Monitoring Analytics

ORDC Simulation Results: Version 2, Revised

The Independent Market Monitor for PJM

May 24, 2019

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Introduction

PJM's March 29th Price Formation Filing includes simulation results estimating the impact of PJM's proposal. The Market Monitor replicated PJM's simulations using identical software and the same input data as PJM. Replication allows the Market Monitor to verify the results, understand the modelling assumptions, analyze the results in greater detail, and perform alternative simulation scenarios.

The Market Monitor also performed simulations using alternative specifications of the Operating Reserve Demand Curve (ORDC) to demonstrate how market results may change under different proposals.

PJM used PowerGEM's PROBE Perfect Dispatch Model (PROBE Ver 2.85_1-M) to run its simulations. PROBE Ver 2.85_1-M contained an error that caused the synchronized reserve shadow price (used to determine the price of synchronized reserves) to be greater than the prices indicated by the ORDC curves. The result of the error is that the simulation results overstate the prices and the overall costs of reserves. This issue was identified and corrected in PROBE Ver 2.85_1-P and later versions. The Market Monitor used PROBE Ver 2.85 1-R, which incorporated the fix, to produce its own simulation results. PROBE Ver 2.85_1-R produces synchronized reserve shadow prices that are consistent with the ORDC curves.

The PowerGEM PROBE Perfect Dispatch software is designed to optimize resource commitment and dispatch to the find the lowest production cost solution for energy and reserve requirements, subject to resource and network constraints in a given 24 hours period. One of the inputs to this optimization is the set of resources types that can have their commitment and dispatch changed relative to an initial assumed start state. In the typical perfect dispatch case only diesel and combustion turbine resources can have commitment changes, while other resource types are limited to redispatch, unless otherwise specified. The larger the set of resource types than can have their commitment and dispatch optimized, the more optimal the solution in terms of minimizing production cost given energy and reserve requirements. The PROBE software will change the commitment and dispatch of a given resource set to minimize the cost of any significant changes in market conditions within the 24 hour period. This same flexibility in system dispatch and commitment is generally not available in actual operations. This means that the simulations will tend to have fewer periods of high prices and that the high prices will tend to be lower than in an actual real-time market day with the same load conditions. The simulated market results will underestimate the real world costs of meeting the energy and reserve requirements in the simulation cases.

PJM Simulations

PJM performed three simulations: Cases A, B, and C.

Case A includes no changes in the dispatch and pricing process from PJM's standard Perfect Dispatch simulation software.[1] PJM currently uses the Perfect Dispatch software to benchmark its actual real-time market performance against a simulated outcome that economically optimizes resource dispatch and fast start resource commitment.[2] Case A represents this optimal dispatch and commitment and does not represent the actual status quo. Thus, comparisons using Case A as the benchmark will underestimate the real world costs of meeting the energy and reserve requirements in the simulation cases. PJM also modifies the Case A results by incorporating the payment of a single clearing price to all synchronized reserves.

Case B uses a change in the Perfect Dispatch software settings to extend the economic evaluation of resource commitments to steam units, typically committed prior to the operating day by the Day-Ahead Energy Market, the Day-Ahead Reliability Assessment, or manually by reliability processes. Case B presents a significant departure from reality by allowing the software to decommit resources required by PJM for reliability. Day-ahead reliability commitments accounted for an average of 1,100 MW of generation per hour in 2018.

Case C introduces PJM's proposed ORDC to Case B. PJM argues that the relevant comparison to assess the impact of the ORDC proposal is the comparison of Case B to Case C. Because Case B modifies actual PJM operating conditions, it is not an accurate base case. The Market Monitor also compares Case A to Case C and creates a Case A ORDC that implements the ORDC in the Case A model. If it is the case, and PJM implies that it is, that the ORDC would replace manual operator commitments with market commitments, the relevant comparison is Case A to Case C, because Case A contains the steam unit commitments made by operators.[3] Case B removes all uneconomic operator commitments.

The Market Monitor disagrees with PJM's conclusion that a 30 minute time horizon is appropriate for the 10 minute reserve products. Case C 15 minute presents a case where the ORDC is shifted inward using a 15 minute forecast time horizon for the synchronized and primary reserve demand curves.

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1 The Perfect Dispatch software is PowerGEM's PROBE Perfect Dispatch Model.

2 *See* PJM Perfect Dispatch Fact Sheet, <https://www.pjm.com/-/media/about-pjm/newsroom/fact-sheets/perfect-dispatch-fact-sheet.ashx?la=en>, last accessed April 19, 2019.

3 *See* March 29th Filing, Pilong Testimony.

Table 1 shows the summary results for the five simulation cases.

Table 1 Comparison of simulation cases

	Case A	Case B	Case C	Case A ORDC	Case C 15
Load-Weighted LMP ($/MWh)	$35.80	$37.30	$37.76	$36.91	$37.61
Generation-Weighted LMP ($/MWh)	$33.29	$34.72	$35.18	$34.39	$35.03
Generator Energy Revenue ($ millions)	$26,796.6	$27,943.2	$28,312.6	$27,679.3	$28,191.9
Weighted Synchronized Reserve MCP ($/MWh)	$1.99	$2.58	$6.33	$6.05	$4.66
Weighted Non-Synchronized Reserve MCP ($/MWh)	$1.03	$1.25	$3.21	$3.08	$2.34
Weighted Secondary Reserve MCP ($/MWh)	NA	NA	$0.0004	$0.0004	$0.0015
Hourly Average Cleared Synchronized Reserve (MW/hour)	1,817.8	1,818.2	3,167.3	3,189.6	2,866.6
Hourly Average Cleared Non-Synchronized Reserve (MW/hour)	634.6	634.2	677.6	678.1	677.3
Hourly Average Cleared Secondary Reserve (MW/hour)	NA	NA	1,944.0	1,928.2	2,195.2
Hourly Average Cleared Total Reserve (MW/hour)	2,452.4	2,452.4	5,789.0	5,795.9	5,739.0
Total Cleared Synchronized Reserve (millions MWh)	15.5	15.5	27.0	27.2	24.4
Total Cleared Non-Synchronized Reserve (millions MWh)	5.4	5.4	5.8	5.8	5.8
Total Cleared Secondary Reserve (millions MWh)	NA	NA	16.6	16.4	18.7
Reserve Revenue ($ millions)	$36.4	$46.7	$189.3	$182.1	$127.3
Uplift ($ millions)	$109.9	$30.4	$27.5	$93.0	$28.0
Bid Production Cost ($ millions)	$13,229.6	$13,121.2	$13,152.0	$13,256.8	$13,135.8
Total Energy and Reserve Market Revenues ($ millions)	$26,833.0	$27,989.9	$28,501.9	$27,861.5	$28,319.2

The Market Monitor provides the detailed hourly and daily simulation results on its website.

Case B to Case C

PJM argues that the relevant comparison to assess the impact of the ORDC proposal is the comparison of Case B to Case C. Because Case B modifies actual PJM operating conditions, it is not an accurate base case. The comparison of Case B to Case C understates the impact of PJM's proposed changes on the actual market outcomes. The Market Monitor includes this comparison in order to highlight some of the detailed impacts of the comparison that PJM did not include in their filing. PJM presents the changes from Case B to Case C for the calendar year 2018 as the impact of implementing its proposed ORDC. In addition to the summary metrics provide in PJM's filing, the Market Monitor provides additional detailed metrics for each case.

Table 2 provides monthly load weighted average energy prices. The increase in LMP due to the ORDC is much greater in January, primarily resulting from higher base prices during the first week of January.

Table 2 PJM load-weighted average LMP: 2018, Case B to Case C

	Load-Weighted LMP ($/Mwh)		
	Case B	Case C	Difference
Jan	$73.87	$75.01	$1.14
Feb	$27.58	$28.00	$0.42
Mar	$30.64	$30.97	$0.34
Apr	$34.10	$34.73	$0.63
May	$31.96	$32.33	$0.37
Jun	$30.13	$30.48	$0.35
Jul	$34.53	$34.85	$0.31
Aug	$36.02	$36.22	$0.20
Sep	$35.59	$35.72	$0.13
Oct	$33.90	$34.52	$0.63
Nov	$37.45	$38.05	$0.60
Dec	$33.23	$33.66	$0.43
Total	$37.30	$37.76	$0.46

The LMP increases vary geographically. Table 3 shows the differences in annual average hub LMPs and Table 4 shows zonal load-weighted average LMP increases.

Table 3 Average hub LMP: 2018, Case B to Case C

	Average LMP ($/Mwh)		
	Case B	Case C	Difference
AEP GEN HUB	$32.20	$32.68	$0.48
AEP-DAYTON HUB	$33.52	$34.02	$0.49
ATSI GEN HUB	$34.40	$34.87	$0.47
CHICAGO GEN HUB	$28.68	$29.07	$0.39
CHICAGO HUB	$29.29	$29.68	$0.38
DOMINION HUB	$37.25	$37.73	$0.48
EASTERN HUB	$37.34	$37.64	$0.30
N ILLINOIS HUB	$29.09	$29.47	$0.38
NEW JERSEY HUB	$35.14	$35.55	$0.40
OHIO HUB	$33.28	$33.78	$0.50
WEST INT HUB	$35.30	$35.75	$0.46
WESTERN HUB	$35.51	$36.01	$0.50

Table 4 PJM load-weighted average LMP by zone: 2018, Case B to Case C

	Load-Weighted LMP ($/Mwh)		
	Case B	Case C	Difference
AECO	$37.81	$38.30	$0.49
AEP	$36.65	$37.17	$0.51
APS	$38.12	$38.62	$0.50
ATSI	$37.23	$37.71	$0.48
BGE	$42.13	$42.63	$0.50
ComEd	$30.74	$31.15	$0.41
DAY	$36.44	$36.97	$0.53
DEOK	$36.12	$36.61	$0.49
DLCO	$36.95	$37.42	$0.47
Dominion	$41.06	$41.56	$0.50
DPL	$41.46	$41.72	$0.26
EKPC	$35.75	$36.28	$0.53
JCPL	$37.81	$38.22	$0.41
Met-Ed	$38.14	$38.55	$0.42
PECO	$37.55	$37.98	$0.43
PENELEC	$36.94	$37.46	$0.52
Pepco	$40.86	$41.35	$0.50
PPL	$37.40	$37.77	$0.38
PSEG	$37.34	$37.72	$0.38
RECO	$37.72	$38.27	$0.54

Average generation-weighted, average LMP increases differ from load-weighted, average LMP increases. Table 5 shows the generation-weighted, average LMP at generation pricing nodes by zone. Typically, load LMP exceeds generator LMP due to congestion and losses, which is the case for most zones in both Cases B and C. However, generator LMPs increase more than load LMPs from Case B to Case C for nine of 20 zones.

