

Bifurcated Regulation Products – Impact of Resource Eligibility on Reliability and Pricing

Shubhrajit Bhattacharjee, Sr. Engineer

Advanced Analytics

Operating Committee

October 8, 2026

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Background

Simulation Framework

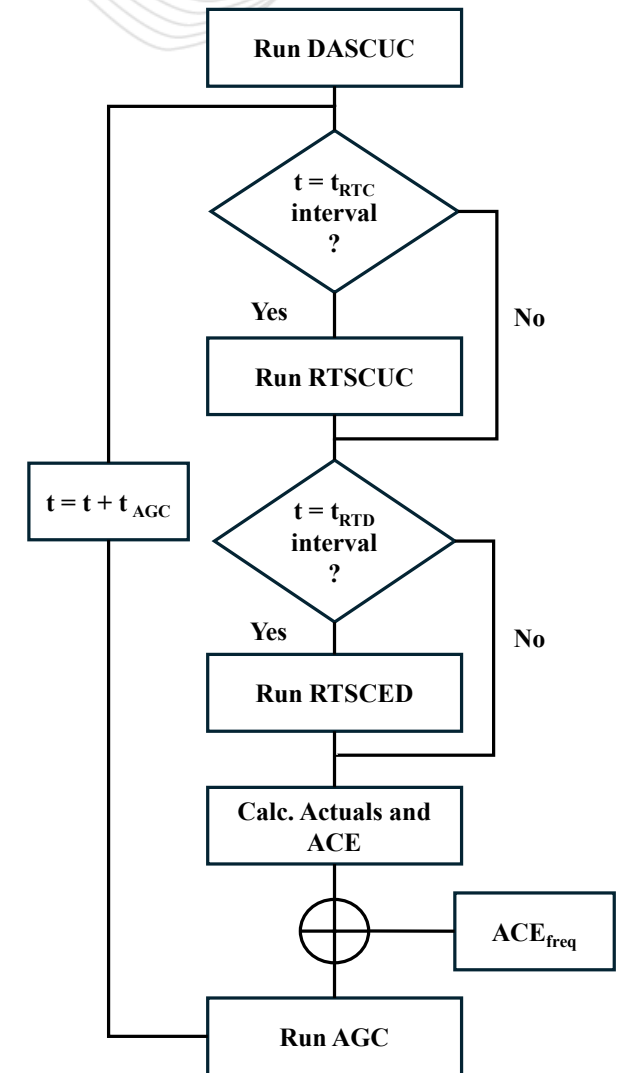
Case Details

Results

- Area Control Error and CPS2 Statistics
- Controller Saturation-up and –down
- Resource Mix
- Regulation clearing price and production cost

Key Takeaways

- FESTIV is an open-source multi-timescale steady-state wholesale market simulation software.
- Utilizes AGC sub-model which can simulate deployment of regulating reserve to correct ACE imbalance.
- Input Details
 - PJM Zonal Model with inter-zonal transmission lines
 - Perfect forecast for load and renewable generation
 - Aggregated generator model
- Simulated Period
 - One representative week per season in 2024



- The following cases are simulated:

Case	Regulation Eligibility	AGC	Purpose
Broad Eligibility	All non-renewable/non-nuclear resources eligible	Included	Original benchmark
Restricted Eligibility	PJM regulation-eligible resources from one representative simulated days; same set used for all simulated days	Included	More realistic regulation-supply sensitivity
Broad Eligibility - No AGC	Same Broad Eligible pool as Broad Eligibility case	Excluded	Separate market-clearing impact from AGC deployment feedback

- Common comparison in every case:
 - A single bidirectional regulation product.
 - Separate unidirectional regulation up and down products.

Mean-Absolute ACE

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	175.09	139.87	173.71	148.16
Summer	239.65	217.22	243.03	217.11
Fall	172.94	136.67	169.94	140.70
Winter	166.17	133.63	167.62	138.11

Area Control Error (ACE) is generally the MW imbalance in a balancing area (BA) and is calculated as sum of BA's interchange error and frequency error.

