SPP Southwest Power Pool
MARKET MONITORING UNIT

Virtual activity during the 2021 winter weather event: An analysis

Version 2 published

September 13, 2022

Note: Version 2 of this report corrects Figure 4-7, which originally showed a repeat of data from Figure 4-6, and provides enhanced language to describe the data in Figure 4-7.

TABLE OF CONTENTS

LIST OF FIGURES

1 OVERVIEW AND RECOMMENDATIONS

During the winter weather event, occurring between February 10 and February 21, 2021, virtual transactions in SPP's Integrated Marketplace netted over $412 million in profit for a total for over $425 million for the month of February. This figure is nearly six times the total *annual* virtual profit for 2020.[1] In light of the unprecedented level of profitability, the Market Monitoring Unit (MMU) sought to:

1) identify what drove virtual profitability;
2) determine if and to what extent virtual transactions provided positive and/or negative impacts to the integrated marketplace during the winter weather event; and
3) provide insights and recommendations into any potential market considerations or learnings related to virtual trading during exceptional grid events.

Toward those ends, we conducted a comparative financial analysis of virtual transactions during two different time frames: the entire month of February versus December, January, March, and April, hereto referred to as the comparable months, and for the duration of the winter weather event and its equivalent 12-day windows in December, January, March, and April.[2] After a preliminary examination of the data, we modified the scope of the study to include a special focus on virtual transactions placed at interface settlement locations since those positions represented a significant change in virtual trading behavior from comparable time periods and were responsible for a disproportionate amount of the total profit compared to their total volume.

---

[1] SPP Market Monitoring Unit Annual State of the Market Report 2020, p. 68, available at https://www.spp.org/documents/65161/2020 percent20annual percent20state percent20of percent20the percent20market percent20report.pdf

[2] December 9-20, 2020, January 13-24, 2021, March 10-21, 2021, and April 14-25, 2021 represent 12 day periods, mid-month, running Wednesday through Sunday to mimic the winter weather event timeframe in February.

Our analysis also included re-running the market two different ways: without any virtual positions and without any virtual positions at interchange settlement locations. We conducted these re-runs for the five most profitable days (February 15-19) of the winter weather event and five other days with more typical grid conditions during the same month as a comparison (February 2, 3, 4, 27, and 28). We used the results of these re-runs to perform a modified benefit-cost analysis to measure what impact virtual transactions had on price convergence and total production cost[3] compared to their total net profit during relatively normal grid conditions versus the winter weather event to determine, among other things, if these impacts are similar or demonstrate diminishing or increasing returns as prices and scarcity increase. We focused on price convergence and production costs in particular because the most value from virtual trading is derived by their "…potential to converge day-ahead and real-time market prices, and improve day-ahead unit commitment decisions."[4][5] However, the results of the re-runs revealed that virtual transactions had broader impacts that likely affected the overall efficiency of the market. As such, we went further and looked at the impact virtual transactions had on total market convergence (bringing the day-ahead market closer to real-time beyond price convergence) as well.

---

[3] A. Long and A. Giacomoni, "Exploring the Impacts of Virtual Transactions in the PJM Wholesale Energy Market," 2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1-5, doi: 10.1109/PESGM41954.2020.9282166.

[4] SPP Market Monitoring Unit Annual State of the Market Report 2020, p. 64, available at https://www.spp.org/documents/65161/2020 percent20annual percent20state percent20of percent20the percent20market percent20report.pdf

[5] While in some markets they are also a valuable hedging tool for market participants with physical resources and load, the majority of market participants trading virtual transactions in SPP are financial-only, speculative players.

1.1 HIGH LEVEL FINDINGS AND RECOMMENDATIONS

Key takeaways from our analysis include:

- **Virtual transactions were abnormally profitable despite dropping significantly in volume**
  - Virtual transactions netted just over $412 million during the 10 days of the winter weather event despite a significant drop in total volume (45 percent decrease) and cleared volume (35 percent decrease). Around 90 percent of the profit can be attributed to transactions cleared between February 15 and 19 when profits stayed, on average, over $1,000/MWh.
- **Virtual Transactions shifted significantly**
  - The majority of virtual transaction volume and profit came from virtual offers placed and cleared at interchange locations. This is a marked shift in virtual trading behavior, which typically occurs primarily at resource settlement locations, particularly at wind resource settlement locations.
- **Virtual transactions were costly to the market and their benefits were less cost-effective**
  - While virtual transactions did aid price convergence in both periods, proportionately the effect was muted and not cost-effective during the winter weather event.
  - Virtual transactions lowered production costs during the comparison days while significantly raising production costs during the winter weather event, largely due to higher prices and virtual transactions. On net, having a *positive* overall cost to the market due to lower volumes of cleared virtual bids compared to virtual offers and a shift in where virtual transactions were placed.
  - Virtual transactions did displace more costly physical megawatts during both re-run periods; however, during the winter weather event, it cost the market $736 in virtual cost per megawatt hour of physical energy displaced equating to $2 in

virtual cost to displace every $1 of physical energy cost. During the comparison days, virtual transactions *paid* the market $68 for every megawatt hour of physical energy displaced, equating to -$7 for every $1 of energy cost displaced.

- Virtual transactions also increased market efficiency by increasing overall convergence between the day-ahead and real-time markets. However, for every $1 in market convergence, the market paid virtual transactions $12 in profit during the winter weather event versus $0.43 in profit per $1 in market convergence during the comparison days. This indicates that during the winter weather event, the positive effect of virtual transactions on market convergence was not worth the cost.

Based on our findings, the MMU recommends the following:

- **The RTO and SPP members should consider suspending virtual trading during scarcity events.** Data from the winter weather event suggests that while virtual transactions still aid in price and overall market convergence, they are no longer cost-effective when day-ahead prices exceed the $1,000/MWh offer cap;
- **The RTO and/or MMU should conduct further analysis to determine the level of average day-ahead prices, price spreads, and virtual volume to load ratios where virtual transactions typically no longer become a cost-effective tool for aiding price and market convergence.**
- **The RTO and SPP members should consider studying how violation relaxation limits interact with the profitability and cost-effectiveness of virtual transactions under different levels of scarcity.**
- **The RTO should partner with our member load-serving entities to research potential reasons real-time load deviated from net load forecast during the winter weather event and during other times when the system was experiencing stress.**

1.2 OUTLINE

The paper is organized as follows. Chapter 2 provides an overview of virtual activity from December 2020 through April 2021 and for the duration of the winter weather event and its equivalent 12-day windows in December, January, March, and April. The metrics provided mimic some included in the Annual State of the Market Report published by the MMU. Chapter 3 examines virtual trading during the winter weather event at interface settlement locations to provide a closer look at how market participants' virtual behavior changed and how this drove overall virtual profitability. Chapter 4 details the results of the market reruns we conducted and provides an assessment of the impact virtual positions had on price convergence, total production cost, and total market convergence. Finally, chapter 5 provides a brief discussion on our conclusions and recommendations based on the findings of this study.

