QUANTA TECHNOLOGY

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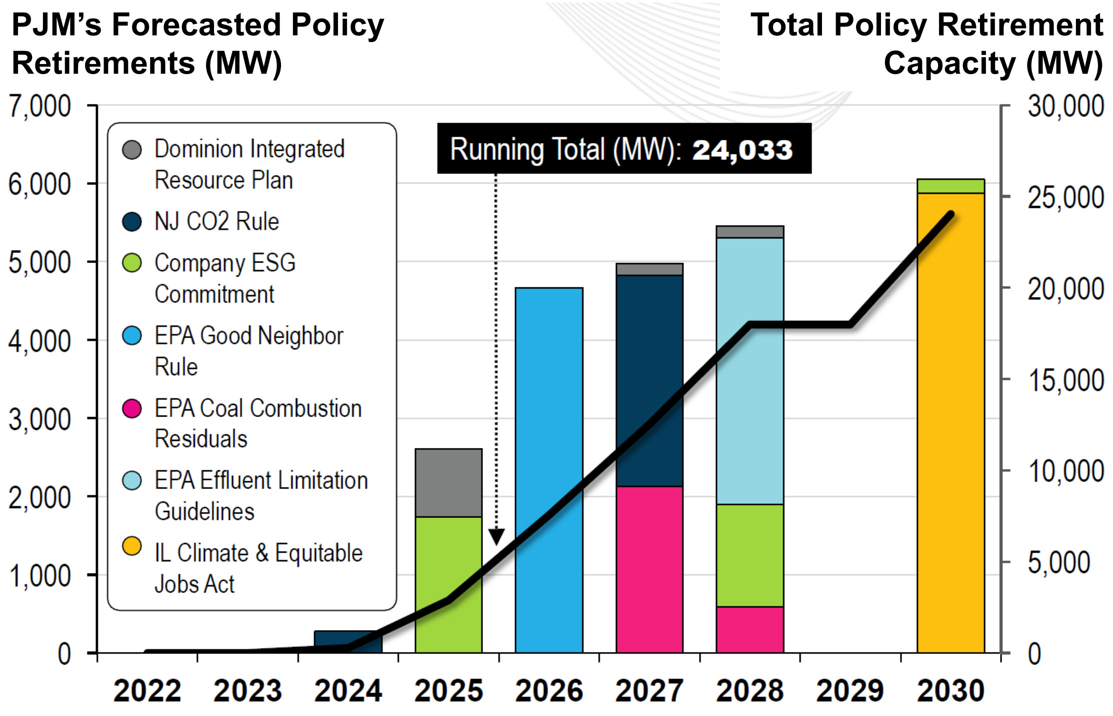
Ensuring Reliability: A Case Study of the PJM Grid

Background: An Update to Quanta Technology's 2018 PJM Grid Reliability and Resilience Study

- The 2018 study used the PJM system as a case study to illustrate the potential reliability consequences of two major risks: ***increased coal retirements*** and ***fuel insecurity***. The study showed that premature retirement of fossil fuel generation could adversely impact PJM's ability to meet reliability criteria.
- PJM and other grid operators have issued warnings recently that the reliability of the grid in many regions of the country is at risk for electricity shortages due to:
  - Premature retirement of dispatchable electricity resources driven by federal and state policies,
  - Delays in new or replacement capacity coming on-line,
  - Increasing electricity demand (e.g., data centers and electrification).
- Retirements have continued to increase since the 2018 study:
  - More than one-third of the nation's coal fleet has retired.
  - Electricity generators have announced plans to retire roughly one-third (more than 60,000 MW) of the remaining fleet within the next 5 years.
  - In total, almost two-thirds of the nation's coal fleet will have retired by the end of 2028.