Table 5 PJM generation-weighted, average LMP by zone: 2018, Case B to Case C

	Generation-Weighted LMP ($/Mwh)		
	Case B	Case C	Difference
AECO	$37.18	$37.55	$0.38
AEP	$33.41	$33.91	$0.50
APS	$35.26	$35.75	$0.49
ATSI	$35.95	$36.45	$0.49
BGE	$41.81	$42.30	$0.49
ComEd	$28.99	$29.36	$0.37
DAY	$38.76	$39.46	$0.70
DEOK	$33.44	$33.94	$0.50
DLCO	$35.68	$36.14	$0.45
Dominion	$40.34	$40.85	$0.50
DPL	$44.92	$45.12	$0.20
EKPC	$36.29	$36.87	$0.58
JCPL	$33.85	$34.24	$0.39
Met-Ed	$34.06	$34.45	$0.39
OVEC	$31.31	$31.80	$0.49
PECO	$34.78	$35.18	$0.40
PENELEC	$34.75	$35.37	$0.62
Pepco	$43.84	$44.50	$0.66
PPL	$35.42	$35.81	$0.39
PSEG	$34.80	$35.21	$0.42

Table 6 shows the increases in monthly MW weighted average reserve clearing prices for synchronized and primary reserves. Average prices for secondary reserves are zero. Reserve prices more than double annually, increasing in all months and by the largest amounts in the winter months.

Table 6 Monthly PJM reserve market prices: 2018, Case B to Case C

Reserve Weighted Average Market Clearing Prices ($/MW)						
	Case B		Case C		Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	$6.03	$1.43	$15.80	$6.66	$9.77	$5.23
Feb	$2.36	$0.31	$6.65	$2.57	$4.30	$2.26
Mar	$3.85	$1.94	$6.71	$3.04	$2.85	$1.10
Apr	$4.96	$2.47	$7.90	$3.87	$2.94	$1.40
May	$3.20	$1.09	$5.82	$2.82	$2.62	$1.72
Jun	$1.29	$1.06	$3.74	$2.30	$2.45	$1.24
Jul	$1.45	$1.08	$4.11	$2.25	$2.65	$1.17
Aug	$0.81	$0.45	$3.59	$1.89	$2.78	$1.44
Sep	$1.74	$1.47	$4.23	$2.82	$2.49	$1.35
Oct	$2.38	$1.94	$6.04	$3.83	$3.66	$1.89
Nov	$1.93	$1.29	$5.92	$3.13	$3.99	$1.84
Dec	$0.95	$0.59	$5.46	$2.89	$4.50	$2.30
Annual	$2.58	$1.25	$6.33	$3.21	$3.75	$1.95

Table 7 shows the monthly increases in the quantity of reserves. The increase in synchronized reserves ranges from 51.0 percent in April to 92.9 percent in February. The increases in primary reserves range from 0.7 percent in October to 19.5 percent in February.

Table 7 Monthly PJM reserve market clearing: 2018, Case B to Case C

Cleared Reserve MWh								
	Case B		Case C		Difference		Percent Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	1,333,092.8	460,168.2	2,418,397.5	546,578.3	1,085,304.7	86,410.1	81.4%	18.8%
Feb	1,104,579.4	424,887.5	2,130,543.1	507,781.1	1,025,963.7	82,893.6	92.9%	19.5%
Mar	1,320,246.7	480,453.2	2,040,335.0	508,224.3	720,088.4	27,771.1	54.5%	5.8%
Apr	1,242,142.7	444,263.6	1,875,125.5	478,559.4	632,982.8	34,295.9	51.0%	7.7%
May	1,224,596.4	450,672.8	1,926,473.6	487,224.9	701,877.2	36,552.1	57.3%	8.1%
Jun	1,260,166.9	415,391.3	2,259,288.5	423,859.6	999,121.6	8,468.4	79.3%	2.0%
Jul	1,311,952.1	484,208.9	2,367,598.0	507,157.2	1,055,645.9	22,948.3	80.5%	4.7%
Aug	1,298,609.1	481,900.0	2,377,283.8	512,919.8	1,078,674.7	31,019.7	83.1%	6.4%
Sep	1,307,381.3	372,220.2	2,329,466.3	378,763.9	1,022,085.0	6,543.7	78.2%	1.8%
Oct	1,462,476.9	435,479.7	2,450,038.5	438,649.3	987,561.6	3,169.7	67.5%	0.7%
Nov	1,310,593.5	471,232.5	2,278,685.6	489,567.6	968,092.0	18,335.2	73.9%	3.9%
Dec	1,315,281.3	482,772.0	2,532,455.1	494,226.7	1,217,173.9	11,454.7	92.5%	2.4%
Total	15,491,118.8	5,403,649.7	26,985,690.1	5,773,512.0	11,494,571.3	369,862.3	74.2%	6.8%

Increases in energy prices, reserve prices, and reserve clearing MW create higher revenues for suppliers. Table 8 provides the monthly generator revenue comparison for Case B to Case C. The total generator revenue increase from Case B to Case C is $511.9 million. Energy revenues increase by $369.4 million, accounting for 72.1 percent of the increase. Synchronized reserve revenues increase by $130.8 million, accounting for 25.6 percent of increased revenues.

Table 8 Monthly PJM generator revenue: 2018, Case B to Case C

	Revenue ($)											
	Case B				Case C				Difference			
	Generation	SR	PR	OR	Generation	SR	PR	OR	Generation	SR	PR	OR
Jan	$5,081,623,092.5	$8,041,039.6	$657,447.2	$0.0	$5,179,435,042.5	$38,219,472.1	$3,640,986.1	$6,807.5	$97,811,950.0	$30,178,432.6	$2,983,538.9	$6,807.5
Feb	$1,519,472,468.7	$2,603,153.7	$132,698.2	$0.0	$1,543,724,380.7	$14,175,045.2	$1,307,337.2	$0.0	$24,251,912.0	$11,571,891.5	$1,174,639.1	$0.0
Mar	$1,859,115,556.6	$5,089,052.2	$933,042.7	$0.0	$1,880,105,031.9	$13,687,271.3	$1,546,359.5	$0.0	$20,989,475.3	$8,598,219.1	$613,316.8	$0.0
Apr	$1,826,358,822.0	$6,159,167.4	$1,098,624.4	$0.0	$1,859,479,992.5	$14,809,220.0	$1,853,779.5	$0.0	$33,121,170.5	$8,650,052.6	$755,155.2	$0.0
May	$1,775,298,936.7	$3,915,318.4	$492,517.1	$0.0	$1,796,050,045.9	$11,202,492.5	$1,372,517.0	$0.0	$20,751,109.2	$7,287,174.1	$879,999.9	$0.0
Jun	$1,935,187,664.6	$1,628,149.4	$439,857.2	$0.0	$1,958,510,650.6	$8,451,910.9	$976,354.2	$0.0	$23,322,986.0	$6,823,761.5	$536,496.9	$0.0
Jul	$2,580,228,898.0	$1,907,918.9	$521,565.1	$0.0	$2,604,621,249.7	$9,728,911.1	$1,140,853.8	$0.0	$24,392,351.7	$7,820,992.2	$619,288.7	$0.0
Aug	$2,750,194,638.6	$1,050,710.0	$214,835.1	$0.0	$2,768,400,772.2	$8,531,431.0	$967,552.5	$0.0	$18,206,133.6	$7,480,720.9	$752,717.3	$0.0
Sep	$2,222,742,250.0	$2,271,640.2	$546,674.0	$0.0	$2,234,089,436.4	$9,855,606.3	$1,067,524.7	$0.0	$11,347,186.4	$7,583,966.2	$520,850.7	$0.0
Oct	$2,024,751,056.9	$3,481,601.1	$845,140.1	$0.0	$2,062,113,922.3	$14,807,457.1	$1,680,044.1	$0.0	$37,362,865.4	$11,325,855.9	$834,904.0	$0.0
Nov	$2,273,655,880.6	$2,530,961.9	$608,868.5	$0.0	$2,305,248,950.4	$13,485,785.4	$1,531,255.5	$0.0	$31,593,069.8	$10,954,823.6	$922,387.0	$0.0
Dec	$2,094,561,286.0	$1,254,060.2	$283,817.4	$0.0	$2,120,810,211.0	$13,815,461.4	$1,427,978.3	$0.0	$26,248,925.0	$12,561,401.2	$1,144,160.8	$0.0
Total	$27,943,190,551.2	$39,932,773.1	$6,775,087.1	$0.0	$28,312,589,686.1	$170,770,064.5	$18,512,542.5	$6,807.5	$369,399,134.9	$130,837,291.4	$11,737,455.4	$6,807.5

Table 9 shows generator revenues by technology type. Table 10 shows generator revenues per installed capacity (ICAP) MW by technology type. Consistent with their, roughly equal, high shares of energy output in PJM, steam, nuclear, and combined cycle gas units receive the greatest benefits from the ORDC.[4]

Revenues increase most for coal steam units. This result is expected. Coal steam units have high capacity factors due to their moderate marginal costs and inflexibility in starting and shutting down, so steam units receive a large share of the benefit of higher energy prices. Coal units' energy revenues increase by $120.4 million, reserve revenues increase by $23.2 million and total revenues increase by $143.6 million.

Nuclear units also have high capacity factors due to their low marginal cost and inflexibility. Nuclear units' energy revenues increase by $110.1 million but nuclear units do not provide reserves.

Combined cycle units have high capacity factors, but not as high as nuclear and steam units. Combined cycle units' energy revenues increase by $75.0 million, reserve revenues increase by $72.6 million, and total revenues increase by $147.6 million. Combined cycle units greater flexibility leads to the largest increase in reserve revenues by technology type.

Table 9 Generator revenues by technology type: 2018, Case B to Case C

	Revenue ($)								
	Case B			Case C			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$148,766.5	$0.9	$0.0	$151,937.2	$533.1	$55.4	$3,170.7	$532.2	$55.4
CC	$7,759,725,631.2	$22,947,672.0	$563.7	$7,834,745,587.7	$95,559,023.1	$4,333.1	$75,019,956.5	$72,611,351.1	$3,769.4
CT Natural Gas	$888,699,914.9	$5,773,510.7	$2,003,092.8	$926,170,750.9	$26,927,506.5	$6,407,041.0	$37,470,836.0	$21,153,995.8	$4,403,948.2
CT Oil	$46,324,308.3	$1,690,138.3	$4,474,516.6	$46,963,248.8	$5,005,884.6	$11,325,661.7	$638,940.5	$3,315,746.3	$6,851,145.1
CT Other	$5,899,724.1	$11,965.6	$23,344.2	$5,975,629.3	$41,186.5	$60,698.1	$75,905.2	$29,220.9	$37,353.9
Fuel Cell	$7,469,775.2	$0.0	$0.0	$7,556,319.5	$0.0	$0.0	$86,544.3	$0.0	$0.0
Hydro	$484,669,838.3	$2,887,448.2	$104,804.6	$489,809,456.5	$9,556,905.8	$265,559.0	$5,139,618.2	$6,669,457.6	$160,754.4
Nuclear	$9,049,991,523.7	$0.0	$0.0	$9,160,068,376.6	$0.0	$0.0	$110,076,852.9	$0.0	$0.0
RICE Natural Gas	$14,189,947.6	$96,194.4	$0.0	$14,478,100.4	$461,374.5	$0.0	$288,152.7	$365,180.1	$0.0
RICE Oil	$1,457,402.1	$2,056.5	$104,177.5	$1,401,120.9	$7,445.1	$264,985.1	($56,281.2)	$5,388.6	$160,807.6
RICE Other	$53,295,887.4	$505,299.9	$57,816.4	$53,795,291.6	$1,397,551.4	$141,371.5	$499,404.1	$892,251.5	$83,555.1
Solar	$66,827,029.5	$0.0	$0.0	$67,156,170.0	$0.0	$0.0	$329,140.5	$0.0	$0.0
Steam Coal	$8,410,313,995.3	$5,163,185.9	$6,771.2	$8,530,672,556.5	$28,365,453.2	$42,837.5	$120,358,561.3	$23,202,267.4	$36,066.3
Steam Natural Gas	$271,573,014.0	$587,459.2	$0.0	$278,003,548.3	$2,641,350.2	$0.0	$6,430,534.3	$2,053,890.9	$0.0
Steam Oil	$40,052,929.0	$40,336.8	$0.0	$40,905,504.0	$187,324.2	$0.0	$852,575.1	$146,987.5	$0.0
Steam Other	$230,868,650.2	$226,751.1	$0.0	$233,449,453.0	$616,857.5	$0.0	$2,580,802.8	$390,106.4	$0.0
Wind	$611,688,031.0	$0.0	$0.0	$621,289,059.6	$0.0	$0.0	$9,601,028.6	$0.0	$0.0
Total	$27,943,196,368.3	$39,932,019.4	$6,775,087.1	$28,312,592,110.7	$170,768,395.8	$18,512,542.5	$369,395,742.4	$130,836,376.4	$11,737,455.4