2 OVERVIEW OF VIRTUAL ACTIVITY

To provide a baseline for comparison and demonstrate the extent of change in virtual activity and degree of profitability, we began our study by calculating metrics on virtual activity similar to those reported in the Annual State of the Market report.[6]

2.1 VIRTUAL VOLUME

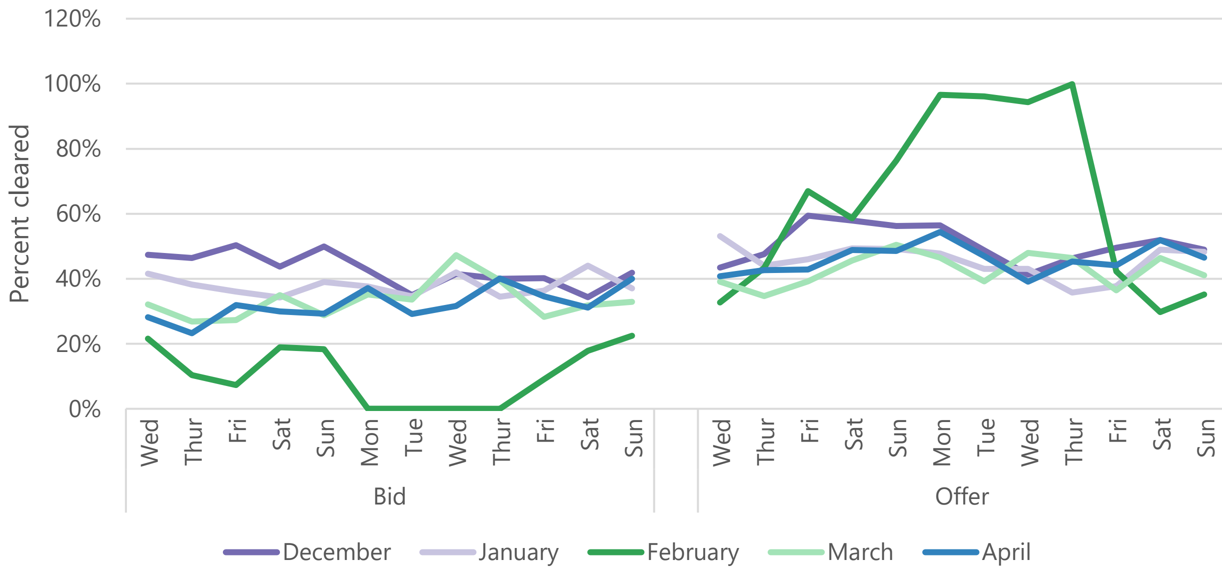
One of the main value propositions of virtual transactions lies in their potential to help converge day-ahead and real-time prices. To have this desired impact, virtual volume has to be large enough relative to the size of the market. During the winter weather event, there were substantial decreases in *total* virtual volume and total cleared virtual volume. Average daily bid and offer volumes decreased by 9 percent and 34 percent, respectively, in February versus the comparable months, for a total average decrease in daily virtual volume of 24 percent. During the winter weather event, average daily bids and offers decreased by and by 27.8 percent and 63.5 percent, respectively versus the equivalent 12-day windows, for a total average decrease in virtual volume of 49 percent. The decrease in volume was concentrated between February 15 and February 19.

Cleared volume followed the same pattern. During the 12 day winter weather event, average daily *cleared* virtual volume decreased 35 percent compared to the equivalent windows in comparable months. This decrease was driven primarily by a decrease in the volume of cleared virtual bids, though the volume of cleared virtual offers also decreased. Between February 15 and February 18, almost no virtual bids cleared. This was no doubt due to generation being extremely tight, with a large number of megawatts offline due to lack of fuel and/or weather-driven equipment failures.

---

[6] SPP Market Monitoring Unit Annual State of the Market Report 2020, Section 2.8, available at https://www.spp.org/documents/65161/2020 percent20annual percent20state percent20of percent20the percent20market percent20report.pdf

Figure 2-1 Percent of cleared bids and offers – winter weather event (February) vs equivalent weeks



As a percent of real-time load, virtual transactions averaged around 19 percent during 2020, a figure that has steadily increased since virtual trading began in 2014.[7] In the comparable months, cleared virtual transactions represented 26 percent of real-time load. This metric decreased 45 percent in February to 14.4 percent and decreased 21 percent to 20.6 percent during the winter weather event.

[7] SPP Market Monitoring Unit Annual State of the Market Report 2020, p. 65, available at https://www.spp.org/documents/65161/2020 percent20annual percent20state percent20of percent20the percent20market percent20report.pdf

Figure 2-2 Virtual transactions as a percent of real-time load

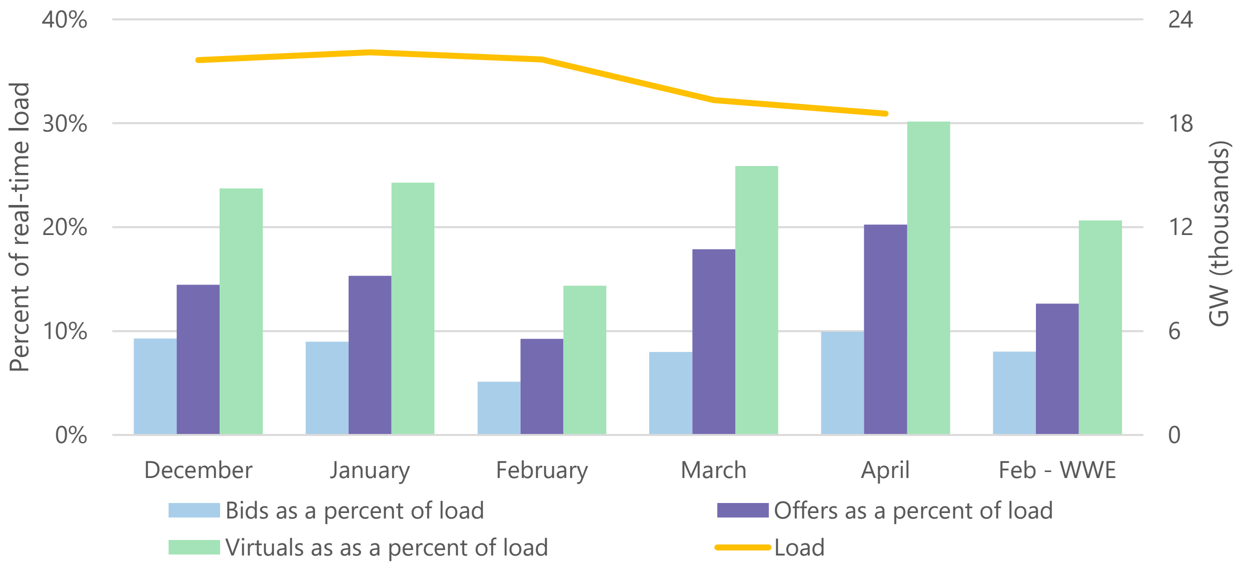
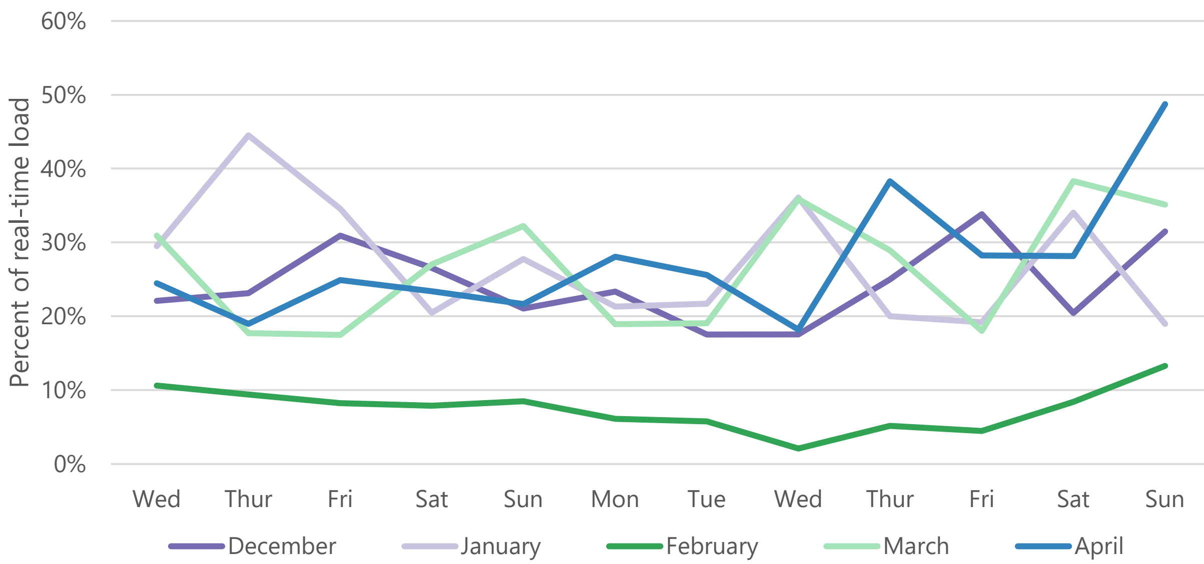


