 1-in-10 reserve margins generally make very conservative assumptions (so its not really1-in-10)
- New considerations (intermittent resources, resilience, common mode failures, etc.) do not fundamentally change this picture
- With scarcity pricing, energy storage, and an increasingly price-responsive demand side, the distinction between voluntary and involuntary load drop becomes meaningless, as does 1-in-10 and other physical reliability measures

Wilson, James F., *Reconsidering Resource Adequacy Part 1: Has the one-day-in-ten-years criterion outlived its usefulness*? and *Reconsidering Resource Adequacy, Part 2: Capacity planning for the smart grid,* Public Utilities Fortnightly, April and May 2010

A Regulator's Perspective on Reliability

"Among our most important responsibilities as regulators is to ensure that electricity is available to all Maryland ratepayers, whenever and wherever they need it. Electric service … is the life blood of modern society… Put another way, the public expects *us* to keep the lights on …

… Among the things that go bump in the night, the thought that the lights might go out in Maryland as a result of our actions, or inactions, during our term as Commissioners is one that keeps us awake….

Maryland Public Service Commission Order No. 84815, April 12, 2012, p. 1, 18, 22

An Economist's Perspective on Resource Adequacy

"Resource adequacy practices based on the 1-in-10 criterion perhaps make more sense for utility planners and regulatory authorities, who would have to answer for any curtailments that occur, than for the consumers who are directly affected if reliability isn't maintained, but who also bear the cost of the additional capacity."

Wilson, James F., *Reconsidering Resource Adequacy Part 1: Has the one-day-in-ten-years criterion outlived its usefulness*? Public Utilities Fortnightly, April 2010, p. 1.

Alternatives to LOLE and "1-in-10"

Resource Adequacy Metric	What is Measured	Typical Criterion Applied	Advantages	Disadvantages
LOLE: Loss of Load Expectation	Event frequency only	One event in 10 years	Simple to calculate with readily available data; widely accepted metric and criterion	Physical only, and # events only; widely accepted criterion is overly conservative
EUE: Expected Unserved Energy (*LOLH is similar*)	Event size, duration (MWh)	? MWh of outage in 10 years	Better represents impacts of outages (MWh)	Rests on additional assumptions; no widely accepted criterion
EORM: Economically Optimal Reserve Margin	Marginal cost and marginal benefit	Minimum cost (or w/ confidence interval)	In principle, balances cost and benefit of additional reserve margin...	Driven by problematic economic assumptions (VOLL, scarcity pricing, etc. etc...)

Economics of Resource Adequacy (Over/Under Approach Used to Calculate EORMs)

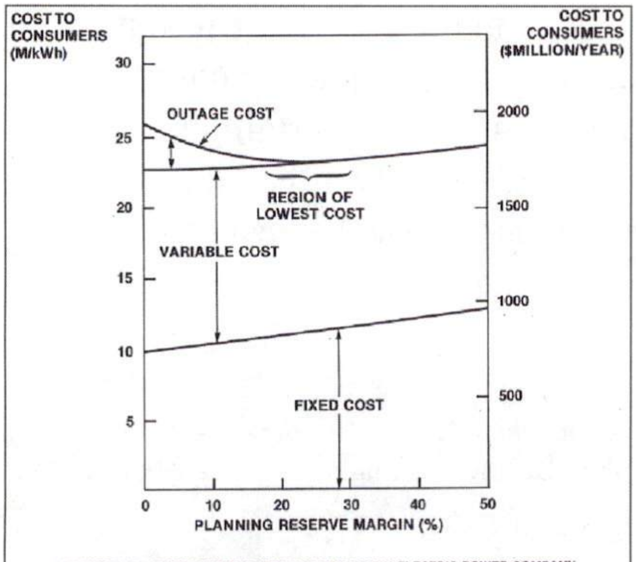


FIGURE 6-12. BASE CASE RESULTS FOR WISCONSIN ELECTRIC POWER COMPANY

Source: Decision Focus, Inc. *Costs and Benefits of Over/Under Capacity in Electric Power System Planning*, EPRI Report EA-927, Oct. 1978

- Conceptual approach used in IRP, in 2013 Brattle/Astrape study for FERC, and in earlier studies back to 1970s
- Requires modeling likelihood *and consequences* of extreme events
  - Probability of combinations of "tail" events (load, resource, regional)
  - Assumptions about scarcity pricing, neighbor assistance, cost impact on customers, etc. in such situations

Requires many assumptions about which there is no history or other reliable information

- (Duke response to Commission questions p. 3 – cites to a 1982 event!)