Objectives of the Updated Study

The objectives were to assess reliability challenges due to fossil generation retirement in terms of:

- Resource and energy adequacy
- Transmission System Security

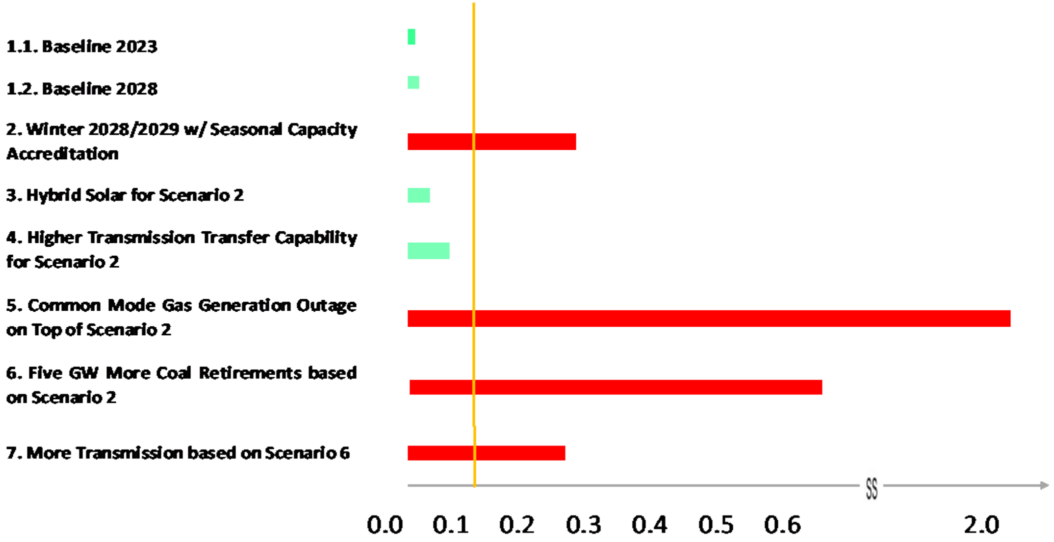
11 scenarios assessed to quantify possible reliability standard violations.

#	Scenario Name	Description
Resource Adequacy		
1.1	Baseline 2023	Latest ELCC is not considered for renewable, gas, and coal units.
1.2	Baseline 2028	Latest ELCC is not considered for gas and coal units.
2	Winter 2028/2029 w/Latest Capacity Accreditation	Latest ELCC and capacity accreditation for winter are considered.
3	Hybrid Solar for Scenario 2	Future solar units are paired with battery storage for Scenario 2.
4	Higher Transmission Transfer Capability for Scenario 2	50% higher interzonal transmission capacity to improve Scenario 2.
5	Common Mode Outage on Top of Scenario 2	30 GW gas units unavailable during extreme winter for Scenario 2.
6	5 GW More Coal Retirements Based on Scenario 2	5 GW additional coal retirements for Scenario 2.
7	More Transmission Based on Scenario 6	50% higher interzonal tie-line limits to improve Scenario 6's LOLE.
Transmission Security		
8	2028 Summer Peak Condition	2028 summer peak based on Scenario 1.2.
9	2028/2029 Winter Peak Condition w/o Retirement	2028/2029 winter peak for Scenario 1.2 before coal retirements.
10	2028/2029 Winter Peak with Retirements	Winter peak condition based on Scenario 1.2.
11	5 GW More Coal Retirements based on Scenario 6	5 GW additional coal retirements based on Scenario 6.