Figure 2-3 Virtual transactions as a percent of real-time load – winter weather event (February) versus equivalent weeks



2.2 VIRTUAL PROFITABILITY

The main impetus of this study was the increased level of virtual profitability in the month of February. As shown in Figure 2-4, virtual profit for February 2021 dwarfed profit totals from all other months despite a significant, single month drop off in total virtual volume. Totaling over

$425 million, virtual profit in February 2021 was nearly 6 times higher than the *annual* total virtual profit in 2020.

About 97 percent of the $425 million came from transactions cleared during the 12-day window of the winter weather event, with the most profitable days falling between February 15 and 19. During these 5 days, profit exceeded $1,000/MWh, topping out at $3,200/MWh on February 18. As a basis for comparison, 2020 saw an average profit per megawatt of $0.63, with the most profitable month seeing a per megawatts profit of $3.

Figure 2-4 Monthly virtual profit trends

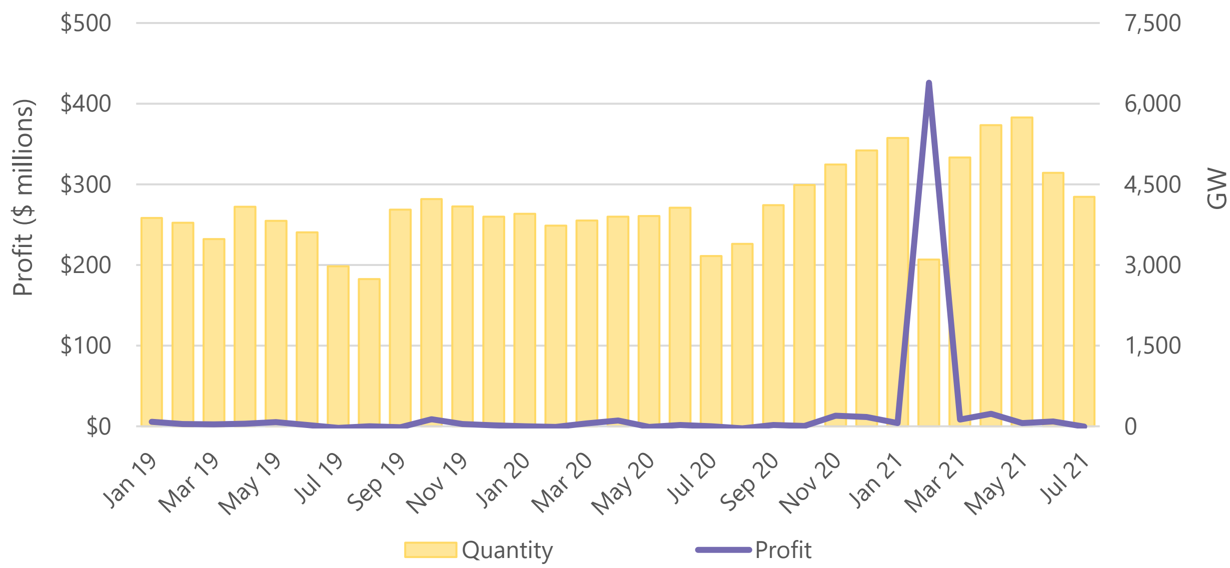
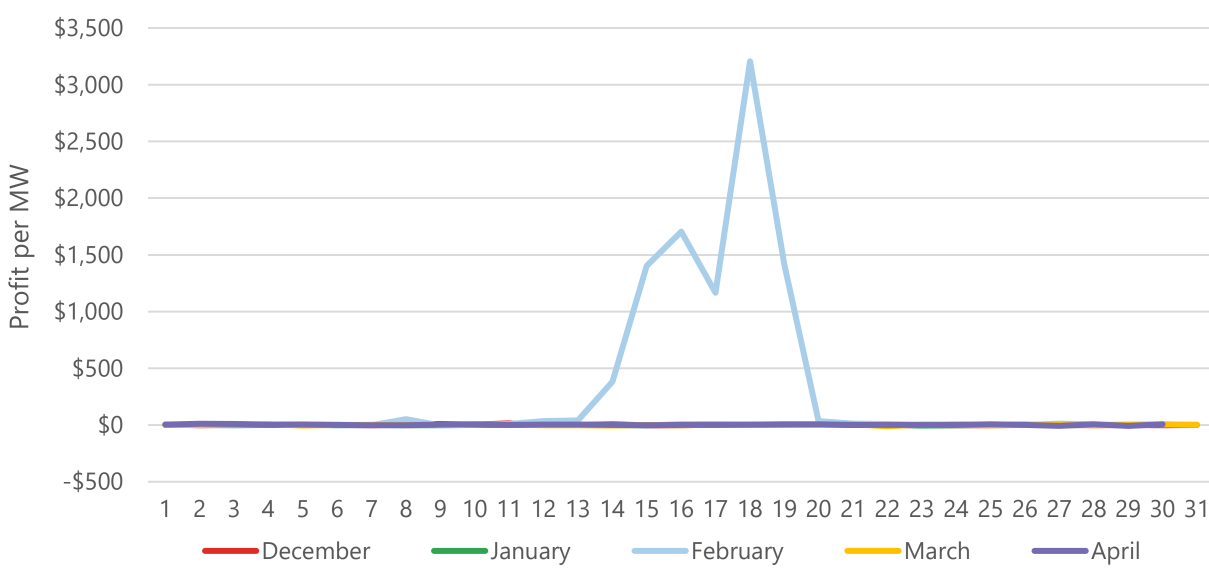


Figure 2-5 Average profit per megawatt by day – monthly comparison



Virtual profitability was not consistent across the market, but concentrated at specific settlement location types. In February, average profit per megawatt was highest at interface and hub settlement locations at $484 per megawatt and $152 per megawatt, respectively. Looking specifically at the winter weather event window, these figures jump to over $700 per megawatt on average. While relatively close in profitability during the winter weather event, cleared virtual transactions at interface locations dwarfed those at hubs in total volume, accounting for 40 percent of all virtual megawatts versus only 11 percent at hubs. Thus, while both contributing to the increased per-unit profitability seen during the winter weather event and February more generally, the majority of the $425 million in virtual profit came from positions placed at interface locations.