[4] *See* Monitoring Analytics, LLC, *2018 State of the Market Report for PJM*, Vol. 2, Section 3: Energy Market, Table 3-9.

Table 10 Generator revenues per ICAP MW by technology: 2018, Case B to Case C

	Revenue ($/MW)								
	Case B			Case C			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$3,719.16	$0.02	$0.00	$3,798.43	$13.33	$1.38	$79.27	$13.31	$1.38
CC	$161,695.31	$478.18	$0.01	$163,258.56	$1,991.24	$0.09	$1,563.25	$1,513.06	$0.08
CT Natural Gas	$35,493.90	$230.59	$80.00	$36,990.46	$1,075.46	$255.89	$1,496.55	$844.87	$175.89
CT Oil	$11,688.61	$426.46	$1,129.02	$11,849.83	$1,263.09	$2,857.71	$161.22	$836.63	$1,728.69
CT Other	$132,876.67	$269.50	$525.77	$134,586.24	$927.62	$1,367.07	$1,709.58	$658.13	$841.30
Fuel Cell	$248,992.51	$0.00	$0.00	$251,877.32	$0.00	$0.00	$2,884.81	$0.00	$0.00
Hydro	$60,032.93	$357.65	$12.98	$60,669.54	$1,183.75	$32.89	$636.61	$826.10	$19.91
Nuclear	$259,519.54	$0.00	$0.00	$262,676.13	$0.00	$0.00	$3,156.59	$0.00	$0.00
RICE Natural Gas	$117,856.71	$798.96	$0.00	$120,250.00	$3,832.01	$0.00	$2,393.30	$3,033.06	$0.00
RICE Oil	$6,344.81	$8.95	$453.54	$6,099.79	$32.41	$1,153.61	($245.02)	$23.46	$700.08
RICE Other	$147,642.22	$1,399.80	$160.17	$149,025.68	$3,871.55	$391.63	$1,383.47	$2,471.75	$231.47
Solar	$48,151.96	$0.00	$0.00	$48,389.13	$0.00	$0.00	$237.16	$0.00	$0.00
Steam Coal	$130,644.23	$80.20	$0.11	$132,513.86	$440.62	$0.67	$1,869.63	$360.42	$0.56
Steam Natural Gas	$27,083.90	$58.59	$0.00	$27,725.22	$263.42	$0.00	$641.32	$204.83	$0.00
Steam Oil	$17,459.86	$17.58	$0.00	$17,831.52	$81.66	$0.00	$371.65	$64.07	$0.00
Steam Other	$194,252.12	$190.79	$0.00	$196,423.60	$519.02	$0.00	$2,171.48	$328.23	$0.00
Wind	$67,824.41	$0.00	$0.00	$68,888.98	$0.00	$0.00	$1,064.57	$0.00	$0.00
Total	$133,665.02	$191.01	$32.41	$135,432.01	$816.86	$88.55	$1,766.99	$625.85	$56.15

To estimate the increase in carbon dioxide emissions due to the ORDC, the emissions rate for each technology, as calculated by the EIA, is multiplied by a generic heat rate for the technology and the simulated MWh of energy.[5] Table 11 provides the estimated increase in CO_2 emissions in short tons.

Table 11 Estimated emissions increase: 2018, Case B to Case C

	CO2 Rate (lbs/MMBtu)	Heat Rate (MMBtu/MWh)	CO2 Rate (tons/MWh)	CO2 Case B (tons)	CO2 Case C (tons)	CO2 Difference (tons)
Battery						
CC	117.00	7.5	0.44	99,811,925	99,450,170	(361,755)
CT Natural Gas	117.00	11.0	0.64	11,023,488	11,471,605	448,117
CT Oil	161.30	13.0	1.05	246,259	246,871	613
CT Other	117.00	11.0	0.64	106,222	106,192	(30)
Fuel Cell						
Hydro						
Nuclear						
RICE Natural Gas	117.00	11.0	0.64	205,511	209,061	3,550
RICE Oil	161.30	13.0	1.05	9,586	9,543	(43)
RICE Other	117.00	11.0	0.64	947,615	947,067	(548)
Solar						
Steam Coal	210.20	11.0	1.16	271,043,498	271,055,453	11,955
Steam Natural Gas	117.00	11.0	0.64	3,309,329	3,366,226	56,897
Steam Oil	161.30	11.0	0.89	287,795	288,764	969
Steam Other	117.00	11.0	0.64	4,074,738	4,074,302	(436)
Wind						
Total				386,991,227	387,150,952	159,725

[5] Carbon Dioxide Emissions Coefficients, Energy Information Administration, <https://www.eia.gov/environment/emissions/co2_vol_mass.php>, accessed May 9, 2019.

Case A to Case C

The comparison of Case A to Case C provides a better estimate of the results of PJM's proposed ORDC compared to the status quo, although the status quo is adjusted to incorporate optimal resource dispatch and fast start resource commitment. A comparison of Case A to Case C shows a higher increase in energy prices, because Case A has lower prices than Case B. Case A prices are lower because more generation is online in Case A, reflecting actual market operations. Case C and Case B allow the software to decommit uneconomic steam units, which are online for reliability or constraints at PJM's instruction.

If it is the case, and PJM implies that it is, that the ORDC would replace manual operator commitments with market commitments, the relevant comparison is Case A to Case C, because Case A contains the steam unit commitments made by operators. Case B removes all uneconomic operator commitments.

Table 12 provides monthly load-weighted, average energy prices. The increases in LMP due to the ORDC are higher when comparing Case A to Case C, rather than Case B to Case C.

Table 12 PJM load-weighted, average LMP: 2018, Case A to Case C

	Load-Weighted LMP ($/Mwh)		
	Case A	Case C	Difference
Jan	$68.39	$75.01	$6.62
Feb	$25.67	$28.00	$2.33
Mar	$28.82	$30.97	$2.16
Apr	$33.19	$34.73	$1.54
May	$30.80	$32.33	$1.53
Jun	$28.75	$30.48	$1.72
Jul	$33.64	$34.85	$1.21
Aug	$35.42	$36.22	$0.80
Sep	$34.73	$35.72	$0.99
Oct	$32.92	$34.52	$1.60
Nov	$36.87	$38.05	$1.18
Dec	$32.37	$33.66	$1.29
Total	$35.80	$37.76	$1.96

Table 13 shows the differences in annual average PJM trading hub LMPs.

Table 13 Average hub LMP: 2018, Case A to Case C

	Average LMP ($/MWh)		
	Case A	Case C	Difference
AEP GEN HUB	$31.08	$32.68	$1.60
AEP-DAYTON HUB	$32.43	$34.02	$1.59
ATSI GEN HUB	$33.18	$34.87	$1.69
CHICAGO GEN HUB	$27.39	$29.07	$1.67
CHICAGO HUB	$27.97	$29.68	$1.71
DOMINION HUB	$35.66	$37.73	$2.07
EASTERN HUB	$35.78	$37.64	$1.86
N ILLINOIS HUB	$27.77	$29.47	$1.70
NEW JERSEY HUB	$33.69	$35.55	$1.86
OHIO HUB	$32.21	$33.78	$1.57
WEST INT HUB	$34.01	$35.75	$1.74
WESTERN HUB	$34.10	$36.01	$1.91

Table 14 shows the zonal load-weighted average LMP increases.

Table 14 PJM load-weighted, average LMP by zone: 2018, Case A to Case C

	Load-Weighted LMP ($/Mwh)		
	Case A	Case C	Difference
AECO	$36.31	$38.30	$1.99
AEP	$35.36	$37.17	$1.80
APS	$36.59	$38.62	$2.03
ATSI	$35.98	$37.71	$1.73
BGE	$40.04	$42.63	$2.59
ComEd	$29.47	$31.15	$1.68
DAY	$35.17	$36.97	$1.79
DEOK	$34.74	$36.61	$1.87
DLCO	$35.67	$37.42	$1.75
Dominion	$39.25	$41.56	$2.31
DPL	$39.62	$41.72	$2.10
EKPC	$34.44	$36.28	$1.84
JCPL	$36.23	$38.22	$1.99
Met-Ed	$36.63	$38.55	$1.93
PECO	$35.89	$37.98	$2.09
PENELEC	$35.67	$37.46	$1.80
Pepco	$38.96	$41.35	$2.39
PPL	$35.73	$37.77	$2.04
PSEG	$35.84	$37.72	$1.88
RECO	$36.67	$38.27	$1.60

Table 15 shows the increases in energy prices at generation pricing nodes.

Table 15 PJM generation-weighted, average LMP by zone: 2018, Case A to Case C

	Generation-Weighted LMP ($/Mwh)		
	Case A	Case C	Difference
AECO	$35.67	$37.55	$1.89
AEP	$32.25	$33.91	$1.65
APS	$33.90	$35.75	$1.85
ATSI	$34.66	$36.45	$1.79
BGE	$39.54	$42.30	$2.77
ComEd	$27.39	$29.36	$1.96
DAY	$37.03	$39.46	$2.43
DEOK	$32.40	$33.94	$1.54
DLCO	$34.41	$36.14	$1.73
Dominion	$38.59	$40.85	$2.26
DPL	$41.79	$45.12	$3.34
EKPC	$34.99	$36.87	$1.88
JCPL	$32.66	$34.24	$1.58
Met-Ed	$32.61	$34.45	$1.85
OVEC	$30.59	$31.80	$1.21
PECO	$33.39	$35.18	$1.79
PENELEC	$33.60	$35.37	$1.77
Pepco	$41.00	$44.50	$3.50
PPL	$33.79	$35.81	$2.02
PSEG	$33.55	$35.21	$1.66

Table 16 shows the increases in reserve prices. Both synchronized reserve and primary reserve prices are more than three times higher in Case C than in Case A.