Study Findings

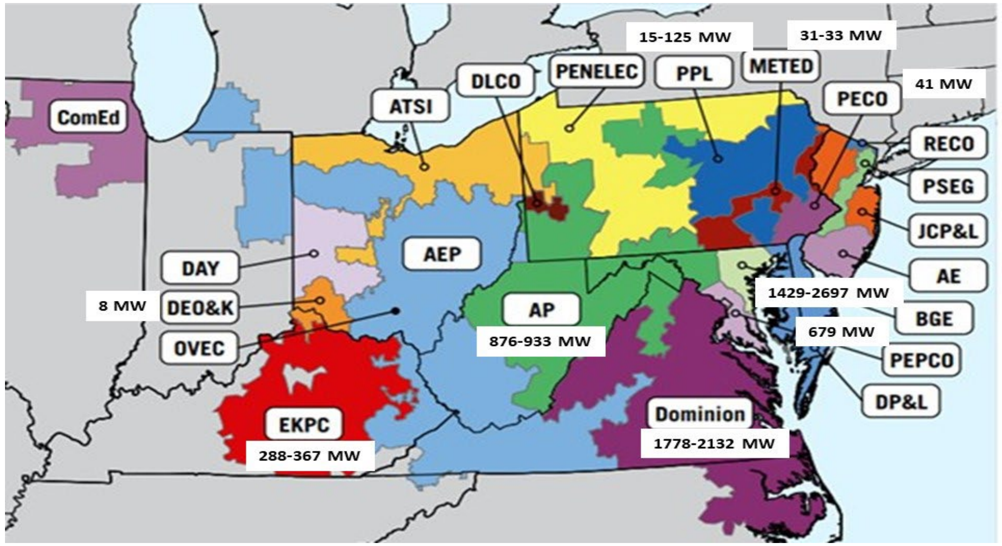
RESOURCE ADEQUACY

1. When ELCCs for renewables not differentiated seasonally, LOLEs in 2023 and 2028 are essentially zero.
2. With ELCCs and capacity accreditations seasonally differentiated, LOLE is 0.243 with risks over winter months.
3. Pairing solar PV with storage reduces LOLE to 0.039
4. 50% higher transmission capacities from resource surplus zones reduces LOLE to 0.067.
5. Significant gas disruptions in winter increases the LOLE from 0.243 to 2.024.
6. Additional 5 GW of coal retirements increases the LOLE from 0.243 to 0.633;
7. 50% more transmission reduces LOLE in Scenario 6 from 0.633 to 0.235.



TRANSMISSION SECURITY

8. 2028 Summer Peak Condition - 32 transmission overloads after fossil generation retirement. To mitigate the overloads, a total of 3,761 MW load in the PJM system needs to be curtailed.
9. 2028/2029 Winter Peak Condition w/o Retirement - 36 transmission overloads; total load curtailment required was 3,567 MW.
10. 2028/2029 Winter Peak with Retirements - 52 transmission overloads; total load curtailment required was 4,708 MW.
11. Five GW More Coal Retirements based on Scenario 6 - 57 transmission overloads; total load curtailment required was 6,826 MW.



Observations

Electricity use drives fast load growth at a speed not historically seen. Furthermore, the regional electric demand is peaking less in summer and more in the winter, presenting a challenge in fueling electric generation during winter peak hours.

Maintaining fuel diversity and understanding new energy resources' seasonal operating attributes are important in maintaining grid reliability and resilience.

- One possible mitigation involves pairing long-duration storage. However, this strategy needs to be supported by PJM's competitive market if it is to be economically attractive for future solar plants.
- Regional transmission expansion can improve the integration of renewable resources and provide the needed capacity and energy for various PJM zones. However, significantly expanding transmission capacity is very difficult and often infeasible.
- Because the natural gas transportation system and the electric power grid were not originally designed to function as an integrated system nor to the same reliability standards, failure in the natural gas delivery system presents a common mode of multiple outages of the natural gas-fueled generation stations, rendering inadequate resources to meet the demand or unavailable generation to mitigate transmission reliability violations.

In Winter 2028, the system may encounter a notable hurdle with the assumed retirements of coal and gas resources, posing significant challenges in delivering energy to consumers while upholding security and reliability standards for the transmission systems.