Figure 2-6 Profit and volume comparison by settlement location type

February

Location type	Quantity (MW)	Profit	Profit per MW	Percent volume	Average percent volume
Hub	401,074	$61,085,727	$152.31	13%	13%
Interface	484,422	$234,462,935	$484.01	16%	8%
Load	546,368	$26,515,807	$48.53	18%	18%
Resource	1,666,829	$103,894,998	$62.33	54%	62%

Winter weather event

Location type	Quantity (MW)	Profit	Profit per MW	Percent volume	Average percent volume
Hub	83,788	$58,854,121	$702.42	11%	13%
Interface	297,665	$233,817,124	$785.50	40%	8%
Load	110,671	$23,529,545	$212.61	15%	18%
Resource	255,446	$96,757,525	$378.78	34%	62%

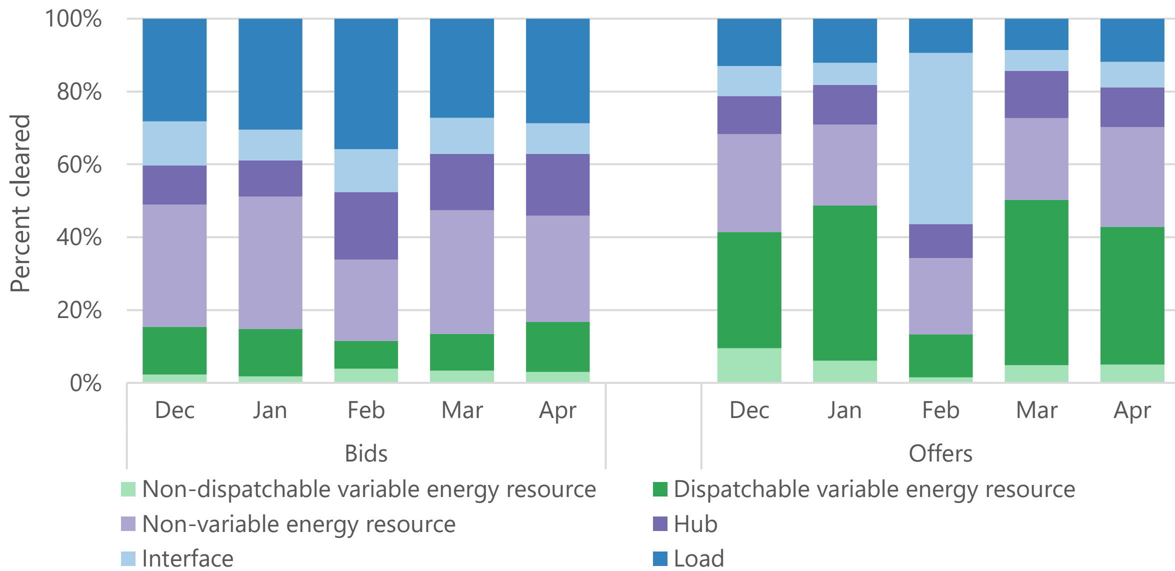
2.3 PARTICIPANT AND LOCATIONAL TRENDS

Generally speaking, who participated in virtual trading in February and during the winter weather event didn't change. In all time periods examined, financial only market participants accounted for more than 90 percent of virtual trading volume and up to 99 percent during some periods. This is consistent with past trends as virtual transactions are predominantly a tool for financial speculation versus hedging physical positions. The percent of bids and offers cleared, however, did change dramatically for some participants. Most market participants saw a 25 percent to 50 percent decrease in the percent of their bids that cleared in February and a five percent decrease to 10 percent increase in the percent of their offers that cleared in February compared to what cleared on average during the comparable months.[8] During the winter weather event, the majority of market participants saw a 50 percent to 85 percent decrease in the percent of their bids that cleared in February and a five percent decrease to 45 percent increase in the percent of their offers that cleared in February versus the percent that cleared on average during the comparable months. This is on top of the decreased volume of bids and offers placed during these periods.

During the winter weather event, the proportion of cleared virtual transactions by settlement location type changed, in some cases significantly so, compared to the equivalent weeks in comparable months. For both bids and offers, fewer megawatts cleared at non-variable energy resource (primarily wind) locations. For bids, this decrease was matched by an increase in megawatts cleared at hub locations. For offers, the most significant changes were a decrease in megawatts cleared at dispatchable variable energy resource locations and a very large increase at the megawatts cleared at interface locations.

[8] These statistics were calculated based on a subset of market participants who consistently placed bids or consistently placed offers across the December 2020 – April 2021 period (at least one megawatt each month).

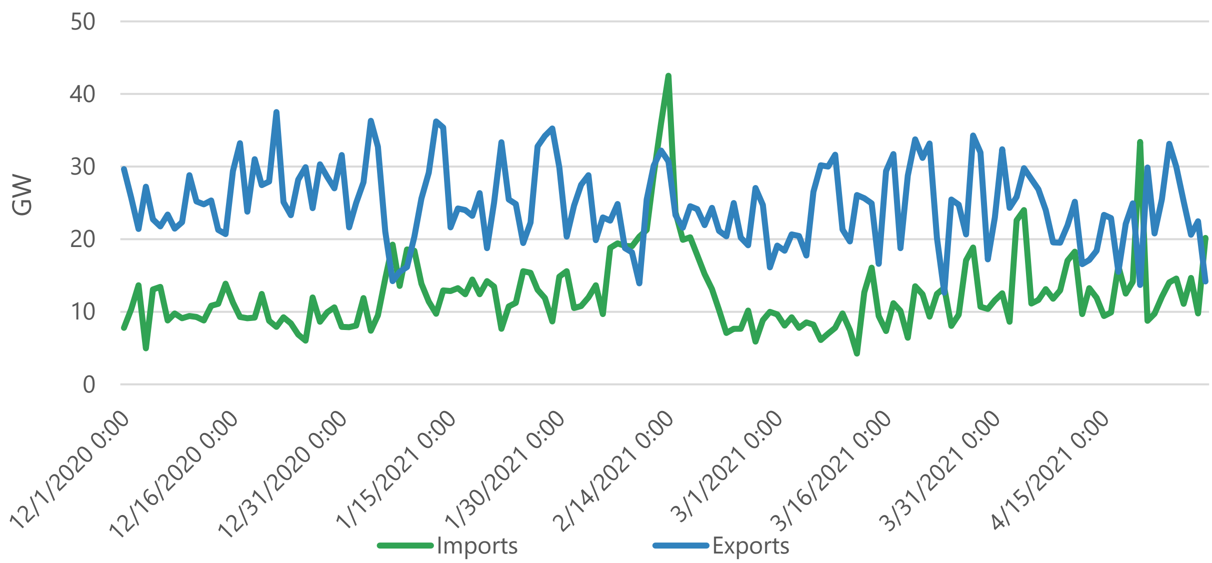
Figure 2-7 Proportion of cleared virtual transactions by settlement location type – winter weather event comparison



Taking a closer look at aggregate settlement location types, during the comparable months, cleared virtual transactions at resource settlement locations represented the greatest proportion of total cleared volume followed by load, hub, and interface locations (60 percent, 18 percent, 13 percent, and eight percent, respectively). In February and the winter weather event, cleared volume increased precipitously at interface locations. During the winter weather event, 40 percent of cleared virtual positions were at interface locations versus 16 percent for the month of February overall. These virtual transactions represented an increase of 100 percent for February and a 500 percent increase during the winter weather event compared to comparable periods. A corresponding decrease in cleared volume at resource locations (34 percent during the winter weather event versus 54 percent for the full month of February) illustrates a significant shift in how market participants constructed their virtual portfolios, particular to the winter weather event.