Table 16 Monthly PJM reserve market prices: 2018, Case A to Case C

	Reserve Weighted Average Market Clearing Prices ($/MW)					
	Case A		Case C		Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	$4.55	$1.28	$15.80	$6.66	$11.25	$5.39
Feb	$1.03	$0.16	$6.65	$2.57	$5.62	$2.41
Mar	$2.42	$1.17	$6.71	$3.04	$4.29	$1.87
Apr	$4.34	$2.37	$7.90	$3.87	$3.56	$1.50
May	$2.82	$1.07	$5.82	$2.82	$2.99	$1.75
Jun	$0.97	$0.74	$3.74	$2.30	$2.77	$1.56
Jul	$1.12	$0.84	$4.11	$2.25	$2.99	$1.41
Aug	$0.73	$0.43	$3.59	$1.89	$2.86	$1.46
Sep	$1.48	$1.25	$4.23	$2.82	$2.75	$1.57
Oct	$2.00	$1.66	$6.04	$3.83	$4.05	$2.17
Nov	$1.68	$0.98	$5.92	$3.13	$4.24	$2.15
Dec	$0.71	$0.50	$5.46	$2.89	$4.75	$2.39
Annual	$1.99	$1.03	$6.33	$3.21	$4.34	$2.18

Table 17 shows monthly reserve market clearing results. Case A and Case B clear similar amounts of reserves, so the difference between Case A and Case C is very similar to the difference between Case B and Case C.

Table 17 Monthly PJM reserve market clearing: 2018, Case A to Case C

	Cleared Reserve MWh							
	Case A		Case C		Difference		Percent Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	1,330,584.2	462,676.8	2,418,397.5	546,578.3	1,087,813.3	83,901.5	81.8%	18.1%
Feb	1,104,579.5	424,887.5	2,130,543.1	507,781.1	1,025,963.6	82,893.6	92.9%	19.5%
Mar	1,320,385.9	480,314.2	2,040,335.0	508,224.3	719,949.2	27,910.2	54.5%	5.8%
Apr	1,242,293.3	444,113.1	1,875,125.5	478,559.4	632,832.2	34,446.3	50.9%	7.8%
May	1,224,815.1	450,454.2	1,926,473.6	487,224.9	701,658.5	36,770.7	57.3%	8.2%
Jun	1,259,202.4	416,355.6	2,259,288.5	423,859.6	1,000,086.1	7,504.0	79.4%	1.8%
Jul	1,311,503.4	484,657.4	2,367,598.0	507,157.2	1,056,094.6	22,499.8	80.5%	4.6%
Aug	1,298,832.7	481,676.6	2,377,283.8	512,919.8	1,078,451.1	31,243.2	83.0%	6.5%
Sep	1,307,345.4	372,256.5	2,329,466.3	378,763.9	1,022,120.9	6,507.5	78.2%	1.7%
Oct	1,462,599.6	435,356.9	2,450,038.5	438,649.3	987,438.9	3,292.4	67.5%	0.8%
Nov	1,310,571.2	471,254.9	2,278,685.6	489,567.6	968,114.4	18,312.7	73.9%	3.9%
Dec	1,315,103.5	482,949.9	2,532,455.1	494,226.7	1,217,351.6	11,276.8	92.6%	2.3%
Total	15,487,815.9	5,406,953.4	26,985,690.1	5,773,512.0	11,497,874.2	366,558.6	74.2%	6.8%

Table 18 provides the monthly generator revenue comparison for Case A and Case C. Total generator revenues increase from Case A to Case C by $1.7 billion. Increased energy revenues account for 90.8 percent of the increase, and increased synchronized reserve payments account for 8.4 percent. The increase in generator revenues is more than $1 billion higher when comparing Case C to Case A than when comparing Case B to Case C.

Table 18 Monthly PJM generator revenue: 2018, Case A to Case C

	Revenue ($)											
	Case A				Case C				Difference			
	Generation	SR	PR	OR	Generation	SR	PR	OR	Generation	SR	PR	OR
Jan	$4,721,942,931.8	$6,059,690.0	$590,123.9	$0.0	$5,179,435,042.5	$38,219,472.1	$3,640,986.1	$6,807.5	$457,492,110.7	$32,159,782.1	$3,050,862.3	$6,807.5
Feb	$1,415,723,162.9	$1,141,654.3	$68,865.7	$0.0	$1,543,724,380.7	$14,175,045.2	$1,307,337.2	$0.0	$128,001,217.8	$13,033,390.9	$1,238,471.6	$0.0
Mar	$1,747,326,457.6	$3,196,953.8	$563,993.6	$0.0	$1,880,105,031.9	$13,687,271.3	$1,546,359.5	$0.0	$132,778,574.3	$10,490,317.6	$982,365.9	$0.0
Apr	$1,772,922,354.2	$5,387,102.6	$1,053,933.7	$0.0	$1,859,479,992.5	$14,809,220.0	$1,853,779.5	$0.0	$86,557,638.3	$9,422,117.5	$799,845.8	$0.0
May	$1,708,618,722.9	$3,458,761.1	$482,879.6	$0.0	$1,796,050,045.9	$11,202,492.5	$1,372,517.0	$0.0	$87,431,323.0	$7,743,731.5	$889,637.5	$0.0
Jun	$1,847,286,164.8	$1,220,012.8	$307,677.3	$0.0	$1,958,510,650.6	$8,451,910.9	$976,354.2	$0.0	$111,224,485.8	$7,231,898.1	$668,676.9	$0.0
Jul	$2,505,939,506.7	$1,468,835.0	$405,465.1	$0.0	$2,604,621,249.7	$9,728,911.1	$1,140,853.8	$0.0	$98,681,743.0	$8,260,076.1	$735,388.7	$0.0
Aug	$2,691,708,750.5	$944,817.0	$205,406.4	$0.0	$2,768,400,772.2	$8,531,431.0	$967,552.5	$0.0	$76,692,021.7	$7,586,614.0	$762,146.1	$0.0
Sep	$2,165,046,703.9	$1,935,343.8	$466,280.8	$0.0	$2,234,089,436.4	$9,855,606.3	$1,067,524.7	$0.0	$69,042,732.5	$7,920,262.5	$601,243.9	$0.0
Oct	$1,960,059,046.6	$2,923,290.1	$722,045.5	$0.0	$2,062,113,922.3	$14,807,457.1	$1,680,044.1	$0.0	$102,054,875.7	$11,884,167.0	$957,998.7	$0.0
Nov	$2,228,604,987.3	$2,198,883.6	$461,822.2	$0.0	$2,305,248,950.4	$13,485,785.4	$1,531,255.5	$0.0	$76,643,963.1	$11,286,901.8	$1,069,433.3	$0.0
Dec	$2,031,396,902.8	$931,137.4	$241,804.3	$0.0	$2,120,810,211.0	$13,815,461.4	$1,427,978.3	$0.0	$89,413,308.2	$12,884,324.0	$1,186,173.9	$0.0
Total	$26,796,575,692.0	$30,866,481.3	$5,570,298.0	$0.0	$28,312,589,686.1	$170,770,064.5	$18,512,542.5	$6,807.5	$1,516,013,994.1	$139,903,583.2	$12,942,244.5	$6,807.5

Table 19 shows the increases in revenues by generator technology from Case A to Case C. Table 20 shows the increases in revenues by generator per ICAP MW by generator technology from Case A to Case C. The nuclear units receive the largest increase in revenues because the energy revenues account for a larger share of the revenue increase from Case A to Case C, compared to Case B to Case C.

Table 19 Generator revenues by technology type: 2018, Case A to Case C

	Revenue ($)								
	Case A			Case C			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$144,174.4	$0.0	$0.0	$151,937.2	$533.1	$55.4	$7,762.7	$533.1	$55.4
CC	$7,484,861,343.8	$17,275,747.1	$539.5	$7,834,745,587.7	$95,559,023.1	$4,333.1	$349,884,243.9	$78,283,276.0	$3,793.6
CT Natural Gas	$805,127,285.3	$4,795,045.9	$1,616,514.3	$926,170,750.9	$26,927,506.5	$6,407,041.0	$121,043,465.5	$22,132,460.6	$4,790,526.7
CT Oil	$39,567,721.2	$1,470,433.3	$3,708,429.6	$46,963,248.8	$5,005,884.6	$11,325,661.7	$7,395,527.5	$3,535,451.3	$7,617,232.1
CT Other	$5,669,809.6	$8,580.7	$19,434.9	$5,975,629.3	$41,186.5	$60,698.1	$305,819.7	$32,605.8	$41,263.2
Fuel Cell	$7,146,807.5	$0.0	$0.0	$7,556,319.5	$0.0	$0.0	$409,511.9	$0.0	$0.0
Hydro	$467,552,732.7	$2,305,817.9	$87,871.0	$489,809,456.5	$9,556,905.8	$265,559.0	$22,256,723.8	$7,251,087.8	$177,688.0
Nuclear	$8,624,960,212.6	$0.0	$0.0	$9,160,068,376.6	$0.0	$0.0	$535,108,164.0	$0.0	$0.0
RICE Natural Gas	$13,132,167.2	$65,537.6	$0.0	$14,478,100.4	$461,374.5	$0.0	$1,345,933.1	$395,837.0	$0.0
RICE Oil	$1,301,349.6	$1,957.5	$87,485.9	$1,401,120.9	$7,445.1	$264,985.1	$99,771.4	$5,487.6	$177,499.1
RICE Other	$51,181,770.3	$378,016.8	$46,956.6	$53,795,291.6	$1,397,551.4	$141,371.5	$2,613,521.2	$1,019,534.6	$94,414.9
Solar	$63,794,993.7	$0.0	$0.0	$67,156,170.0	$0.0	$0.0	$3,361,176.3	$0.0	$0.0
Steam Coal	$8,107,721,991.6	$3,817,694.2	$2,868.2	$8,530,672,556.5	$28,365,453.2	$42,837.5	$422,950,564.9	$24,547,759.1	$39,969.3
Steam Natural Gas	$282,552,561.3	$537,800.2	$197.9	$278,003,548.3	$2,641,350.2	$0.0	($4,549,013.0)	$2,103,550.0	($197.9)
Steam Oil	$38,694,864.0	$44,166.4	$0.0	$40,905,504.0	$187,324.2	$0.0	$2,210,640.0	$143,157.8	$0.0
Steam Other	$221,652,709.9	$165,093.6	$0.0	$233,449,453.0	$616,857.5	$0.0	$11,796,743.2	$451,764.0	$0.0
Wind	$581,516,370.5	$0.0	$0.0	$621,289,059.6	$0.0	$0.0	$39,772,689.1	$0.0	$0.0
Total	$26,796,578,865.2	$30,865,891.2	$5,570,298.0	$28,312,592,110.7	$170,768,395.8	$18,512,542.5	$1,516,013,245.4	$139,902,504.6	$12,942,244.5