Emerging Reliability Concern – Flexibility, Ramping

- With increasing variable resources, the ability to balance the system minute to minute, hour to hour is a greater concern
  - Requires flexibility (fast response on supply or demand side)
- A separate issue from resource adequacy
  - Resource adequacy – enough total MW at peak times
  - Flexibility – adequate flexible resource capability at all times (small subset of total) to respond to potential movements in load and resources
- Requires very different tools and analysis
  - An analytical approach and model designed to do resource adequacy won't be able to do this analysis well if at all

LOLE, EUE, EORM: Takeaways

- LOLE w/1-in10 is conservative, established, simple to calculate
  - "1-in-10" has no economic rationale and is very conservative, but is widely accepted; LOLE calculations use readily available data (load shapes, outage frequency)
- EUE (or LOLH) are physical reliability metrics closely related to LOLE; no widely accepted criteria for these metrics
- EORM is conceptually superior (trades off cost and benefit)
  - If done right, EORM is well below the 1-in-10 reserve margin
  - But requires many highly questionable $$ assumptions… enormous range for even more thumbs on the scale than in 1-in-10 calculations

Communicating Resource Adequacy Needs: An Alternative, More Stable Reserve Margin Metric

- "Reserve Margins" typically show *installed* capacity relative to a median or 50-50 forecast summer or winter peak; such reserve margins may change substantially study to study
  - RM is sensitive to changes in resource mix: capacity values are far below installed capacity for some resources such as wind and solar
  - RM is sensitive to changes in load shapes: in RA studies, it's the higher and less frequent (e.g., 90th percentile) peak loads, not the median peaks, that determine the capacity needs
- Suggested additional, more stable RM measure: "unforced" capacity (total capacity value) ratio to 90th percentile peak
  - Is a quite small number, likely only a few percent
  - Similar between regions, stable as resource mix and load shapes change

Duke Has Not Responded to My Criticism of RA Study

- Economic load forecast error
- Impact of extreme cold on load
- Use of Value At Risk and confidence interval for EORM
- Lack of sensitivity analysis, model reports, etc.
- Among others.

Topic 2: Load Forecasting and Peak Load Mitigation

- Load forecasting process should provide key information to guide the assumptions for the resource adequacy study:
  - Forecasts of summer and winter peak loads, of course…
  - Potential for load forecast error: high economic growth/low energy efficiency scenarios, perhaps 90/10 summer/winter peak loads
  - Analysis of load levels resulting from extreme cold or heat
  - End use drivers of extreme peaks (and mitigation assumptions)
- Importance of consistency between load forecasting and resource adequacy study

Which End Uses Contribute to Winter Load Spikes?

- Duke Companies' response (pp. 23-28) mainly cites national and regional data from EIA, EPRI
  - Apparently, still little knowledge about which Duke customers and end uses cause the spikes
- Focuses on residential space heating (and suggests lower income, rural customers are mainly to blame)
- No mention of commercial customers (such as schools, stores, offices) who might represent best potential for mitigation
  - Pre-warm spaces and/or
  - Commit to open late when very extreme cold in forecast

Topic 3: Process to Prepare Resource Adequacy Study

The Proposed Work Plan (Duke Filing pp. 14-16) is Flawed:

- No mention of stakeholder input other than Public Staff
- Work Plan only calls for updating assumptions; apparently no consideration of structure and approach
- Sensitivity analysis performed only *after* "validation", simulation
- Work Plan "hard-wires" some controversial assumptions
  - *e.g.*, 3 year forward load uncertainty, 1980 to 2018 weather data
- Work Plan apparently attempts to limit sensitivity analysis
  - 3 identified; other sensitivity analysis only "Company requested"

Recommended Elements of Work Plan for RA Study

- Stakeholder review and input early on and throughout process
  - Input leads to better choices for structure and assumptions, minimizes later controversy over poorly-chosen assumptions
- Provide requested sensitivity analysis throughout process
  - Necessary early in process, to identify sensitive assumptions that warrant further consideration and analysis
  - Necessary after report is completed, to allow Public Staff, stakeholders and NCUC to fully understand recommended and alternative RMs

Example: PJM annual process for Reserve Requirements Study

Model Validation – Does it Match the Real World?