Given the conditions during the winter weather event, this shift in virtual volume and cleared virtual volume makes sense. With much of SPP's generating capacity on forced outage, the remainder fully committed, and a large quantity of power flowing into the market in the form of imports (creating the rare situation where SPP was a net importer of power rather than exporter overall on February 14, 15, and 16; see Figure 2-8), the best opportunity for financial arbitrage – the primary use of virtual transactions in SPP – would be along the seams at interface settlement locations. This is further supported by the fact that nearly all of the virtual positions at interface settlement locations were held by financial only market participants.

Figure 2-8 Daily imports versus exports



3 VIRTUAL ACTIVITY AT INTERFACES

Based on the preliminary findings regarding the importance of virtual transaction activity at interface locations during the winter weather event, the MMU decided to examine these positions and their impact more closely. This section examines the types of transactions (bids and offers) placed versus cleared, where precisely they were placed, and by whom.

3.1 VOLUME SHIFTS

The change in virtual profitability was not just an artifact of system conditions; during the winter weather event, it is clear that market participants shifted their behavior significantly to favor positions – particularly offers – at interchange locations. Virtual positions at interchange locations averaged six percent of total virtual volume in comparable months versus 10 percent in February. This was driven by virtual offers which represented 15 percent of all offered virtual volume in February, a near three-fold increase versus comparable months.

Figure 3-1 Virtual volume by settlement location type

Total virtuals	Hub		Interface		Load		Resource		Interface percent of total
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	1,090,840	—	726,787	—	1,830,717	—	7,573,87	—	6%
Jan	1,341,994	+23%	665,424	-8%	2,102,840	+15%	8,313,751	+10%	5%
Feb	1,076,492	-20%	882,217	+33%	1,494,551	-29%	5,421,598	-35%	10%
Mar	1,663,109	+54%	659,565	-25%	1,562,311	+5%	9,129,394	+68%	5%
Apr	1,587,826	-5%	847,693	+29%	1,989,041	+27%	9,950,480	+9%	6%

Total bids	Hub		Interface		Load		Resource		Interface percent of load
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	471,720	—	309,749	—	1,046,308	—	2,944,586	—	6%
Jan	554,813	+18%	252,194	-19%	1,237,284	+18%	2,973,596	+1%	5%
Feb	568,837	+3%	213,303	-15%	1,026,377	-17%	2,485,143	-16%	5%
Mar	663,230	+17%	214,375	+1%	803,530	-22%	3,203,885	+29%	4%
Apr	761,104	+15%	276,279	+29%	1,090240	+36%	3,879,492	+21%	5%

Total offers	Hub		Interface		Load		Resource		Interface percent of load
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	619,121	—	417,041	—	784,409	—	4,629,293	—	6%
Jan	787,181	+27%	413,230	-1%	865,556	+10%	5,340,156	+15%	6%
Feb	507,655	-36%	668,914	+62%	468,174	-46%	2,936,455	-45%	15%
Mar	999,878	+97%	445,190	-33%	758,781	+62%	5,925,509	+102%	5%
Apr	826,722	-17%	571,414	+28%	898,801	+18%	6,070,988	+2%	7%

Nearly the same pattern remained true looking only at cleared virtual volume. Driven by a 60 percent increase in cleared virtual offers, total cleared virtual volume at interchange locations went up 18 percent overall compared to January. The proportion of all cleared virtual positions and cleared virtual offers held at interchange locations were 16 percent and 20 percent, respectively, double the average proportion cleared at interchange locations in comparable months.

Figure 3-2 Cleared virtual volume by settlement location type

Cleared virtuals	Hub		Interface		Load		Resource		Interface percent of total
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	567,333	—	477,117	—	1,048,440	—	3,033,742	—	9%
Jan	638,532	+13%	416,959	-13%	1,063,463	+1%	3,243,750	+7%	8%
Feb	404,502	-37%	490,067	+18%	561,399	-47%	1,660,207	-49%	16%
Mar	703,133	+74%	341,509	-30%	681,716	+21%	3,275,389	+97%	7%
Apr	744,636	+6%	492,200	+44%	909,753	+33%	3,451,294	+5%	9%

Cleared bids	Hub		Interface		Load		Resource		Interface percent of load
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	230,444		224,828		655,351		925,932		11%
Jan	229,963	-0%	166,135	-26%	655,351	0%	928,593	+0%	8%
Feb	179,671	-22%	87,502	-47%	372,653	-43%	469,354	-49%	8%
Mar	239,995	+34%	137,105	+57%	379,872	+2%	787,849	+68%	9%
Apr	336,393	+40%	164,550	+20%	503,850	+33%	838,977	+6%	9%

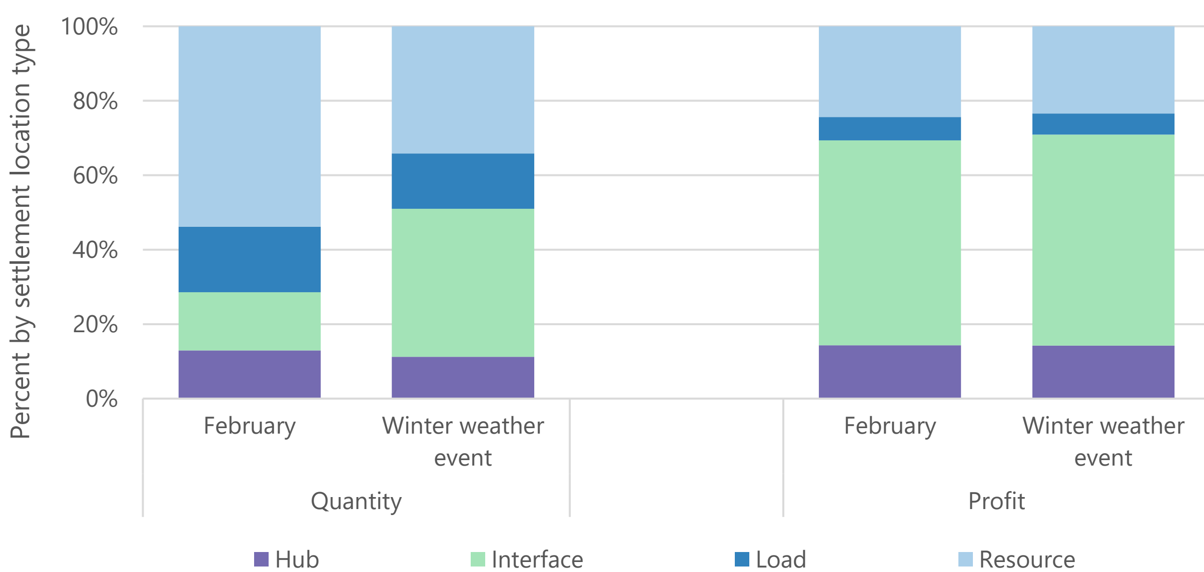
Cleared offers	Hub		Interface		Load		Resource		Interface percent of load
	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	MW	Change from prior month	
Dec	336,889		252,288		421,672		2,107,811		8%
Jan	408,569	+21%	250,824	-1%	408,112	-3%	2,315,156	+10%	7%
Feb	224,831	-45%	402,565	+60%	188,747	-54%	1,190,853	-49%	20%
Mar	463,138	+106%	204,404	-49%	301,844	+60%	2,487,540	+109%	6%
Apr	408,243	-12%	327,650	+60%	405,903	+34%	2,612,317	+5%	9%

The increase in total volume and cleared volume at interface locations coupled with an overall decrease in virtual transaction volume in February indicates market participants did not add these positions to their portfolios but fundamentally shifted their virtual behavior to favor interface locations. This is confirmed looking at market participant level data. Only 3,000 MWhs worth of virtual positions came from market participants who had not taken positions at interface locations in previous months. The remaining volume came from market participants that held virtual offer positions at interface locations in previous months, with half decreasing their offer volume and half increasing their offer volume, for an average increase in volume offered around 400 percent. The largest positions were held by market participants who increased their volume over January by over 1,000 percent.