Table 20 Generator revenues per ICAP MW by technology type: 2018, Case A to Case C

	Revenue ($/MW)								
	Case A			Case C			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$3,604.36	$0.00	$0.00	$3,798.43	$13.33	$1.38	$194.07	$13.33	$1.38
CC	$155,967.75	$359.99	$0.01	$163,258.56	$1,991.24	$0.09	$7,290.80	$1,631.25	$0.08
CT Natural Gas	$32,156.09	$191.51	$64.56	$36,990.46	$1,075.46	$255.89	$4,834.37	$883.95	$191.33
CT Oil	$9,983.78	$371.02	$935.72	$11,849.83	$1,263.09	$2,857.71	$1,866.05	$892.07	$1,921.99
CT Other	$127,698.41	$193.26	$437.72	$134,586.24	$927.62	$1,367.07	$6,887.83	$734.36	$929.35
Fuel Cell	$238,226.92	$0.00	$0.00	$251,877.32	$0.00	$0.00	$13,650.40	$0.00	$0.00
Hydro	$57,912.74	$285.61	$10.88	$60,669.54	$1,183.75	$32.89	$2,756.80	$898.15	$22.01
Nuclear	$247,331.25	$0.00	$0.00	$262,676.13	$0.00	$0.00	$15,344.88	$0.00	$0.00
RICE Natural Gas	$109,071.16	$544.33	$0.00	$120,250.00	$3,832.01	$0.00	$11,178.85	$3,287.68	$0.00
RICE Oil	$5,665.43	$8.52	$380.87	$6,099.79	$32.41	$1,153.61	$434.36	$23.89	$772.74
RICE Other	$141,785.61	$1,047.20	$130.08	$149,025.68	$3,871.55	$391.63	$7,240.07	$2,824.35	$261.55
Solar	$45,967.24	$0.00	$0.00	$48,389.13	$0.00	$0.00	$2,421.88	$0.00	$0.00
Steam Coal	$125,943.83	$59.30	$0.04	$132,513.86	$440.62	$0.67	$6,570.03	$381.32	$0.62
Steam Natural Gas	$28,178.89	$53.63	$0.02	$27,725.22	$263.42	$0.00	($453.67)	$209.79	($0.02)
Steam Oil	$16,867.86	$19.25	$0.00	$17,831.52	$81.66	$0.00	$963.66	$62.41	$0.00
Steam Other	$186,497.86	$138.91	$0.00	$196,423.60	$519.02	$0.00	$9,925.74	$380.11	$0.00
Wind	$64,478.96	$0.00	$0.00	$68,888.98	$0.00	$0.00	$4,410.02	$0.00	$0.00
Total	$128,180.23	$147.65	$26.65	$135,432.01	$816.86	$88.55	$7,251.78	$669.22	$61.91

To estimate the increase in carbon dioxide emissions due to the ORDC, the emissions rate for each technology, as calculated by the EIA, is multiplied by a generic heat rate for the technology and the simulated MWh of energy.[6] Table 21 provides the estimated increase in CO_2 emissions in short tons. For Case A to Case C, the total MWh used to serve load decreases, so the total emissions also fall.

Table 21 Estimated emissions change: 2018, Case A to Case C

	CO2 Rate (lbs/MMBtu)	Heat Rate (MMBtu/MWh)	CO2 Rate (tons/MWh)	CO2 Case A (tons)	CO2 Case C (tons)	CO2 Difference (tons)
Battery						
CC	117.00	7.5	0.44	99,921,281	99,450,170	(471,111)
CT Natural Gas	117.00	11.0	0.64	10,126,406	11,471,605	1,345,199
CT Oil	161.30	13.0	1.05	228,427	246,871	18,444
CT Other	117.00	11.0	0.64	106,225	106,192	(32)
Fuel Cell						
Hydro						
Nuclear						
RICE Natural Gas	117.00	11.0	0.64	191,070	209,061	17,991
RICE Oil	161.30	13.0	1.05	9,573	9,543	(31)
RICE Other	117.00	11.0	0.64	947,109	947,067	(41)
Solar						
Steam Coal	210.20	11.0	1.16	271,630,534	271,055,453	(575,081)
Steam Natural Gas	117.00	11.0	0.64	3,809,895	3,366,226	(443,669)
Steam Oil	161.30	11.0	0.89	296,370	288,764	(7,606)
Steam Other	117.00	11.0	0.64	4,089,342	4,074,302	(15,039)
Wind						
Total				387,266,889	387,150,952	(115,936)

[6] Carbon Dioxide Emissions Coefficients, Energy Information Administration, <https://www.eia.gov/environment/emissions/co2_vol_mass.php>, accessed May 9, 2019.

Case A to Case A ORDC

The Market Monitor also compares Case A to Case A ORDC. The Case A ORDC adds PJM's ORDC directly to the Case A model rather than to the Case B model.

Table 22 shows that the LMP increase between Case A and Case A ORDC is $1.12 per MWh. This is lower than the $1.96 per MWh LMP increase between Case A and Case C, and greater than the $0.46 per MWh increase between Case B and Case C.

Table 22 PJM load-weighted, average LMP: 2018, Case A to Case A ORDC

	Load-Weighted LMP ($/Mwh)		
	Case A	Case A1	Difference
Jan	$68.39	$70.74	$2.34
Feb	$25.67	$27.26	$1.59
Mar	$28.82	$29.58	$0.76
Apr	$33.19	$34.18	$0.99
May	$30.80	$31.45	$0.65
Jun	$28.75	$29.31	$0.56
Jul	$33.64	$34.07	$0.43
Aug	$35.42	$36.01	$0.59
Sep	$34.73	$35.46	$0.73
Oct	$32.92	$34.16	$1.25
Nov	$36.87	$38.27	$1.40
Dec	$32.37	$34.49	$2.12
Total	$35.80	$36.91	$1.12

Table 23 provides average energy prices for the PJM hubs for Case A and Case A with the PJM proposed ORDC.

Table 23 Average hub LMP: 2018, Case A to Case A ORDC

	Average LMP ($/MWh)		
	Case A	Case A ORDC	Difference
AEP GEN HUB	$31.08	$32.11	$1.03
AEP-DAYTON HUB	$32.43	$33.47	$1.04
ATSI GEN HUB	$33.18	$34.28	$1.10
CHICAGO GEN HUB	$27.39	$28.30	$0.91
CHICAGO HUB	$27.97	$28.89	$0.92
DOMINION HUB	$35.66	$36.68	$1.02
EASTERN HUB	$35.78	$36.98	$1.19
N ILLINOIS HUB	$27.77	$28.68	$0.92
NEW JERSEY HUB	$33.69	$34.86	$1.17
OHIO HUB	$32.21	$33.25	$1.04
WEST INT HUB	$34.01	$35.06	$1.04
WESTERN HUB	$34.10	$35.18	$1.07

Table 24 and Table 25 provide the increases in load and generation-weighted average energy prices by zone when PJM's proposed ORDC is applied to Case A.

Table 24 PJM load-weighted, average LMP by zone: 2018, Case A to Case A ORDC

	Load-Weighted LMP ($/Mwh)		
	Case A	Case A ORDC	Difference
AECO	$36.31	$37.53	$1.22
AEP	$35.36	$36.45	$1.09
APS	$36.59	$37.74	$1.15
ATSI	$35.98	$37.13	$1.15
BGE	$40.04	$41.11	$1.07
ComEd	$29.47	$30.41	$0.94
DAY	$35.17	$36.32	$1.14
DEOK	$34.74	$35.86	$1.12
DLCO	$35.67	$36.80	$1.12
Dominion	$39.25	$40.34	$1.09
DPL	$39.62	$40.88	$1.26
EKPC	$34.44	$35.55	$1.11
JCPL	$36.23	$37.45	$1.22
Met-Ed	$36.63	$37.83	$1.21
PECO	$35.89	$37.13	$1.23
PENELEC	$35.67	$36.88	$1.21
Pepco	$38.96	$40.03	$1.07
PPL	$35.73	$36.96	$1.22
PSEG	$35.84	$37.02	$1.18
RECO	$36.67	$37.82	$1.16

Table 25 PJM generation-weighted, average LMP by zone: 2018, Case A to Case A ORDC

	Generation-Weighted LMP ($/Mwh)		
	Case A	Case A ORDC	Difference
AECO	$35.67	$36.83	$1.16
AEP	$32.25	$33.31	$1.05
APS	$33.90	$34.99	$1.09
ATSI	$34.66	$35.85	$1.19
BGE	$39.54	$40.56	$1.03
ComEd	$27.39	$28.32	$0.93
DAY	$37.03	$38.45	$1.42
DEOK	$32.40	$33.48	$1.08
DLCO	$34.41	$35.51	$1.11
Dominion	$38.59	$39.67	$1.08
DPL	$41.79	$43.17	$1.39
EKPC	$34.99	$36.17	$1.18
JCPL	$32.66	$33.75	$1.10
Met-Ed	$32.61	$33.78	$1.17
OVEC	$30.59	$32.65	$2.06
PECO	$33.39	$34.62	$1.23
PENELEC	$33.60	$34.86	$1.26
Pepco	$41.00	$42.11	$1.12
PPL	$33.79	$34.98	$1.20
PSEG	$33.55	$34.72	$1.16

Table 26 shows the increases in reserve prices when the PJM proposed ORDC is applied to Case A.

Table 26 Monthly PJM reserve market prices: 2018, Case A to Case A ORDC

	Reserve Weighted Average Market Clearing Prices ($/MW)					
	Case A		Case A ORDC		Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	$4.55	$1.28	$14.44	$6.11	$9.88	$4.84
Feb	$1.03	$0.16	$6.49	$2.53	$5.46	$2.37
Mar	$2.42	$1.17	$5.56	$2.47	$3.14	$1.30
Apr	$4.34	$2.37	$7.55	$3.71	$3.22	$1.34
May	$2.82	$1.07	$5.60	$2.70	$2.78	$1.63
Jun	$0.97	$0.74	$3.20	$2.00	$2.23	$1.26
Jul	$1.12	$0.84	$3.72	$2.06	$2.60	$1.22
Aug	$0.73	$0.43	$3.47	$1.85	$2.75	$1.42
Sep	$1.48	$1.25	$4.21	$2.82	$2.73	$1.56
Oct	$2.00	$1.66	$5.97	$3.78	$3.97	$2.12
Nov	$1.68	$0.98	$5.92	$3.17	$4.24	$2.19
Dec	$0.71	$0.50	$6.26	$3.37	$5.55	$2.87
Annual	$1.99	$1.03	$6.05	$3.08	$4.05	$2.05

Table 27 shows the monthly reserve clearing levels when the PJM proposed ORDC is applied to Case A.