- *Software* validation (the software correctly reads inputs, calculates, creates outputs) – Duke filing claims they did this – no dispute
- Model validation (review and analyze detailed preliminary results to check that you've got a reasonable model of what would happen in the real world, and how often it might happen)
  - Not done; requires extensive sensitivity analysis and review of details
  - Requires critical eye – stakeholder involvement is needed to do it right

Note: model scenarios are not like scientific observations: larger numbers do not ensure greater accuracy!

CEP Calls for Transparency, Stakeholder Input

Clean Energy Plan Strategy Area C: Require comprehensive utility system planning processes

- C-1. Establish comprehensive utility system planning process that connects generation, transmission and distribution planning in a ***holistic, iterative and transparent process that involves stakeholder input throughout***… [emphasis added]

Prior Work Related to Resource Adequacy

Wilson, James F., *Review and Evaluation of Resource Adequacy and Solar Capacity Value Issues*, and *Review and Evaluation of the Load Forecasts*, NCUC Docket No. E-100 Sub 157, March 7, 2019; also similar analyses in Virginia, South Carolina, Georgia, Alabama

-----, *Maintaining Resource Adequacy in PJM While Accommodating State Policies;* with Rob Gramlich, July 27, 2018; also many other analyses and testimony regarding PJM resource adequacy issues.

-----, *Regional Reliability Standards: Requirements or Replaceable Relics?* Harvard Electricity Policy Group Ninetieth Plenary Session, Washington, DC, March 22-23, 2018

-----, *Resource Adequacy in PJM: The Seasonal Aspect*, Organization of PJM States Annual Meeting, October 19, 2016

-----, *"Missing Money" Revisited: Evolution of PJM's RPM Capacity Construct*, report prepared for the American Public Power Association, September 2016

-----, Post-conference comments, *Centralized Capacity Markets in Regional Transmission Organizations and Independent System Operators*, FERC Docket No. AD13-7, January 8, 2014

-----, Comments on *The Economic Ramifications of Resource Adequacy* (for Eastern Interconnection States' Planning Council, EISPC), March 2013

-----, *Reliability and Economics: Separate Realities?* Harvard Electricity Policy Group 65th Plenary Session, December 2011

-----, *Comments on Proposed Reliability Standard BAL-502-RFC-02: Planning Resource Adequacy Analysis, Assessment and Documentation,* FERC Docket No. RM10-10, Dec. 27, 2010

-----, *Forward Capacity Market CONEfusion,* Electricity Journal, November, 2010

-----, Affidavit in Support of Comments and Protest of the Pennsylvania Public Utility Commission, FERC Docket No. ER09-1063-004 (shortage pricing), July 30, 2010

-----, *Reconsidering Resource Adequacy, Part 1: Has the one-day-in-10-years criterion outlived its usefulness?* Public Utilities Fortnightly, April 2010

-----, *Reconsidering Resource Adequacy, Part 2: Capacity planning for the smart grid,* Public Utilities Fortnightly, May 2010