3.2 INTERFACE VIRTUAL TRANSACTION PROFITABILITY

As demonstrated above, the unusually high profitability of virtual transactions was not consistent across the system, but highly concentrated at interface and hub settlement locations in particular. However, while hubs and interface settlement locations saw similar levels of average profitability per megawatt during the winter weather event (over $700/MWh in both cases), the differences in cleared volumes indicated virtual transactions at interface locations made up a disproportionate amount of total virtual profitability (see Figure 3-3 below). While accounting for only 16 percent of the total cleared megawatts, virtual transactions at interchange locations netted 55 percent of all profit. This was driven primarily by the winter weather event, where virtual transactions at interface locations accounted for 40 percent of the total cleared megawatts and 57 percent of all profit. Fourteen of these settlement locations (about 67 percent of total interchange virtual transaction volume) saw average profits exceed $1,000/MWh for the duration of the winter weather event. The majority of the profitability stemmed from virtual offers in particular.

Figure 3-3 Proportion of virtual volume versus profitability by settlement location type



3.3 INTERFACE LOCATIONS

Looking at just the highest volume of virtual transactions at interface settlement locations, the majority saw an overall increase in virtual offers in February[9] with PJM and MISO seeing the greatest total volume as well as greatest increase in volume. Key exceptions were interface locations with ERCOT, at SOCO, and at MCWEST.

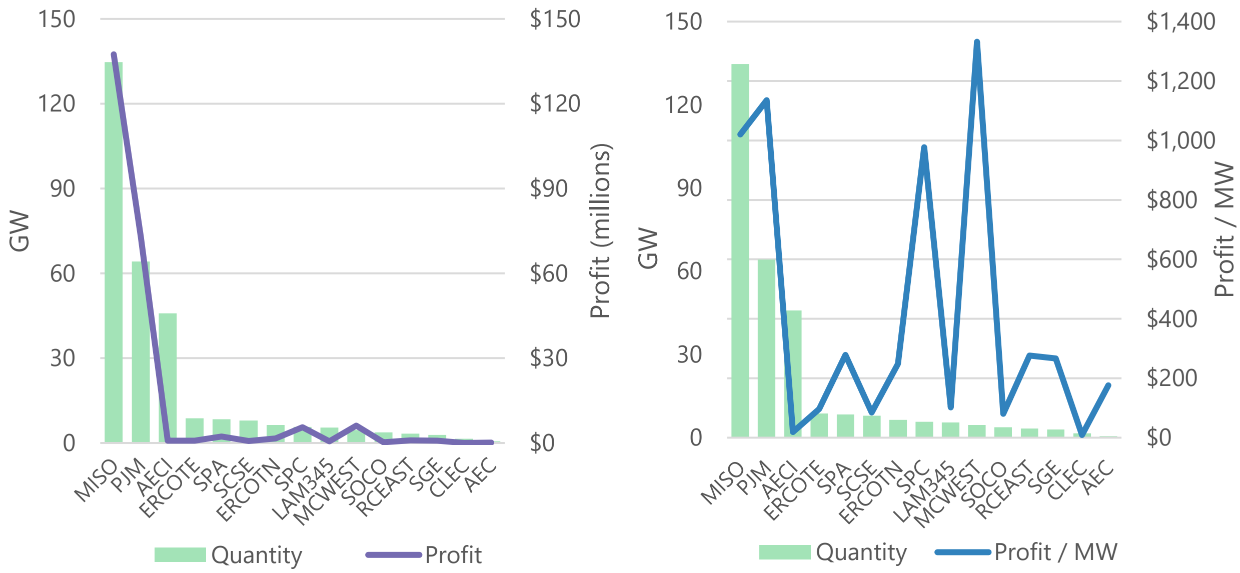
Figure 3-4 Change in offers and cleared offers by major interface settlement location

February offers				February cleared offers			
Interface	MW	Change from prior month		MW	Change from prior month	Percent of total cleared	Change from prior month
AECI	196,225	+0%	AECI	81,712	-23%	42%	-24%
ERCOTE	5,0128	-34%	ERCOTE	2,679	-58%	53%	-37%
ERCOTN	8,715	-32%	ERCOTN	5,538	-55%	64%	-34%
LAM345	17,536	+45%	LAM345	14,124	+38%	81%	-5%
MCWEST	7,125	-8%	MCWEST	2,600	-64%	36%	-61%
MISO	125,544	+329%	MISO	98,196	+401%	78%	+17%
PJM	36,943	+26,157%	PJM	36,901	+209,077%	100%	+697%
RCEAST	10,683	+62%	RCEAST	4,783	-23%	45%	-52%
SCSE	22,462	+88%	SCSE	12,872	+98%	57%	+5%
SGE	11,128	+511%	SGE	7,087	+685%	64%	29%
SOCO	699	-24%	SOCO	219	+410%	31%	+571%
SPA	12,748	+10%	SPA	9,861	+33%	77%	+21%
SPC	7,450	+645%	SPC	2,913	+1,954%	39%	+176%

Volume and unit profitability during the winter weather event were not necessarily correlated. Though MISO and PJM had the highest volumes and near highest per megawatt profitability rate, the correlation breaks down from there; the most profitable locations on a per megawatt basis had some of the smallest volumes.

[9] Here we only look at offers since we have already determined bids decreased in February and played an insignificant roll in overall virtual profitability.

Figure 3-5 Profit and profit per megawatt by major interface settlement location



This lines up with what actually happened during the winter weather event to alleviate shortages within SPP's footprint. As shown in Chapter 2 (Figure 2-8), SPP switched from being a net exporter to a net importer of power for three days during the winter weather event. For the remaining days, the gap between imports and exports were narrower than usual, with SPP importing much more power, particularly during peak hours.

4 MARKET RERUNS: IMPACT OF VIRTUAL TRADING ON MARKET EFFICIENCY

Virtual transactions are considered a valuable product in integrated electric markets for their ability to provide liquidity and ultimately enhance the accuracy of price formation in the day-ahead market. This, in turn, promotes price convergence between the day-ahead and real-time markets. By displacing physical generation in day-ahead, virtual transactions also influence total production cost vis-à-vis unit commitments, the cost of energy, and so on. We utilized market re-runs to determine to what extent, if any, virtual transactions provided these benefits or imposed any related costs to the market under the extreme grid conditions of the winter weather event and whether the extent of the benefit(s) and/or cost(s) were greater or lesser compared to days with normal operating conditions.