Table 27 Monthly PJM reserve market clearing: 2018, Case A to Case A ORDC

	Cleared Reserve MWh							
	Case A		Case A ORDC		Difference		Percent Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	1,330,584.2	462,676.8	2,445,062.7	548,353.4	1,114,478.5	85,676.6	83.8%	18.5%
Feb	1,104,579.5	424,887.5	2,138,010.4	507,611.7	1,033,430.9	82,724.1	93.6%	19.5%
Mar	1,320,385.9	480,314.2	2,096,359.6	508,626.9	775,973.7	28,312.8	58.8%	5.9%
Apr	1,242,293.3	444,113.1	1,886,322.7	478,023.9	644,029.4	33,910.8	51.8%	7.6%
May	1,224,815.1	450,454.2	1,938,602.6	487,486.4	713,787.5	37,032.3	58.3%	8.2%
Jun	1,259,202.4	416,355.6	2,286,218.0	424,304.8	1,027,015.6	7,949.2	81.6%	1.9%
Jul	1,311,503.4	484,657.4	2,387,740.2	508,090.9	1,076,236.8	23,433.5	82.1%	4.8%
Aug	1,298,832.7	481,676.6	2,387,116.6	512,981.3	1,088,283.9	31,304.7	83.8%	6.5%
Sep	1,307,345.4	372,256.5	2,335,838.7	379,079.1	1,028,493.3	6,822.7	78.7%	1.8%
Oct	1,462,599.6	435,356.9	2,456,927.0	439,048.7	994,327.4	3,691.8	68.0%	0.8%
Nov	1,310,571.2	471,254.9	2,291,506.6	489,321.5	980,935.4	18,066.6	74.8%	3.8%
Dec	1,315,103.5	482,949.9	2,525,861.3	494,245.9	1,210,757.8	11,296.0	92.1%	2.3%
Total	15,487,815.9	5,406,953.4	27,175,566.0	5,777,174.3	11,687,750.1	370,221.0	75.5%	6.8%

Table 28 shows the increases in generator revenue when PJM's proposed ORDC is applied to Case A.

Table 28 Monthly PJM generator revenue: 2018, Case A to Case A ORDC

	Revenue ($)											
	Case A				Case A ORDC				Difference			
	Generation	SR	PR	OR	Generation	SR	PR	OR	Generation	SR	PR	OR
Jan	$4,721,942,931.8	$6,059,690.0	$590,123.9	$0.0	$4,903,702,907.4	$35,303,787.8	$3,352,958.5	$6,853.3	$181,759,975.6	$29,244,097.9	$2,762,834.6	$6,853.3
Feb	$1,415,723,162.9	$1,141,654.3	$68,865.7	$0.0	$1,505,390,913.7	$13,879,148.9	$1,284,741.5	$0.0	$89,667,750.8	$12,737,494.6	$1,215,875.8	$0.0
Mar	$1,747,326,457.6	$3,196,953.8	$563,993.6	$0.0	$1,793,996,326.8	$11,661,958.2	$1,257,380.7	$0.0	$46,669,869.2	$8,465,004.5	$693,387.1	$0.0
Apr	$1,772,922,354.2	$5,387,102.6	$1,053,933.7	$0.0	$1,827,296,170.8	$14,247,039.3	$1,775,546.7	$0.0	$54,373,816.6	$8,859,936.7	$721,613.0	$0.0
May	$1,708,618,722.9	$3,458,761.1	$482,879.6	$0.0	$1,747,120,599.4	$10,865,845.1	$1,316,140.9	$0.0	$38,501,876.5	$7,407,084.1	$833,261.4	$0.0
Jun	$1,847,286,164.8	$1,220,012.8	$307,677.3	$0.0	$1,884,384,743.0	$7,316,486.5	$848,315.9	$0.0	$37,098,578.2	$6,096,473.7	$540,638.6	$0.0
Jul	$2,505,939,506.7	$1,468,835.0	$405,465.1	$0.0	$2,539,745,703.8	$8,890,634.9	$1,044,746.0	$0.0	$33,806,197.1	$7,421,800.0	$639,280.9	$0.0
Aug	$2,691,708,750.5	$944,817.0	$205,406.4	$0.0	$2,738,981,078.8	$8,294,350.9	$948,480.0	$0.0	$47,272,328.3	$7,349,534.0	$743,073.6	$0.0
Sep	$2,165,046,703.9	$1,935,343.8	$466,280.8	$0.0	$2,217,133,432.6	$9,834,664.3	$1,067,937.8	$0.0	$52,086,728.7	$7,899,320.5	$601,657.1	$0.0
Oct	$1,960,059,046.6	$2,923,290.1	$722,045.5	$0.0	$2,037,984,679.1	$14,665,751.7	$1,660,008.2	$0.0	$77,925,632.5	$11,742,461.7	$937,962.8	$0.0
Nov	$2,228,604,987.3	$2,198,883.6	$461,822.2	$0.0	$2,317,394,164.9	$13,568,427.3	$1,549,689.7	$0.0	$88,789,177.6	$11,369,543.7	$1,087,867.5	$0.0
Dec	$2,031,396,902.8	$931,137.4	$241,804.3	$0.0	$2,166,214,528.6	$15,817,395.2	$1,667,131.7	$0.0	$134,817,625.8	$14,886,257.9	$1,425,327.4	$0.0
Total	$26,796,575,692.0	$30,866,481.3	$5,570,298.0	$0.0	$27,679,345,248.9	$164,345,490.4	$17,773,077.7	$6,853.3	$882,769,556.9	$133,479,009.0	$12,202,779.7	$6,853.3

Table 29 and Table 30 show the generator revenues by technology type, both total and per ICAP MW, comparing Case A to Case A with the PJM proposed ORDC.

Table 29 Generator revenues by technology type: 2018, Case A to Case A ORDC

	Revenue ($)								
	Case A			Case A ORDC			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$144,174.4	$0.0	$0.0	$155,536.6	$277.1	$55.4	$11,362.2	$277.1	$55.4
CC	$7,484,861,343.8	$17,275,747.1	$539.5	$7,680,684,082.1	$90,320,363.5	$5,000.2	$195,822,738.3	$73,044,616.4	$4,460.7
CT Natural Gas	$805,127,285.3	$4,795,045.9	$1,616,514.3	$869,483,702.5	$26,359,623.3	$6,093,503.0	$64,356,417.2	$21,564,577.4	$4,476,988.7
CT Oil	$39,567,721.2	$1,470,433.3	$3,708,429.6	$40,491,904.3	$5,023,324.6	$10,939,062.3	$924,183.1	$3,552,891.3	$7,230,632.7
CT Other	$5,669,809.6	$8,580.7	$19,434.9	$5,845,941.0	$41,415.9	$56,705.1	$176,131.5	$32,835.2	$37,270.2
Fuel Cell	$7,146,807.5	$0.0	$0.0	$7,403,493.9	$0.0	$0.0	$256,686.3	$0.0	$0.0
Hydro	$467,552,732.7	$2,305,817.9	$87,871.0	$486,117,032.0	$9,186,724.4	$250,957.8	$18,564,299.3	$6,880,906.5	$163,086.9
Nuclear	$8,624,960,212.6	$0.0	$0.0	$8,916,012,522.1	$0.0	$0.0	$291,052,309.6	$0.0	$0.0
RICE Natural Gas	$13,132,167.2	$65,537.6	$0.0	$14,252,185.1	$477,897.2	$0.0	$1,120,017.9	$412,359.7	$0.0
RICE Oil	$1,301,349.6	$1,957.5	$87,485.9	$1,320,746.6	$8,381.2	$248,170.9	$19,397.0	$6,423.7	$160,685.0
RICE Other	$51,181,770.3	$378,016.8	$46,956.6	$52,643,347.3	$1,341,552.8	$135,816.5	$1,461,577.0	$963,536.0	$88,859.9
Solar	$63,794,993.7	$0.0	$0.0	$65,510,189.5	$0.0	$0.0	$1,715,195.8	$0.0	$0.0
Steam Coal	$8,107,721,991.6	$3,817,694.2	$2,868.2	$8,378,605,491.7	$28,082,751.7	$43,579.2	$270,883,500.1	$24,265,057.5	$40,710.9
Steam Natural Gas	$282,552,561.3	$537,800.2	$197.9	$289,145,179.8	$2,736,022.3	$227.2	$6,592,618.5	$2,198,222.1	$29.3
Steam Oil	$38,694,864.0	$44,166.4	$0.0	$39,328,394.9	$185,138.6	$0.0	$633,530.8	$140,972.2	$0.0
Steam Other	$221,652,709.9	$165,093.6	$0.0	$228,374,231.0	$580,406.5	$0.0	$6,721,521.1	$415,312.9	$0.0
Wind	$581,516,370.5	$0.0	$0.0	$603,972,118.5	$0.0	$0.0	$22,455,748.0	$0.0	$0.0
Total	$26,796,578,865.2	$30,865,891.2	$5,570,298.0	$27,679,346,098.9	$164,343,879.0	$17,773,077.7	$882,767,233.7	$133,477,987.8	$12,202,779.7

Table 30 Generator revenue per ICAP MW by technology type: 2018, Case A to Case A ORDC

	Revenue ($/MWh)								
	Case A			Case A ORDC			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$3,604.36	$0.00	$0.00	$3,888.42	$6.93	$1.38	$284.05	$6.93	$1.38
CC	$155,967.75	$359.99	$0.01	$160,048.26	$1,882.07	$0.10	$4,080.51	$1,522.09	$0.09
CT Natural Gas	$32,156.09	$191.51	$64.56	$34,726.43	$1,052.78	$243.37	$2,570.34	$861.27	$178.81
CT Oil	$9,983.78	$371.02	$935.72	$10,216.97	$1,267.49	$2,760.16	$233.19	$896.47	$1,824.44
CT Other	$127,698.41	$193.26	$437.72	$131,665.34	$932.79	$1,277.14	$3,966.92	$739.53	$839.42
Fuel Cell	$238,226.92	$0.00	$0.00	$246,783.13	$0.00	$0.00	$8,556.21	$0.00	$0.00
Hydro	$57,912.74	$285.61	$10.88	$60,212.18	$1,137.90	$31.08	$2,299.44	$852.29	$20.20
Nuclear	$247,331.25	$0.00	$0.00	$255,677.53	$0.00	$0.00	$8,346.28	$0.00	$0.00
RICE Natural Gas	$109,071.16	$544.33	$0.00	$118,373.63	$3,969.25	$0.00	$9,302.47	$3,424.91	$0.00
RICE Oil	$5,665.43	$8.52	$380.87	$5,749.88	$36.49	$1,080.41	$84.45	$27.97	$699.54
RICE Other	$141,785.61	$1,047.20	$130.08	$145,834.53	$3,716.42	$376.24	$4,048.91	$2,669.22	$246.16
Solar	$45,967.24	$0.00	$0.00	$47,203.12	$0.00	$0.00	$1,235.88	$0.00	$0.00
Steam Coal	$125,943.83	$59.30	$0.04	$130,151.68	$436.23	$0.68	$4,207.85	$376.93	$0.63
Steam Natural Gas	$28,178.89	$53.63	$0.02	$28,836.37	$272.86	$0.02	$657.48	$219.23	$0.00
Steam Oil	$16,867.86	$19.25	$0.00	$17,144.03	$80.71	$0.00	$276.17	$61.45	$0.00
Steam Other	$186,497.86	$138.91	$0.00	$192,153.33	$488.35	$0.00	$5,655.47	$349.44	$0.00
Wind	$64,478.96	$0.00	$0.00	$66,968.87	$0.00	$0.00	$2,489.91	$0.00	$0.00
Total	$128,180.23	$147.65	$26.65	$132,402.91	$786.13	$85.02	$4,222.68	$638.49	$58.37

To estimate the increase in carbon dioxide emissions due to the ORDC, the emissions rate for each technology, as calculated by the EIA, is multiplied by a generic heat rate for the technology and the simulated MWh of energy.[7] Table 31 provides the estimated increase in CO_2 emissions in short tons.