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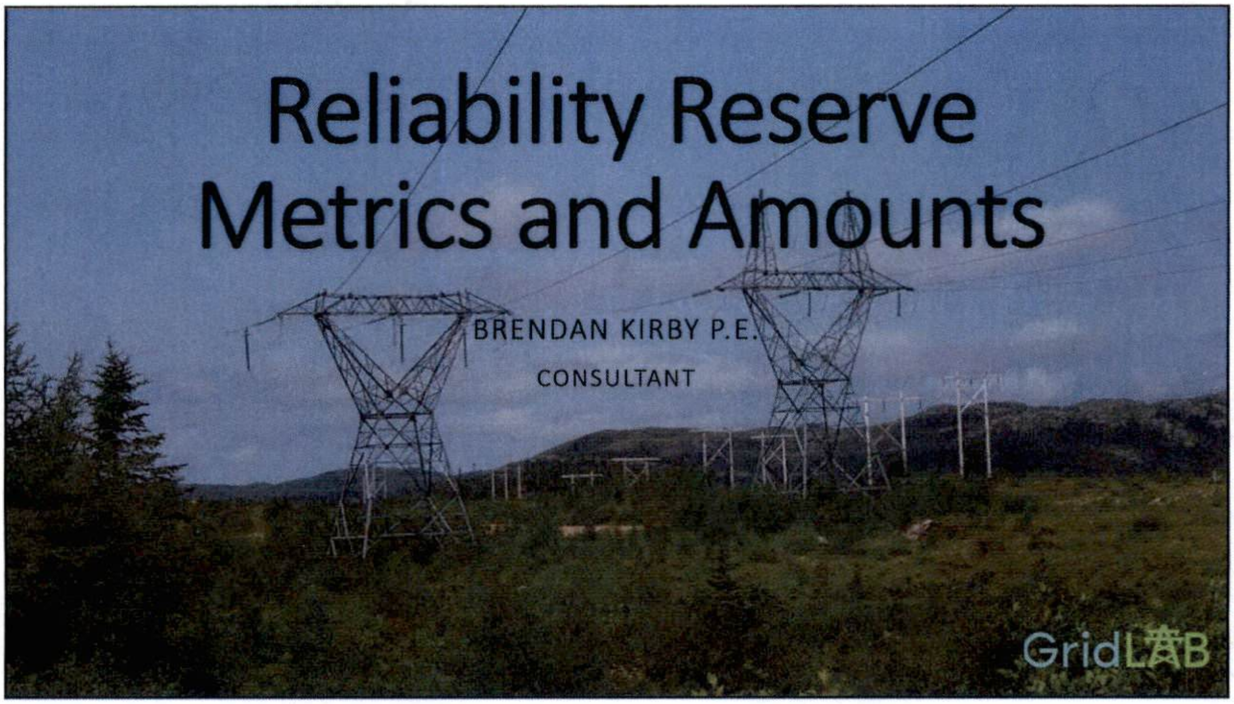
James Wilson is an economist with 35 years of consulting experience in the electric power and natural gas industries. His work has pertained to the economic and policy issues arising from the interplay of competition and regulation in these industries, including restructuring policies, market design, market analysis and market power. Recent engagements have involved resource adequacy and capacity markets, contract litigation, rate cases, modeling of utility planning problems, and many other economic issues arising in these industries. Mr. Wilson has been involved in electricity restructuring and wholesale market design for over twenty years in PJM, New England, Ontario, California, Russia, and other regions. He also spent five years in Russia in the early 1990s advising on the reform, restructuring, and development of the Russian electricity and natural gas industries for the World Bank and other clients.

Prior to founding Wilson Energy Economics, Mr. Wilson was a Principal at LECG, LLC. He holds a B.A. in Mathematics from Oberlin College and an M.S. in Engineering-Economic Systems from Stanford University.

Comment Materials
Brendan Kirby --/A



1

"Resource Adequacy Requirements: Reliability and Economic Implications"

The NC PUC 12/23/2019 Order recognized this Brattle Group and Astrapé Consulting FERC report and asked what the Commission should draw from it:

- Changes in the treatment of reserve margins in the IRP to aid in the advancement of other goals and actions, such as those discussed in the NC CEP?
- Metrics other than "loss of load expectation" (LOLE), including "loss of load hours" (LOLH) and/or "expected unserved energy" (EUE)?
- Risks and costs to mitigate risks arising from scenarios that might depart from the traditional once-in-ten-years LOLE metric?

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"Resource Adequacy Requirements: Reliability and Economic Implications"

Excellent report by the Brattle Group and Astrapé Consulting for FERC

Good narrative explaining issues, discussing options (metrics, for example), including both pros and cons

Good example power system

- Shows numerical trends for reliability concepts
- Demonstrates how the analysis can be performed
  - Tools
  - Data requirements
  - Interpretation of results

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The Second Question First: Yes – EUE is a Much Better Metric than LOLE

The reliability metric should reflect the duration and depth (MW) of outages, not just the number of outages

Expected Unserved Energy (EUE) gives a much better representation of the actual reliability impact for all customers – increasing with the number of outages, outage duration, and outage MW

- Loss of Load Hours (LOLH) is a partial improvement

EUE is also normalized by power system size

- A 0.1 LOLE for 151,000 MW PJM does not represent the same customer reliability as a 0.1 LOLE for the 526 MW Turlock Irrigation District

Computing capability and analysis tools no longer limit the choice of metric

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LOLE, LOLH, and EUE Are Not Directly Comparable
(Be careful, but don't be deterred)

Switching from LOLE to EUE is not like switching from MPH to KPH or from Heat Rate to Efficiency

- A 0.1 events-per-year LOLE is not exactly equal to a 2.4 hours-per-year LOLH or a 0.001% EUE

Trends tend to be the same

- Increased reserves results in increased reliability and increased costs ...