ACE Standard Deviation

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	235.71	181.13	242.55	205.49
Summer	308.38	268.68	310.20	278.84
Fall	240.04	184.30	228.55	189.93
Winter	218.62	175.18	220.98	181.66

FESTIV calculates ACE as interchange error; the frequency error component is added after RT-SCED based on actual PJM error values.

CPS2 Violations

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	16	0	17	10
Summer	203	202	239	211
Fall	11	0	14	2
Winter	11	4	11	3

CPS2 violations represent the number of 10-minute intervals absolute average ACE exceeds a threshold called L10.

CPS2 Score

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	98.41%	100%	98.31%	99%
Summer	79.86%	79.96%	76.29%	79.07%
Fall	98.91%	100%	98.61%	99.80%
Winter	98.91%	99.60%	98.91%	99.70%

The CPS2 score represents the percentage of intervals without violations reflecting how often the system avoids significant imbalances.

Controller Saturation-Up and –Down Event Counts

Saturation-up Event Count

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	218	11	202	58
Summer	104	6	123	33
Fall	157	15	155	19
Winter	220	24	242	59

Controller saturation-up and -down events are defined as AGC intervals where SACE (smoothed ACE) exceeds regulating reserve requirement in either direction (+/-).

Saturation-down Event Count

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	183	177	195	113
Summer	406	423	469	422
Fall	138	127	152	85
Winter	178	143	171	88

Controller Saturation-Up and –Down Event Duration

Average Saturation-up Event Duration

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	4.92	1.45	6.01	6.64
Summer	6.66	2.17	5.99	7.94
Fall	5.57	1.53	5.03	3.58
Winter	4.39	1.46	4.33	3.54

The event durations are in AGC timesteps.

Average Saturation-down Event Duration

Season	Broad 1Reg	Broad 2Reg	Restricted 1Reg	Restricted 2Reg
Spring	3.10	2.65	3.03	2.13
Summer	17.06	16.92	15.86	16.08
Fall	2.97	2.29	2.90	2.11
Winter	3.60	3.24	4.01	3.52

- Regulation contribution by generator type is the percentage of total real-time regulation awarded, calculated by averaging each generator's award and summing by generator type over the simulation period.

Season	Product	Steam (%)	Combined Cycle (%)	Hydro (%)	Pumped Storage (%)	Storage (%)
Spring	1 Reg.	18.19	72.14	0.00	4.64	5.03
Spring	2 Reg. Up	20.60	68.79	0.00	2.31	8.31
	2 Reg. Down	51.36	34.75	7.26	3.62	3.02
Summer	1 Reg.	25.35	67.35	0.00	2.96	4.33
Summer	2 Reg. Up	26.44	63.87	0.00	1.93	7.75
	2 Reg. Down	55.98	33.69	5.97	1.66	2.70
Fall	1 Reg.	15.14	74.43	0.00	5.74	4.68
Fall	2 Reg. Up	17.15	71.41	0.00	2.50	8.93
	2 Reg. Down	47.85	34.70	8.18	5.60	3.67
Winter	1 Reg.	23.42	64.66	0.00	4.16	7.76
Winter	2 Reg. Up	28.27	60.88	0.00	3.08	7.77
	2 Reg. Down	54.27	34.12	6.02	2.70	2.88

Restricted Eligibility – Regulation Contribution by Generator Type

Season	Product	Steam (%)	Combined Cycle (%)	Hydro (%)	Pumped Storage (%)	Storage (%)
Spring	1 Reg.	9.68	63.34	5.48	13.98	7.52
Spring	2 Reg. Up	6.09	63.15	9.24	12.80	8.71
	2 Reg. Down	4.59	42.26	28.60	18.26	6.29
Summer	1 Reg.	11.15	67.74	2.91	10.96	7.24
Summer	2 Reg. Up	9.48	67.72	4.36	10.32	8.13
	2 Reg. Down	8.50	43.36	28.05	15.21	4.89
Fall	1 Reg.	63.98	25.32	0.00	8.68	2.02
Fall	2 Reg. Up	67.43	25.07	0.00	4.43	3.07
	2 Reg. Down	43.37	20.18	22.64	10.70	3.11
Winter	1 Reg.	10.20	65.60	1.82	14.06	8.33
Winter	2 Reg. Up	7.77	66.32	5.67	12.26	7.99
	2 Reg. Down	6.03	43.82	28.03	16.53	5.60

- Real-time co-optimized regulation clearing price.