Discussions

This updated study identified four key actions for meeting NERC reliability standards:

1. Policymakers and the electric industry must carefully consider if and when existing generation resources can be retired without negatively impacting resource adequacy and transmission operations.
2. Regulators and utilities must coordinate to maintain a degree of existing dispatchable generation because new technologies (e.g., hydrogen blending for generation and long-duration energy storage) have yet to be proven on a larger scale to be practical and may not be able to perform to the same level as existing dispatchable generation.
3. The electric industry needs a better understanding of how extreme weather events affect power system needs.
4. The electric power system must remain reliable and become more resilient because the nation is electrifying multiple economic sectors which are increasingly dependent on electricity.

Reliability risk is no longer only driven by summer peak load. The patterns of renewable generation and electricity usage require adequate electric energy produced any time when there is a need.

As load patterns change and increased penetration of renewable resources, the Installed Capacity Market needs to incent the right behaviors by the resource to mitigate the risk, i.e., adequate dispatchable resources without fuel constraints.

Resource Adequacy Study

PJM System and Zonal Level LOLEs

		LOLE							
Zone Name	Zone # / Scenarios -->	1.1	1.2	2	3	4	5	6	7
APS	1	0.000	0.000	0.000	0.000	0.000	0.083	0.003	0.001
AEP	2	0.000	0.000	0.000	0.000	0.000	0.022	0.004	0.000
EMAAC	3	0.000	0.000241	0.000	0.000	0.000	0.000	0.000	0.000
SWMAAC	4	0.000	0.000513	**0.201**	0.034	0.036	**1.926**	**0.476**	0.096
COMED	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DAY	6	0.000	0.000006	0.023	0.002	0.011	**0.699**	**0.175**	0.097
DEOK	7	0.000	0.000063	**0.127**	0.019	0.032	**1.569**	**0.480**	**0.151**
DELCO	8	0.000	0.000020	0.026	0.004	0.007	**0.133**	0.049	0.021
SOUTH	9	0.000	0.000016	**0.105**	0.007	0.031	**1.213**	**0.287**	**0.115**
ATSI	10	0.000	0.000334	0.026	0.004	0.002	**0.643**	0.061	0.004
E. PA	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
W. PA	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
System Level		0.000	0.001	**0.243**	0.039	0.067	**2.024**	**0.633**	**0.235**

Note: The **red LOLE numbers** indicate resource adequacy criterion violations.

System and Zonal Level Average Expected Load Loss (MW)

		LOL (MW)							
Zone Name	Zone # / Scenarios -->	1.1	1.2	2	3	4	5	6	7
APS	1	-	-	0	0	0	79	2	0
AEP	2	-	-	0	0	0	18	3	0
EMAAC	3	-	1.53	-	-	-	0	-	-
SWMAAC	4	0	3.25	1,247	622	588	5,864	1,699	439
COMED	5	-	-	-	-	-	-	-	-
DAY	6	-	0.04	152	30	197	1,337	544	805
DEOK	7	-	0.40	1,055	341	425	3,221	1,756	842
DELCO	8	-	0.13	7	2	4	16	8	5
SOUTH	9	0	0.11	492	37	299	2,772	749	547
ATSI	10	-	2.11	113	36	6	601	103	7
E. PA	11	-	-	-	-	-	0	-	-
W. PA	12	-	-	-	-	-	0	-	0
System Level		0	5	3,066	1,068	1,519	13,909	4,864	2,645

Transmission Security Study

Number of Transmission Facilities Overloaded in Summer 2018

Zone # / Tie Line		Maximum loading [%]		Recurrence of Overloads		Overloaded Equipment	
		Scenario 8	Scenario 8 + Retirements	Scenario 8	Scenario 8 + Retirements	Scenario 8	Scenario 8 + Retirements
215	DLCO	116.3	105.0	1	1	1	1
228	JCPL	103.5	103.5	1	1	1	1
229	PL	116.4	131.3	5	6	1	1
230	PECO	102.0	115.4	4	16	1	4
233	PEPCO	111.4	107.6	4	2	2	2
345	DVP	153.9	153.5	82	70	23	20
229/232	TIE LINE	140.2	155.2	7	6	1	1
230/232	TIE LINE	< 100	104.7	0	4	0	1
232/230	TIE LINE	< 100	107.8	0	3	0	1
TOTALS				104	109	30	32