Equivalent values for LOLE, LOLH, and EUE can be determined *for specific reliability cases*

Switching from LOLE to LOLH or EUE could result in an inadvertent change in reliability – *just be careful*

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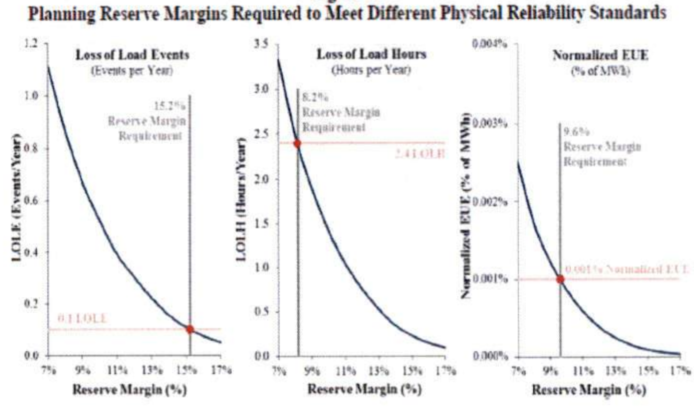
LOLE, LOLH, and EUE Trends Share Similarities

Increasing reserves increases reliability and increases costs

Figure 12
Planning Reserve Margins Required to Meet Different Physical Reliability Standards



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There Is No Standard Definition Of What Constitutes an LOLE "Event"

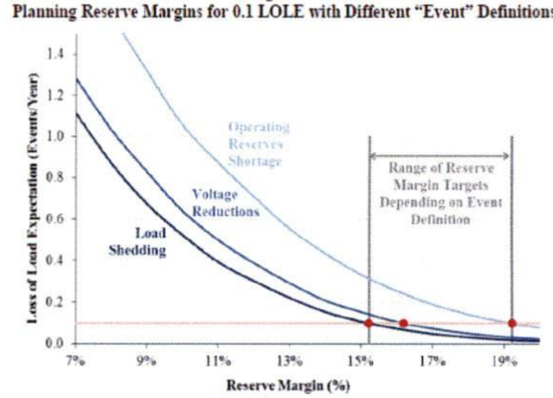
Some LOLE studies count any use of emergency procedures, such as demand response, voltage control, or depleting operating reserves

Others only count events where reserves are depleted, *and* firm load must be shed

Reserve requirements should be based on mandatory NERC reliability standards

In actual operations loss of load due to lack of capacity is extremely rare

Figure 11
Planning Reserve Margins for 0.1 LOLE with Different "Event" Definitions



The Report notes that "resource adequacy-related reliability events account for only a very small fraction customer outages"

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Reliability Events Are Rare

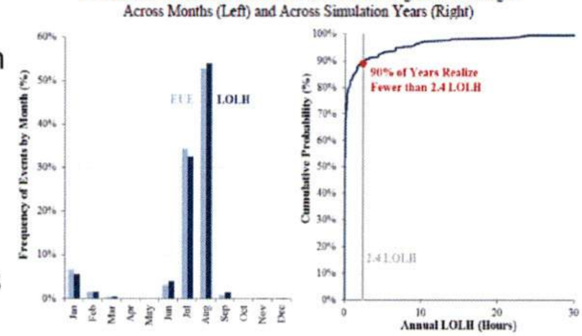
This Has Important Consequences

Thousands of cases are simulated

Reliability metric values are driven by a small number of extreme outage, weather, and load conditions

In this example 45% of all years have no outages but the single worst year has 68 load shed hours

Figure 13
Distribution of Loss of Load Hours at 12% Planning Reserve Margin
Across Months (Left) and Across Simulation Years (Right)



While only 10% of years exceed the 2.4 LOLH threshold, the probability-weighted average over all 9,600 cases is 1.4 LOLH

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Risk Aversion vs Lowest Cost vs Fixed Reserve Margins: *More Than Just An Economic Question*

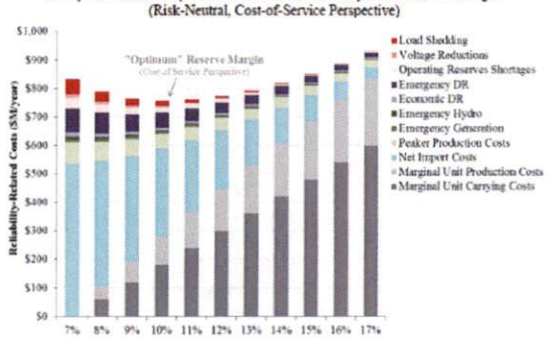
Good discussion of how to set reserve margins to minimize costs vs setting reserve margins exclusively based on physical reliability