Season	1Reg (\$/MWh)	2Reg. Up (\$/MWh)	2Reg. Down (\$/MWh)	2Reg. Up – 1Reg (\$/MWh)
Spring	0.69	0.98	0.00	+0.29
Summer	2.12	2.52	0.00	+0.4
Fall	0.34	0.21	0.00	-0.13
Winter	2.16	3.10	0.00	+0.94

- 2Reg. Up clearing price is above 1Reg in spring, summer and winter, but below 1Reg in fall; bifurcation does not create a uniform price increase or decrease.
- The overall prices and corresponding differences are low due to the broad resource eligibility in providing regulation with 2 Reg. Down never binding.
- The broad eligibility case acts as a benchmark to compare the restricted eligibility cost which is a more realistic market representation.

- Real-time co-optimized regulation clearing price.

Season	1Reg (\$/MWh)	2Reg. Up (\$/MWh)	2Reg. Down (\$/MWh)	2Reg. Up – 1Reg (\$/MWh)
Spring	32.92	32.88	4.83	-0.05
Summer	24.96	25.46	0.97	0.50
Fall	0.51	0.49	0.00	-0.02
Winter	22.67	32.37	1.93	9.71

- Restricting resource eligibility in providing regulation materially raises prices in all seasons except fall compared to the Broad Eligibility case.
- In spring, summer and fall, 1Reg and 2 Reg. Up prices remain close indicating eligibility restriction, not bifurcation alone, is the dominant pricing driver.
- Winter shows the highest price separation indicating higher or more expensive upward capability with 2 Reg. Down binding on some seasons but remained well below 2 Reg. Up prices.

- The RTO LMP remain close between the two cases with no consistent directional pattern. The reserve clearing prices show similar pattern.
- Adjusted Production Cost difference between 2Reg and 1Reg cases.

Case	Spring Δ (\$M)	Summer Δ (\$M)	Fall Δ (\$M)	Winter Δ (\$M)
Broad Eligibility	0.45%	0.23%	0.77%	0.32%
No-AGC Broad Eligibility	-0.01%	0.03%	0.09%	0.03%
Restricted Eligibility	0.19%	0.12%	0.28%	0.29%

- Broad eligibility case shows the largest difference in production cost between the cases; removing AGC deployment reduces the difference to nearly zero.
- Restricted eligibility case appears to show less divergence in regulation procurement and deployment that reduces the difference in production cost.

1	2	3
Reliability improvement persists under bifurcated regulation design with a restricted regulation-eligible resource pool	Tighter resource eligibility has a larger impact on regulation clearing prices than bifurcation alone	Bifurcated regulation production cost impact remain modest, with smaller incremental difference in the restricted eligibility case

Presenter:
Shubhrajit Bhattacharjee,
shubhrajit.bhattacharjee@pjm.com

Simulation of Bifurcated Regulation Products



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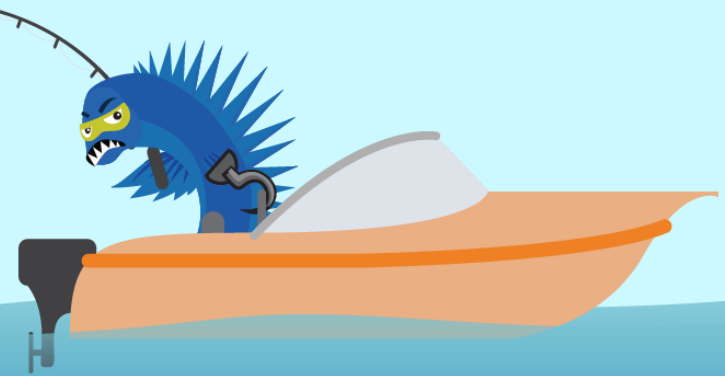
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