Mitigating Load Shedding (MW) in Summer 2028

Zones	Load Shedding (MW)	
	Scenario 8	Scenario 8 + Retirements
201 AP	152	0
205 AEP	0	0
212 DEO&K	100	97
227 ME	0	0
229 PL	7	7
230 PECO	61	50
232 BGE	390	1081
235 DP&L	0	0
345 DVP	2788	2473
231 PSEG	0	0
222 CE	49	55
TOTAL	**3,547**	**3,761**

Number of Transmission Facilities Overloaded Under Winter Scenarios

AREA / CASE		Maximum Loading [%]			Recurrence of Overloads			Overloaded Equipment		
		Scenario 9	Scenario 10	Scenario 11	Scenario 9	Scenario 10	Scenario 11	Scenario 9	Scenario 10	Scenario 11
201	AP	< 100	102.7	< 100	0	1	0	0	1	0
227	ME	114.0	134.8	152.2	5	19	26	1	2	2
228	JCPL	102.8	102.8	102.8	1	1	1	1	1	1
229	PL	113.7	134.4	147.4	14	42	63	4	9	13
230	PECO	196.1	239.3	270.2	34	212	227	3	3	3
232	BGE	112.5	127.3	135.3	24	64	106	8	12	15
233	PEPCO	114.0	123.9	122.2	11	13	13	2	2	2
345	DVP	119.3	126.7	123.7	19	33	27	7	10	9
227/229	TIE LINE	117.0	140.1	157.6	10	10	11	2	2	3
229/232	TIE LINE	135.1	158.4	173.0	12	22	37	2	2	2
230/232	TIE LINE	183.8	225.8	256.0	5	27	76	1	1	1
233/345	TIE LINE	118.6	127.5	128.7	5	5	5	1	1	1
225/232	TIE LINE	102.1	114.3	118.4	6	11	14	2	2	2
225/229	TIE LINE	108.4	112.9	112.3	5	6	6	2	2	2
225/233	TIE LINE	< 100	100.6	105.5	0	1	1	0	1	1
340/345	TIE LINE	< 100	102.0	< 100	0	1	0	0	1	0
TOTAL					151	467	613	36	52	57

Mitigating Load Shedding (MW) Under Winter Scenarios

Zones	Load Shedding (MW)		
	Scenario 9	Scenario 10	Scenario 11
201 AP	654	867	933
205 AEP	0	0	0
212 DEO&K	8	8	8
225 PJM	0	0	0
226 PENELEC	0	0	0
227 ME	28	31	33
229 PL	125	125	15
230 PECO	41	41	41
232 BGE	1103	1492	2697
233 PEPCO	0	0	679
235 DP&L	0	0	0
320 EKPC	379	367	288
345 DVP	1228	1778	2132
222 CE	0	0	0
228 JCPL	0	0	0
209 DAY	0	0	0
TOTAL	3,567	4,708	6,826