- Further discussion of risk-neutral vs risk aversion costs

Quantifying the customer costs of calling on demand response, of voltage reductions, and of curtailments allows economic reserve optimization

- Precise customer cost quantification is not necessary

Figure ES-1
Study RTO Reliability Costs as a Function of Study RTO Reserve Margin
(Risk-Neutral, Cost-of-Service Perspective)



The Report notes that "resource adequacy-related reliability events account for only a very small fraction customer outages"

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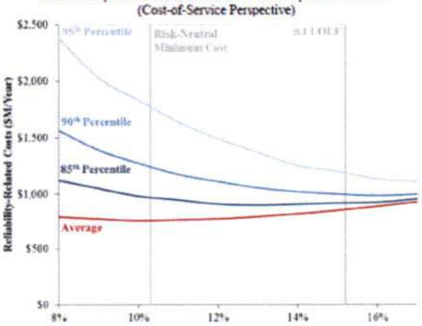
Much Greater Year-to-Year Cost *Volatility* at Lower Reserve Margins

"Most years have only very modest reliability costs, while a small number of years have very high reliability costs. These high-cost outcomes account for the majority of the weighted average annual costs. The majority of all reliability-related costs are concentrated in the most expensive 15% of all simulation runs"

"While total average costs change by a relatively modest amount over a range of planning reserve margins, differences in planning reserve margins have a much larger impact on the *uncertainty* in reliability costs and the likelihood of high-cost outcomes than can be encountered *in any particular year*"

"Considering the much higher cost uncertainty exposure at lower reserve margins, many planners and policy makers may wish to set planning reserve margins above the risk-neutral economic optimum. In our sample system, even a several percentage point increase in the target reserve margin would only slightly increase the average annual costs, but substantially reduce the likelihood of experiencing very high-cost events."

Figure 16
Uncertainty Distribution of Annual Reliability-Related Costs
(Cost-of-Service Perspective)



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Further Example Cost Details

10.3% Risk-neutral optimal reserve

15.2% 0.1 LOLE reserve margin costs +$90 million/yr

Reduces the 1-in-10-yr (90th percentile) cost by $270 million (for that bad year)

Reduces the 1-in-20-yr (95th percentile) cost by $630 million (for that bad year)

Report Conclusion:

a) a risk-neutral policy maker would not increase reserve margins above the 10.3% risk-neutral optimum because, by definition, the expected costs would exceed expected benefits;

b) a somewhat risk-averse policy maker might increase reserve margins slightly but possibly not enough to meet 0.1 LOLE at 15.2% reserve margin where the *costs exceed the benefits by a ratio of approximately three-to-one;*

c) a highly risk-averse policy maker might wish to meet or even exceed the 15.2% reserve margin needed to meet 0.1 LOLE"

Note too – "the increase in total customer costs with reserve margin is quite small as a percent of total costs", $1.63/MWh or only 1.5% to increase from 7.9% to 15.2% in one example

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More Than Just An Economic/Risk-Aversion Question With High Solar Penetration

Reducing year-to-year cost volatility by focusing on low probability years (80th-90th percentile) and increasing reserve margins increases costs but also changes the selected generation resource mix – switching from summer peaking to winter peaking, for example

- The 2016 Resource Adequacy Studies show the Forecasted Winter Peak is 99.6% of the Forecasted Summer Peak (DEC+DEP) while the Maximum Winter Peak is 111% of the Maximum Summer Peak

This appears to change the assigned capacity value of resources

This also impacts other priorities of the NC Clean Energy Plan

"Self-insuring" against year-to-year cost volatility *may make economic and policy sense*

- *The FERC report also notes that much of the weather-related risk can be hedged through forward contracts*

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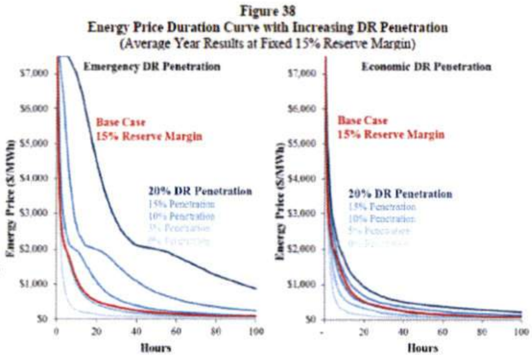
Emergency and Economic Demand Response

"We show that increasing DR levels will result in increasing average energy prices, *increasing energy price volatility*, but decreasing capacity prices."