Based on results from the market re-runs, we expanded our analysis to look at all aspects of production cost and pricing to determine the impact of virtual transactions on broader market convergence (bringing the day-ahead market closer to real-time). This included looking at how virtual transactions influenced price in conjunction with both injection (energy, virtual offers, imports, ancillary services) and withdrawal (load, exports, virtual bids) quantities in the day-ahead market to determine if they brought the day-ahead market closer to the real-time market.

4.1 SCENARIOS

To analyze the aforementioned benefits of virtual transactions during the winter weather event, the MMU conducted re-runs on the five most profitable days for virtual transactions, February 15-19, and for February 2, 3, 4, 27, and 28 to serve as a basis of comparison. The first re-run was a control case with no market changes to ensure the integrity of the re-run engine itself on each day. For the second scenario, only re-run during the winter weather event days, we removed virtual transactions at interface settlement locations so we could determine what proportion of the total impact virtual transactions had can be attributed to these specific transactions. For the third and final scenario, we removed all virtual transactions in order to measure their full impact on price convergence and total production cost. In the two latter scenarios, all offers and other inputs were held constant; the only change to the day-ahead market run was to remove interface, and then all, virtual transactions from the market, respectively.

For the purposes of this study, we had to make assumptions/modifications to make an analysis of the re-runs feasible and defendable:

- We exclude reliability unit commitment and real-time effects, assuming they are negligible. While we acknowledge that the removal of virtual transactions could lead to changes in unit commitments which, in turn, could affect real-time production costs, make-whole payments, etc., estimating these effects would require us to make an assumption about the decisions SPP's operators would make during reliability unit commitment and real-time in response to conditions that are theoretical. We do not believe such assumptions would provide solid analytical grounds upon which we could estimate reliability unit commitment and real-time effects. In addition, because most, and sometimes all, units that could be committed were committed during many periods of the winter weather event, the opportunity for changes in unit commitments and make-whole payments were likely extremely small and hence, their costs and benefits small compared to total system costs.
- We do not assume any substitution effects made by market participants in the day-ahead market resulting from the removal of virtual transactions. After exploring several theories on what drove virtual trading behavioral changes and examining which market participants were active in virtual trading during the winter weather event, it became clear that virtual trading was primarily speculative. **As such, the only change we made was removing virtual transactions from the market, as it is likely we would not expect to see other behaviors / transactions to arise as a substitute in lieu of virtual transactions.**
- On February 18, generation was so tight that removing virtual transactions from the market led the market software to clear a significantly less amount of demand – 38,561

megawatt hours or 4.6 percent less compared to the base scenario. This represents a curtailment or shedding of load by the day-ahead market solution, indicating that virtual offers may have been pivotal in the market software arriving at a feasible day-ahead solution that did not require load curtailment. Due to the extreme changes the re-run produces on this day and the low quality of the day-ahead and re-run solutions, we still included February 18 as part of our analysis, but provide several metrics with and without data from February 18 where appropriate.

For each metric of interest, we tested the explanatory power of the re-runs by calculating the coefficient of determination off of the differences between the original metric from the actual day-ahead market solution and our base re-run. In most cases, our base re-run scenario demonstrated a high level of integrity with a coefficient of determination of 0.99 for most day/metric pairs. We also looked at key market metrics such as cleared demand to see if the re-run solutions were realistic. Finally, we looked at the quality of the day-ahead market clearing engine (MCE) solutions as recorded in the casefile logs and compared those to the quality of the solutions for the re-runs as lower quality solutions can produce (and explain) abnormal results. Taken in total, the quality of the re-runs was generally high, though the removal of virtual transactions did decrease the quality of the market clearing engine solution in most cases, particularly on February 18.

An overview of the adjustments the market clearing engine made to re-balance supply and demand under the most severe scenario, removing all virtual transactions, can be seen in Figure 4-1. The red columns show changes to elements of demand, blue columns changes to elements of supply, and the green columns show how much of the megawatts displaced from virtual transactions were made up by other supply or demand elements.

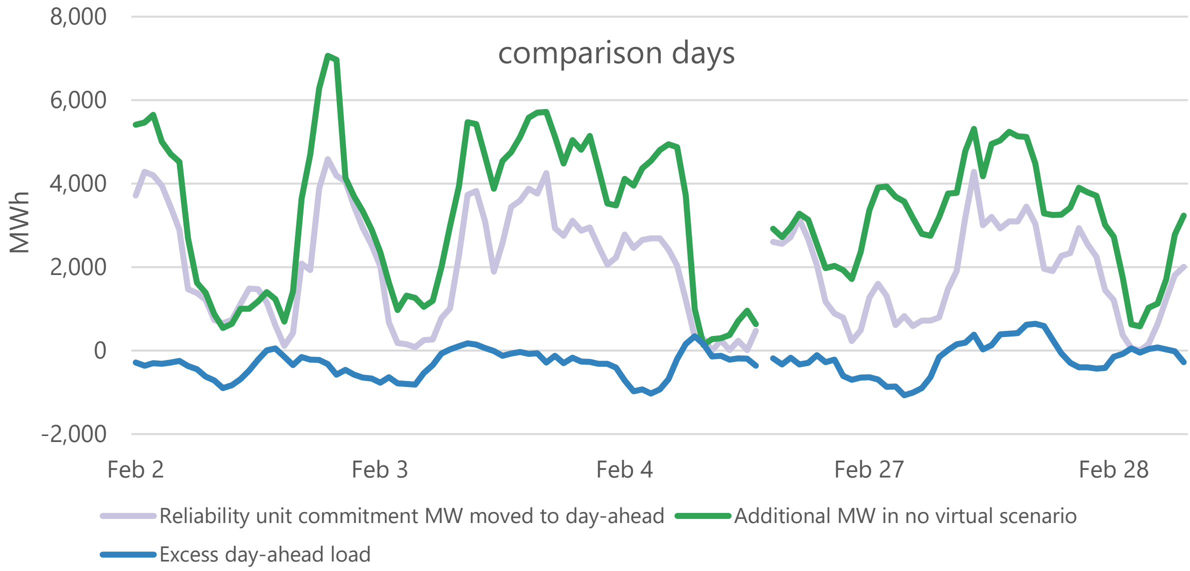
Figure 4-1 Overview of changes to supply and demand elements under the no virtual transactions scenario