Appendix: PJM Resource Assumptions in 2028

PJM Resource Mix

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BESS	209	2,101	2,629	2,629	2,729	2,729	2,729	2,729	2,729	2,729
Coal	43,295	42,103	35,830	34,951	33,022	33,022	29,775	21,963	21,963	20,425
DR	0	6,917	6,917	6,917	6,917	6,917	6,917	6,917	6,917	6,917
Gas	84,911	91,987	101,877	101,019	101,019	100,787	97,861	97,861	97,861	90,971
Hydro	3,091	3,129	3,207	3,252	3,261	3,261	3,261	3,261	3,261	3,261
Nuclear	32,749	32,749	32,749	32,749	32,749	32,749	32,749	32,749	32,749	32,749
Oil	5,810	5,739	4,952	3,943	3,546	3,546	3,538	3,538	3,538	3,438
OSW	162	410	428	1,417	2,690	4,810	9,715	10,315	10,815	10,815
Other	358	358	358	358	358	358	358	358	358	358
PS-Hydro	5,232	5,932	5,932	5,932	5,932	5,932	5,932	5,932	5,932	5,932
Renewable	1,506	1,481	1,481	1,481	1,481	1,481	1,481	1,481	1,481	1,481
Solar	7,300	33,092	42,180	43,679	44,279	44,279	44,279	44,279	44,279	44,279
Wind	11,058	22,887	24,074	24,074	24,074	24,194	24,194	24,194	24,194	24,194
Total*	195,680	248,884	262,614	262,401	262,057	264,065	262,789	255,577	256,077	247,549

Note: Red highlighted numbers are the total generation capacity for PJM for 2023 and 2028. These include the generation resources that were not physically retired or existing but not offered to the PJM capacity auction in and before 2023. In the table, "Renewable" refers to clean energy resources other than solar, wind, hydro, offshore wind (OSW), or nuclear; solar and wind capacities stay constant after 2025 to reflect the activities of the PJM Queue.

Year 2028 Load Forecast (MW)

Area Name	50/50 SP	90/10 SP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ratio*	max
APS	9,568	10,238	9,245	8,745	7,899	6,539	7,087	8,076	8,769	8,519	7,726	6,474	7,340	8,459	5.88%	9,245
AEP	22,797	24,393	22,902	21,684	19,738	16,425	18,370	20,731	22,472	22,199	20,353	16,268	18,375	21,021	14.01%	22,902
EMAAC	30,863	33,023	24,298	23,081	19,962	17,453	22,836	28,776	31,835	30,662	25,941	19,716	19,330	23,232	18.96%	31,835
SWMAAC	12,520	13,396	11,485	10,844	9,656	7,831	9,715	11,266	12,237	11,940	10,412	8,130	8,814	10,415	7.69%	12,237
COMED	20,102	21,509	15,226	14,499	12,493	11,244	14,387	18,546	20,223	19,719	16,694	12,112	12,196	14,597	12.35%	20,223
DAY	3,280	3,510	2,962	2,804	2,627	2,197	2,625	2,979	3,275	3,171	2,858	2,214	2,398	2,733	2.02%	3,275
DEOK	5,204	5,568	4,684	4,403	3,953	3,523	4,299	4,996	5,382	5,219	4,883	3,619	3,734	4,331	3.20%	5,382
DELCO	2,702	2,891	2,030	1,943	1,816	1,713	2,191	2,605	2,812	2,705	2,464	1,845	1,778	1,942	1.66%	2,812
SOUTH	30,768	32,922	27,990	26,317	23,675	20,683	22,758	24,797	26,204	26,078	23,852	21,019	23,066	25,561	18.90%	27,990
ATSI	11,828	12,656	10,192	9,827	9,327	8,106	9,761	11,605	12,499	12,018	10,669	8,253	8,771	9,733	7.27%	12,499
E. PA	10,300	11,021	10,261	9,716	8,998	7,632	8,544	9,994	10,685	10,332	8,993	7,464	8,348	9,407	6.33%	10,685
W. PA	2,830	3,028	2,769	2,678	2,403	2,139	2,214	2,638	2,808	2,672	2,425	2,175	2,344	2,619	1.74%	2,808
Total*	**162,762**	**174,155**	**144,044**	**136,541**	**122,547**	**105,485**	**124,787**	**147,009**	**159,201**	**155,234**	**137,270**	**109,289**	**116,494**	**134,050**	**100%**	**161,893**

Note: Ratio refers to the percentage of the peak load in the respective region to PJM's total peak load.

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