Again, the laudable goal of reducing cost volatility runs counter to cost savings and environmental goals with this alternative technology



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Conclusions

Brattle Group and Astrape produced an excellent *Resource Adequacy Requirements: Reliability and Economic Implications* report for FERC

- The report provides a good discussion of issues with analysis examples

EUE is a much better reliability metric than LOLE or LOLH

Quantifying the cost of customer response and curtailment allows economic reserve optimization

- It must be done correctly with reasonable assumptions and based on NERC reliability requirements
- Stakeholder involvement should strive for consensus that the analysis is done correctly

Setting the reserve margins is now a more complex and nuanced Commission task

- Don't confuse *Volatility* mitigation with *Risk* mitigation
- There are costs of mitigation through increased reserves
  - $$$ cost
  - Shift in resource mix from renewables and demand response to fuel burning thermal generation with consequent impacts on NC Clean Energy Plan goals

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Brendan Kirby is a private consultant with numerous clients including the Hawaii PUC, National Renewable Energy Laboratory, ESIG, EPRI, AWEA, Oak Ridge National Laboratory, and others. He retired from the Oak Ridge National Laboratory's Power Systems Research Program. He has been working on restructuring and ancillary services since 1994 and spot retail power markets since 1985.

Brendan has 44 years of experience in the electrical utility sector, fifteen of which were spent at the Oak Ridge National Laboratory where he was a senior power systems researcher. He spent a year providing technical support to the Federal Energy Regulatory Commission as it established mandatory reliability standards. He was the FERC representative to the initial NERC Reliability Readiness Audits of Control Areas and Reliability Coordinators. He coauthored an amicus brief cited by the United States Supreme Court in its January 2016 ruling confirming FERC's demand response authority. He has been consulting full time since 2007. He has testified in proceedings regarding wind and solar integration, bulk power system reliability, ancillary services, and demand response before Commissions in Georgia, California, Minnesota, Texas, Wyoming, North Carolina, South Carolina, and Hawaii, as well as before the FERC.

Brendan's interests include electric bulk system reliability, renewables integration, industry restructuring, energy storage, ancillary services, demand side response, and advanced analysis techniques. He has published over 180 papers, articles, and reports. He coauthored a pro bono amicus brief cited by the Supreme Court in their January 2016 ruling confirming FERC demand response authority. He has a patent for responsive loads providing real-power regulation and is the author of a NERC certified course on Introduction to Bulk Power Systems: Physics / Economics / Regulatory Policy. He served on the NERC Standards Committee and the Integration of Variable Generation Task Force. He has conducted research projects concerning restructuring for the NRC, DOE, NREL, EEI, AWEA, UWIG, numerous utilities, state regulators, and EPRI.

Brendan is a licensed Professional Engineer with a M.S degree in Electrical Engineering (Power Option) from Carnegie-Mellon University and a B.S. in Electrical Engineering from Lehigh University.

Industry Activity on Probabilistic Risk Assessment

Brendan Kirby, P.E. www.consultkirby.com 1/8/2020

Both the NERC Probabilistic Assessment Forum and the IEEE LOLE Working Group (which is working on a new name) have strong utility and regional reliability group participation. They already utilize multiple metrics, sometimes include transmission, and are generally way ahead of the rest of the industry. There appears to be less activity on the policy side at present. MISO may be the most advanced in actual deployment.

NERC

NERC Probabilistic Assessment Working Group formed in 2017

"identifying, assessing and prioritizing emerging risks to reliability by using probabilistic approaches to develop resource adequacy measures that reflect variability and overall reliability characteristics of the resources and composite loads, including non-peak system conditions"

NERC Strategic Documents: https://www.nerc.com/AboutNERC/Pages/Strategic-Documents.aspx

NERC Probabilistic Analysis Forum (PAF)

Materials at: https://www.nerc.com/comm/PC/Pages/Probabilistic-Assessment-WorkingGroup-(PAWG).aspx

- New Approaches to Managing Uncertainty given the Changing Resource Mix
- Probabilistic Resource Adequacy Measures
- Resilience, Energy Assurance, and Fuel Security
- New Applications for Probabilistic Analysis (Economically Optimum Reserve Margins, Root Cause Analysis, Composite Reliability, etc.)