Table 31 Estimated emissions increase: 2018, Case A to Case A ORDC

	CO2 Rate (lbs/MMBtu)	Heat Rate (MMBtu/MWh)	CO2 Rate (tons/MWh)	CO2 Case A (tons)	CO2 Case A ORDC (tons)	CO2 Difference (tons)
Battery						
CC	117.00	7.5	0.44	99,921,281	99,218,180	(703,101)
CT Natural Gas	117.00	11.0	0.64	10,126,406	10,842,983	716,577
CT Oil	161.30	13.0	1.05	228,427	230,241	1,814
CT Other	117.00	11.0	0.64	106,225	106,182	(42)
Fuel Cell						
Hydro						
Nuclear						
RICE Natural Gas	117.00	11.0	0.64	191,070	206,866	15,797
RICE Oil	161.30	13.0	1.05	9,573	9,550	(23)
RICE Other	117.00	11.0	0.64	947,109	946,662	(447)
Solar						
Steam Coal	210.20	11.0	1.16	271,630,534	272,133,017	502,483
Steam Natural Gas	117.00	11.0	0.64	3,809,895	3,814,332	4,437
Steam Oil	161.30	11.0	0.89	296,370	295,936	(434)
Steam Other	117.00	11.0	0.64	4,089,342	4,088,432	(909)
Wind						
Total				387,266,889	387,803,950	537,061

[7] Carbon Dioxide Emissions Coefficients, Energy Information Administration, <https://www.eia.gov/environment/emissions/co2_vol_mass.php>, accessed May 9, 2019.

Case B to Case C 15 minute

When PJM's 30 minute ORDC is replaced with an ORDC based on 15 minute forecast error uncertainty, the price and revenue differences are lower.

Table 32 shows the increase in monthly energy prices between Case B and Case C 15 minute.

Table 32 PJM load-weighted average LMP: 2018, Case B to Case C 15 minute

	Load-Weighted LMP ($/Mwh)		
	Case B	Case C 15	Difference
Jan	$73.87	$74.91	$1.04
Feb	$27.58	$27.88	$0.30
Mar	$30.64	$30.73	$0.09
Apr	$34.10	$34.47	$0.37
May	$31.96	$32.13	$0.17
Jun	$30.13	$30.18	$0.05
Jul	$34.53	$34.70	$0.16
Aug	$36.02	$36.15	$0.13
Sep	$35.59	$35.75	$0.16
Oct	$33.90	$34.26	$0.36
Nov	$37.45	$38.02	$0.57
Dec	$33.23	$33.51	$0.28
Total	$37.30	$37.61	$0.31

Table 33 shows the increase in energy prices at PJM hubs. The differences range from $0.13 per MWh to $0.35 per MWh, about $0.15 per MWh less than the differences for Case B to Case C.

Table 33 Average hub LMP: 2018, Case B to Case C 15 minute

	Average LMP ($/Mwh)		
	Case B	Case C 15	Difference
AEP GEN HUB	$32.20	$32.52	$0.32
AEP-DAYTON HUB	$33.52	$33.85	$0.33
ATSI GEN HUB	$34.40	$34.69	$0.29
CHICAGO GEN HUB	$28.68	$28.94	$0.27
CHICAGO HUB	$29.29	$29.56	$0.27
DOMINION HUB	$37.25	$37.55	$0.30
EASTERN HUB	$37.34	$37.47	$0.13
N ILLINOIS HUB	$29.09	$29.35	$0.27
NEW JERSEY HUB	$35.14	$35.42	$0.28
OHIO HUB	$33.28	$33.61	$0.33
WEST INT HUB	$35.30	$35.61	$0.31
WESTERN HUB	$35.51	$35.86	$0.35

Table 34 and Table 35 show the differences in zonal load and generation-weighted average energy prices.

Table 34 PJM load-weighted, average LMP by zone: 2018, Case B to Case C 15 minute

	Load-Weighted LMP ($/Mwh)		
	Case B	Case C 15	Difference
AECO	$37.81	$38.17	$0.36
AEP	$36.65	$36.99	$0.33
APS	$38.12	$38.47	$0.35
ATSI	$37.23	$37.55	$0.31
BGE	$42.13	$42.52	$0.39
ComEd	$30.74	$31.03	$0.28
DAY	$36.44	$36.79	$0.35
DEOK	$36.12	$36.46	$0.34
DLCO	$36.95	$37.25	$0.30
Dominion	$41.06	$41.37	$0.31
DPL	$41.46	$41.59	$0.13
EKPC	$35.75	$36.10	$0.35
JCPL	$37.81	$38.11	$0.29
Met-Ed	$38.14	$38.44	$0.31
PECO	$37.55	$37.85	$0.30
PENELEC	$36.94	$37.32	$0.38
Pepco	$40.86	$41.21	$0.35
PPL	$37.40	$37.67	$0.27
PSEG	$37.34	$37.60	$0.26
RECO	$37.72	$38.08	$0.36

Table 35 PJM generation-weighted, average LMP by zone: 2018, Case B to Case C 15 minute

	Generation-Weighted LMP ($/Mwh)		
	Case B	Case C 15	Difference
AECO	$37.18	$37.42	$0.24
AEP	$33.41	$33.74	$0.33
APS	$35.26	$35.59	$0.33
ATSI	$35.95	$36.28	$0.32
BGE	$41.81	$42.17	$0.35
ComEd	$28.99	$29.26	$0.27
DAY	$38.76	$39.28	$0.52
DEOK	$33.44	$33.78	$0.34
DLCO	$35.68	$35.97	$0.29
Dominion	$40.34	$40.65	$0.30
DPL	$44.92	$45.15	$0.23
EKPC	$36.29	$36.67	$0.38
JCPL	$33.85	$34.07	$0.23
Met-Ed	$34.06	$34.35	$0.29
OVEC	$31.31	$31.63	$0.32
PECO	$34.78	$35.05	$0.27
PENELEC	$34.75	$35.16	$0.41
Pepco	$43.84	$44.25	$0.42
PPL	$35.42	$35.69	$0.27
PSEG	$34.80	$35.10	$0.30

Table 36 shows the change in reserve clearing prices between Case B and Case C 15 minute. Reserve price increases are high, but they do not more than double as in Case B or Case A to Case C.

Table 36 Monthly PJM reserve market prices: 2018, Case B to Case C 15 minute

	Reserve Weighted Average Market Clearing Prices ($/MW)					
	Case B		Case C 15		Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	$6.03	$1.43	$12.45	$5.25	$6.41	$3.82
Feb	$2.36	$0.31	$5.52	$2.18	$3.16	$1.87
Mar	$3.85	$1.94	$4.63	$1.93	$0.78	($0.01)
Apr	$4.96	$2.47	$5.48	$2.74	$0.52	$0.27
May	$3.20	$1.09	$3.43	$1.67	$0.23	$0.58
Jun	$1.29	$1.06	$2.30	$1.47	$1.01	$0.41
Jul	$1.45	$1.08	$2.77	$1.55	$1.32	$0.47
Aug	$0.81	$0.45	$2.35	$1.26	$1.54	$0.81
Sep	$1.74	$1.47	$3.07	$2.10	$1.34	$0.63
Oct	$2.38	$1.94	$4.51	$2.84	$2.12	$0.90
Nov	$1.93	$1.29	$4.47	$2.41	$2.53	$1.12
Dec	$0.95	$0.59	$4.42	$2.33	$3.47	$1.75
Annual	$2.58	$1.25	$4.66	$2.34	$2.08	$1.09

Table 37 shows that the amount of synchronized reserves cleared with the 15 minute ORDC is much less than the amount cleared with the 30 minute ORDC. The difference in primary reserves changes little.

Table 37 Monthly PJM reserve market clearing: 2018, Case B to Case C 15

	Cleared Reserve MWh							
	Case B		Case C 15		Difference		Percent Difference	
	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve	Synchronized Reserve	Primary Reserve
Jan	1,333,092.8	460,168.2	2,228,540.3	549,776.7	895,447.5	89,608.6	67.2%	19.5%
Feb	1,104,579.4	424,887.5	1,965,775.9	507,575.8	861,196.4	82,688.2	78.0%	19.5%
Mar	1,320,246.7	480,453.2	1,797,395.2	507,862.2	477,148.5	27,409.0	36.1%	5.7%
Apr	1,242,142.7	444,263.6	1,636,792.8	477,526.3	394,650.1	33,262.8	31.8%	7.5%
May	1,224,596.4	450,672.8	1,705,638.6	486,468.2	481,042.2	35,795.4	39.3%	7.9%
Jun	1,260,166.9	415,391.3	2,008,779.8	423,307.1	748,612.9	7,915.8	59.4%	1.9%
Jul	1,311,952.1	484,208.9	2,092,166.6	505,553.7	780,214.6	21,344.8	59.5%	4.4%
Aug	1,298,609.1	481,900.0	2,097,757.4	510,334.8	799,148.3	28,434.8	61.5%	5.9%
Sep	1,307,381.3	372,220.2	2,190,349.4	380,285.2	882,968.1	8,065.0	67.5%	2.2%
Oct	1,462,476.9	435,479.7	2,257,125.9	438,064.3	794,649.0	2,584.6	54.3%	0.6%
Nov	1,310,593.5	471,232.5	2,088,334.8	488,764.7	777,741.2	17,532.3	59.3%	3.7%
Dec	1,315,281.3	482,772.0	2,354,808.2	494,782.0	1,039,526.9	12,009.9	79.0%	2.5%
Total	15,491,118.8	5,403,649.7	24,423,464.6	5,770,300.8	8,932,345.8	366,651.1	57.7%	6.8%

Table 38 provides monthly and annual generator revenue by product. Total generator revenues increase by $329.3 million from Case B to Case C 15 minute.

Table 38 Monthly PJM generator revenue: 2018, Case B to Case C 15

	Revenue ($)											
	Case B				Case C 15				Difference			
	Generation	SR	PR	OpSev	Generation	SR	PR	OpRev	Generation	SR	PR	OpRev
Jan	$5,081,623,092.5	$8,041,039.6	$657,447.2	$0.0	$5,164,719,346.6	$27,737,483.1	$2,885,555.4	$13,623.1	$83,096,254.1	$19,696,443.5	$2,228,108.2	$13,623.1
Feb	$1,519,472,468.7	$2,603,153.7	$132,698.2	$0.0	$1,536,564,230.3	$10,850,811.1	$1,108,521.8	$0.0	$17,091,761.6	$8,247,657.4	$975,823.6	$0.0
Mar	$1,859,115,556.6	$5,089,052.2	$933,042.7	$0.0	$1,864,570,295.1	$8,327,706.0	$980,355.9	$0.0	$5,454,738.5	$3,238,653.7	$47,313.2	$0.0
Apr	$1,826,358,822.0	$6,159,167.4	$1,098,624.4	$0.0	$1,846,381,111.9	$8,969,897.6	$1,308,754.1	$14,835.2	$20,022,289.9	$2,810,730.2	$210,129.7	$14,835.2
May	$1,775,298,936.7	$3,915,318.4	$492,517.1	$0.0	$1,784,878,867.9	$5,846,893.8	$812,023.9	$0.0	$9,579,931.2	$1,931,575.3	$319,506.8	$0.0
Jun	$1,935,187,664.6	$1,628,149.4	$439,857.2	$0.0	$1,939,986,706.5	$4,623,571.9	$623,395.9	$0.0	$4,799,041.9	$2,995,422.5	$183,538.7	$0.0
Jul	$2,580,228,898.0	$1,907,918.9	$521,565.1	$0.0	$2,592,662,571.0	$5,800,174.5	$783,547.7	$0.0	$12,433,673.0	$3,892,255.6	$261,982.5	$0.0
Aug	$2,750,194,638.6	$1,050,710.0	$214,835.1	$0.0	$2,761,741,273.6	$4,927,006.9	$642,904.1	$0.0	$11,546,635.0	$3,876,296.8	$428,068.9	$0.0
Sep	$2,222,742,250.0	$2,271,640.2	$546,674.0	$0.0	$2,234,223,570.8	$6,730,050.8	$799,958.9	$0.0	$11,481,320.8	$4,458,410.6	$253,284.9	$0.0
Oct	$2,024,751,056.9	$3,481,601.1	$845,140.1	$0.0	$2,045,976,189.9	$10,168,382.5	$1,246,072.1	$0.0	$21,225,133.0	$6,686,781.4	$400,932.0	$0.0
Nov	$2,273,655,880.6	$2,530,961.9	$608,868.5	$0.0	$2,308,388,830.5	$9,324,641.1	$1,176,746.4	$0.0	$34,732,949.9	$6,793,679.3	$567,877.9	$0.0
Dec	$2,094,561,286.0	$1,254,060.2	$283,817.4	$0.0	$2,111,816,591.9	$10,414,915.4	$1,155,014.1	$0.0	$17,255,305.9	$9,160,855.1	$871,196.6	$0.0
Total	$27,943,190,551.2	$39,932,773.1	$6,775,087.1	$0.0	$28,191,909,586.0	$113,721,534.5	$13,522,850.2	$28,458.3	$248,719,034.8	$73,788,761.3	$6,747,763.1	$28,458.3

Table 39 shows the change in generator revenues by technology with the 15 minute ORDC. Table 40 shows the change in generator revenues per ICAP MW by technology with the 15 minute ORDC. The distribution of increased revenue across technology types is similar to the 30 minute ORDC, but the magnitudes are smaller.

Table 39 Generator revenues by technology type: 2018, Case B to Case C 15 minute

	Revenue ($)								
	Case B			Case C 15			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$148,766.5	$0.9	$0.0	$151,503.7	$305.4	$37.9	$2,737.2	$304.5	$37.9
CC	$7,759,725,631.2	$22,947,672.0	$563.7	$7,816,207,204.6	$64,143,239.3	$2,772.2	$56,481,573.4	$41,195,567.3	$2,208.5
CT Natural Gas	$888,699,914.9	$5,773,510.7	$2,003,092.8	$907,809,179.2	$16,306,920.9	$4,707,542.6	$19,109,264.3	$10,533,410.2	$2,704,449.8
CT Oil	$46,324,308.3	$1,690,138.3	$4,474,516.6	$46,794,643.1	$3,550,917.7	$8,249,808.3	$470,334.9	$1,860,779.4	$3,775,291.7
CT Other	$5,899,724.1	$11,965.6	$23,344.2	$5,949,933.6	$30,718.5	$44,295.4	$50,209.6	$18,753.0	$20,951.1
Fuel Cell	$7,469,775.2	$0.0	$0.0	$7,527,969.7	$0.0	$0.0	$58,194.5	$0.0	$0.0
Hydro	$484,669,838.3	$2,887,448.2	$104,804.6	$487,308,991.8	$6,771,463.1	$188,746.2	$2,639,153.5	$3,884,014.9	$83,941.6
Nuclear	$9,049,991,523.7	$0.0	$0.0	$9,129,040,875.8	$0.0	$0.0	$79,049,352.1	$0.0	$0.0
RICE Natural Gas	$14,189,947.6	$96,194.4	$0.0	$14,398,092.1	$277,466.1	$0.0	$208,144.5	$181,271.7	$0.0
RICE Oil	$1,457,402.1	$2,056.5	$104,177.5	$1,454,166.1	$5,956.4	$192,180.2	($3,236.0)	$3,899.9	$88,002.7
RICE Other	$53,295,887.4	$505,299.9	$57,816.4	$53,638,706.8	$999,598.8	$105,214.4	$342,819.4	$494,299.0	$47,398.0
Solar	$66,827,029.5	$0.0	$0.0	$66,845,393.9	$0.0	$0.0	$18,364.4	$0.0	$0.0
Steam Coal	$8,410,313,995.3	$5,163,185.9	$6,771.2	$8,489,007,895.6	$19,217,436.0	$32,253.0	$78,693,900.3	$14,054,250.1	$25,481.8
Steam Natural Gas	$271,573,014.0	$587,459.2	$0.0	$274,847,880.8	$1,847,087.4	$0.0	$3,274,866.7	$1,259,628.2	$0.0
Steam Oil	$40,052,929.0	$40,336.8	$0.0	$40,595,454.0	$136,886.7	$0.0	$542,525.1	$96,549.9	$0.0
Steam Other	$230,868,650.2	$226,751.1	$0.0	$232,480,068.2	$432,362.9	$0.0	$1,611,418.0	$205,611.8	$0.0
Wind	$611,688,031.0	$0.0	$0.0	$617,855,871.3	$0.0	$0.0	$6,167,840.3	$0.0	$0.0
Total	$27,943,196,368.3	$39,932,019.4	$6,775,087.1	$28,191,913,830.5	$113,720,359.2	$13,522,850.2	$248,717,462.2	$73,788,339.8	$6,747,763.1

Table 40 Generator revenues per ICAP MW by technology type: 2018, Case B to Case C 15 minute

	Revenue ($/MWh)								
	Case B			Case C 15			Difference		
	Generation	SR	PR	Generation	SR	PR	Generation	SR	PR
Battery	$3,719.16	$0.02	$0.00	$3,787.59	$7.64	$0.95	$68.43	$7.61	$0.95
CC	$161,695.31	$478.18	$0.01	$162,872.26	$1,336.60	$0.06	$1,176.95	$858.42	$0.05
CT Natural Gas	$35,493.90	$230.59	$80.00	$36,257.11	$651.28	$188.02	$763.21	$420.70	$108.01
CT Oil	$11,688.61	$426.46	$1,129.02	$11,807.29	$895.97	$2,081.60	$118.68	$469.51	$952.59
CT Other	$132,876.67	$269.50	$525.77	$134,007.51	$691.86	$997.64	$1,130.85	$422.36	$471.87
Fuel Cell	$248,992.51	$0.00	$0.00	$250,932.32	$0.00	$0.00	$1,939.82	$0.00	$0.00
Hydro	$60,032.93	$357.65	$12.98	$60,359.82	$838.74	$23.38	$326.89	$481.09	$10.40
Nuclear	$259,519.54	$0.00	$0.00	$261,786.38	$0.00	$0.00	$2,266.84	$0.00	$0.00
RICE Natural Gas	$117,856.71	$798.96	$0.00	$119,585.48	$2,304.54	$0.00	$1,728.77	$1,505.58	$0.00
RICE Oil	$6,344.81	$8.95	$453.54	$6,330.72	$25.93	$836.66	($14.09)	$16.98	$383.12
RICE Other	$147,642.22	$1,399.80	$160.17	$148,591.91	$2,769.13	$291.47	$949.69	$1,369.33	$131.30
Solar	$48,151.96	$0.00	$0.00	$48,165.20	$0.00	$0.00	$13.23	$0.00	$0.00
Steam Coal	$130,644.23	$80.20	$0.11	$131,866.65	$298.52	$0.50	$1,222.42	$218.32	$0.40
Steam Natural Gas	$27,083.90	$58.59	$0.00	$27,410.51	$184.21	$0.00	$326.60	$125.62	$0.00
Steam Oil	$17,459.86	$17.58	$0.00	$17,696.36	$59.67	$0.00	$236.50	$42.09	$0.00
Steam Other	$194,252.12	$190.79	$0.00	$195,607.97	$363.79	$0.00	$1,355.84	$173.00	$0.00
Wind	$67,824.41	$0.00	$0.00	$68,508.31	$0.00	$0.00	$683.89	$0.00	$0.00
Total	$133,665.02	$191.01	$32.41	$134,854.75	$543.98	$64.69	$1,189.73	$352.96	$32.28

To estimate the increase in carbon dioxide emissions due to the ORDC, the emissions rate for each technology, as calculated by the EIA, is multiplied by a generic heat rate for the technology and the simulated MWh of energy.[8] Table 41 provides the estimated increase in CO_2 emissions in short tons.

Table 41 Estimated emissions increase: 2018, Case B to Case C 15 minutes

	CO2 Rate (lbs/MMBtu)	Heat Rate (MMBtu/MWh)	CO2 Rate (tons/MWh)	CO2 Case B (tons)	CO2 Case C 15 (tons)	CO2 Difference (tons)
Battery						
CC	117.00	7.5	0.44	99,811,925	99,674,572	(137,353)
CT Natural Gas	117.00	11.0	0.64	11,023,488	11,229,780	206,291
CT Oil	161.30	13.0	1.05	246,259	245,507	(752)
CT Other	117.00	11.0	0.64	106,222	106,210	(12)
Fuel Cell						
Hydro						
Nuclear						
RICE Natural Gas	117.00	11.0	0.64	205,511	208,057	2,546
RICE Oil	161.30	13.0	1.05	9,586	9,603	17
RICE Other	117.00	11.0	0.64	947,615	947,331	(284)
Solar						
Steam Coal	210.20	11.0	1.16	271,043,498	270,982,403	(61,095)
Steam Natural Gas	117.00	11.0	0.64	3,309,329	3,330,236	20,907
Steam Oil	161.30	11.0	0.89	287,795	288,846	1,050
Steam Other	117.00	11.0	0.64	4,074,738	4,073,092	(1,646)
Wind						
Total				386,991,227	387,022,544	31,317

[8] Carbon Dioxide Emissions Coefficients, Energy Information Administration, <https://www.eia.gov/environment/emissions/co2_vol_mass.php>, accessed May 9, 2019.