Current NERC Long Term Reliability Assessment primarily a peak hour reserve margin assessment:

- Does not address energy assurance or loss of load across all hours
- Current ProbA addresses loss of load (LOLE) and unserved energy expectations (EUE) for all hours of the year
- Current format data and time intensive, does not support off-year LTRA
- Develop a pilot screening approach methodology for potential reliability risks to look at indices such as LOLH, EUE, % chance Emergency Operating Procedures (EOPs), Average Hourly Operating Reserve Margins

Institute of Electrical and Electronic Engineers (IEEE)

Reliability, Risk and Probability Application Subcommittee and the Resource Adequacy Working Group.

Reports, presentations, meeting minutes etc. at http://sites.ieee.org/pes-rrpasc/working-groups/wg-on-lole-best-practices/

Just a small sample of the material available from the August 2019 meeting:

Presentations from August 2019 meeting

- **LOLE WG Agenda**
- **Draft RAWG Scope**
- Daniel Hua and John Fazio (NWPCC), **Resource Adequacy Analysis in the Pacific Northwest under Climate-Change in the 2030's (2020 – 2049)**
- MISO, **Resource Availability and Need (RAN)**
- Milorad Papic, R**eport on CSR Task Force and PACME WG Activities**
- Kevin Carden (ASTRAPE CONSULTING), **Energy Storage Capacity and Flexibility Value & Renewable Integration**
- Daniel Burke (EEE RAWG), **Wind and Solar PV Participating in the GB Capacity Market**
- IEEE LOLE, **Multi-Area Reliability Assessment with Variable Energy Resources and Optimal Importance Sampling based on Monte Carlo Markov Chains**
- Chris Dent, Amy Wilson and Stan Zachary (University of Edinburgh), **Storage & Variable Generation in Capacity Auctions**
- Lazaros Exizidis (EEE LOLE Best Practices WG), **Pan-European Adequacy Methodology at ENTSO-E: Current Practice & Upcoming Challenges**
- Gord Stephen (NREL), **Impact of Storage Dispatch Assumptions on Resource Adequacy Assessment: Preliminary Work**
- Eduardo Ibanez (GE), **Modeling Battery Storage**
- Jaeseok Choi (Gyeongsang National University), **Probabilistic Reliability of HVDC Expansion Planning in South Korea**
- NERC, **LOLE Best Practices WG NERC PAWG Activities**
- Simon Tindemans (TU Delft), Michael Evans, David Angeli (Imperial College London), **Dispatch of Storage for Adequacy Studies**
- Muhammad Bashar Anwar (UCD Dublin), **Capacity Value of Residential Thermal Demand Response**
- Patricio Rocha Garrido (PJM), **Fuel Security Analysis Phase 1, A PJM Resilience Initiative**
- Dimitry Gorinevsky (Stanford University), **Grid Reliability with High Penetration of Renewables and Storage**

MISO LOLE Working Group

MISO may be the most advanced in actual deployment of probabilistic analysis methods in actual operations and planning with an active public process: https://www.misoenergy.org/stakeholder-engagement/committees/loss-of-load-expectation-working-group/

Dr. Michael Milligan

Dr. Milligan (retired from the National Renewables Energy Laboratory) publishes extensively on probabilistic reliability assessments: www.milligangridsolutions.com. Examples include:

Aidan Tuohy, Eamonn Lannoye, Jody Dillon, Chris Dent, Amy Wilson, S. Zachary, E. Ibanez, M. Milligan: **Capacity Adequacy and Variable Generation: *Improved Probabilistic Methods for Representing***

Variable Generation in Resource Adequacy Assessment. Electric Power Research Institute in collaboration with National Renewable Energy Laboratory; Heriot-Watt University, Edinburgh, UK; Durham University, Durham, UK; Ecar Energy Ltd, Ireland.

Milligan, Michael; Bethany Frew; Ibanez, Eduardo; Kiviluoma, Juha; Holttinen, Hannele; Söder, Lennart, **Capacity Value Assessments for Wind Power: An IEA Task 25 Collaboration**. Wiley Wires. 2016.

E. Ibanez, M. Milligan (NREL, USA) (WIW14-1063), **Comparing Resource Adequacy Metrics**. 13th International Workshop on Large-Scale Integration of Wind Power into Power Systems. Berlin, Germany. Nov 11-13, 2014.

Ibanez, E.; Milligan, M. (2014). **Comparing Resource Adequacy Metrics and Their Influence on Capacity Value**: Preprint. Probabilistic Methods Applied to Power Systems Conference, Durham, England. 8 pp.; NREL Report No. CP-5D00-61017. Pre-print available at http://www.nrel.gov/docs/fy14osti/61017.pdf.