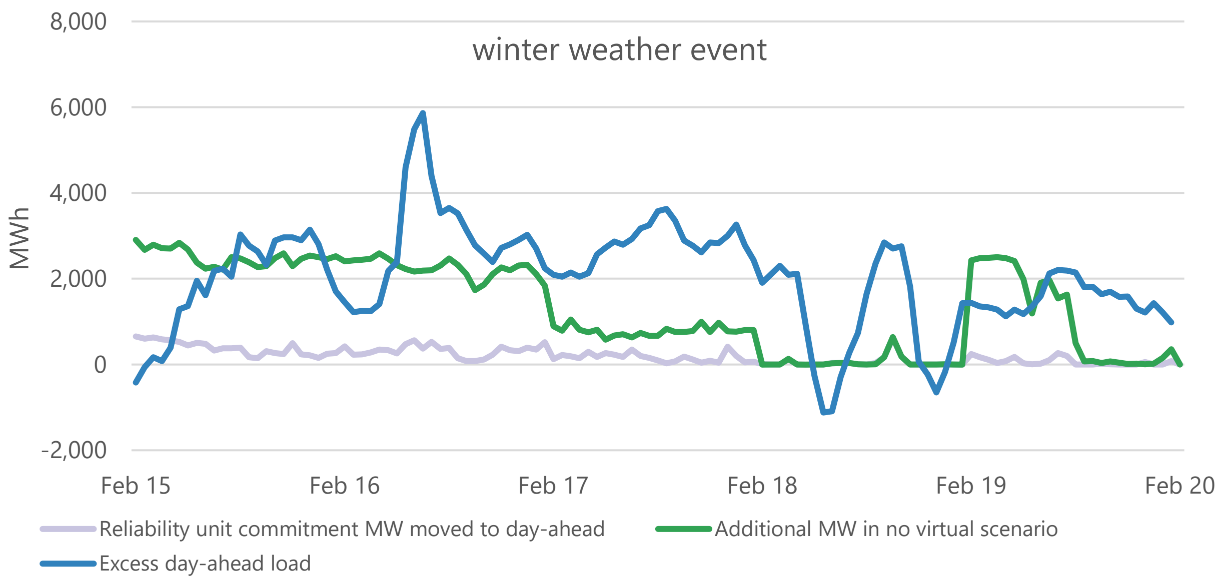
	Day	Demand: Virtual bid change	Demand: Price sensitive demand change	Demand: Fixed demand change	Demand: Total demand change	Demand: Export change	Demand: Loss change	Supply: Virtual offer change	Supply: Generation change	Supply: Emergency MWh change	Supply: Import change	Virtual netting offset	Additional generation offset	Other offset
Comparison days	Feb 2	-55,027	-139	0	-139	-4	-916	-117,752	61,555	0	112	47%	52%	1%
	Feb 3	-76,651	-237	0	-237	-240	-1,323	-146,881	68,431	0	0	52%	47%	1%
	Feb 4	-85,473	38	0	38	11	-1,833	-140,048	53,171	0	-380	61%	38%	1%
	Feb 27	-45,352	-13	0	-13	0	-113	-110,876	65,397	0	0	41%	59%	0%
	Feb 28	-56,575	-173	0	-173	-6	-308	-110,126	53,065	0	0	51%	48%	1%
	Average	**-63,815**	**-105**	**0**	**-105**	**-48**	**-899**	**-125,137**	**60,324**	**0**	**-54**	**50%**	**49%**	**1%**
Winter weather event	Feb 15	0	0	0	0	0	-1,087	-58,941	57,854	49,368	0	0%	98%	2%
	Feb 16	-28	0	0	0	0	-961	-52,392	51,403	38,428	0	0%	98%	2%
	Feb 17	-14	0	-75	-75	10	-33	-17,573	17,461	16,691	0	0%	99%	1%
	Feb 18	0	0	-38,561	-38,561	-1,122	-2,374	-42,236	179	53	0	0%	0%	100%
	Feb 19	-5,917	36	-1,039	-1,003	65	-1,177	-29,934	22,015	6,069	-114	20%	74%	7%
	Average	**-1,192**	**7**	**-7,935**	**-7,928**	**-209**	**-1,127**	**-40,215**	**29,782**	**22,122**	**-23**	**4%**	**74%**	**22%**
	Average w/o Feb 18	**-1,490**	**9**	**-278**	**-269**	**19**	**-815**	**-39,710**	**37,183**	**27,639**	**-28**	**5%**	**92%**	**3%**

During the comparison days, both virtual offers and bids cleared. Because virtual bids and offers net each other, removing virtual bids from the market offset, on average, 50 percent of the impact of removing virtual offers from the market. The other 50 percent was offset by committing additional generation (49 percent) and reducing price sensitive demand, exports, and losses (one percent). By contrast, during the winter weather event re-run days, very few virtual bids cleared and generation was extremely tight. On February 18, conditions were the most extreme. As Figure 4-1 illustrates, the market ran out of generation and cleared no virtual bids and no price sensitive demand. This meant that 100 percent of the impact removing virtual offers from the market had on supply, had to be offset by changes in fixed demand (92 percent), exports (two percent), and losses (six percent). On average, however, 74 percent of the impact removing virtual transactions from the market had on supply during the winter weather event re-run days was offset by generation, or 92 percent when not including February 18. Removing virtual bids only offset five percent while price sensitive and fixed demand, losses, and exports offset another 22 percent, or only percent when excluding February 18.

Another way to look at what role virtual transactions played in the market is to compare net virtual volume (in this case, net offers) to commitments by reliability unit commitment and real-time settlements to estimate, 1) what virtual transactions displaced in day-ahead; and 2) what took the place of virtual transactions in real-time. During the comparison days, the day-ahead commitments by reliability unit commitments followed the same trend as hourly net virtual supply closely, indicating that, like in the day-ahead table above, virtual transactions primarily displaced generation in the day-ahead market. However, this also indicates that they were replaced by physical generation in real-time. Real-time meter data substantiates this. During the winter weather event, this was not the case. Day-ahead commitments by reliability unit commitment were extremely small compared to net virtual supply. This indicates that while virtual offers likely displaced physical generation in the day-ahead, they were not replaced by physical generation in real-time. Instead, real-time data suggests that in most hours, load was over forecasted in the day-ahead market. As a result, net virtual supply did not have to be replaced in real-time with actual generation.

Figure 4-2 Reliability unit commitments versus virtual megawatts





Examining day-ahead re-run, reliability unit commitment, and real-time data, all point to a similar conclusion: during the comparison days and winter weather event, data suggest that net virtual transactions offset more expensive generation in day-ahead market. What differed during the winter weather event, due to load being substantially over forecast in day-ahead, is the physical generation displaced in day-ahead by virtual transactions was not manifested in real-time, at least not to replace virtual supply.

4.2 PRODUCTION COST IMPACT

Virtual transactions should, in theory, lower total production cost in the day-ahead market by displacing physical megawatts from higher cost resources and, in some cases, prevent higher cost resources that would otherwise be marginal from being committed in the day-ahead market. This is already evidenced in Figure 4-1, which shows the converse, that physical generation was needed to offset the majority of any reduction in virtual megawatt hours. Displacing physical generation megawatt hours has a cascading effect, potentially changing start-up and no load costs, import-export costs, and so on.[10] In addition, the net cost of virtual transactions (offer cost – bid cost) is nearly always negative in SPP, which lowers production cost.

During the winter weather event re-run days, total daily production cost varied from $220 million on February 19 when the winter weather event began to wane and $559 million on February 15, totaling $2.1 billion over the five days or $1.7 billion excluding February 18. Virtual transactions increased total production costs by $31 million (1.9 percent); virtual transactions at interface locations decreased total production costs by $3.2 million (0.2 percent). Including February 18, virtual transactions increased production costs by $86 million (4.2 percent); virtual transactions at interface locations alone increased production costs by $21 million (1 percent). Overall, this indicates that virtual transactions tended to *increase* production costs, though virtual transactions at interface locations showed slight cost savings when not factoring in February 18. This is in contrast to the comparable re-run days where virtual transactions lowered total production costs from -$2.4 million to -$25.8 million, due to virtual transactions on net paying into the market.[11]

---

[10] It is important to note that savings from re-running the day-ahead market are only valid for the day-ahead market as reliability unit commitment and real-time processes could reverse cost savings in the scenario where virtual transactions cause units to be committed and dispatched in reliability unit commitment or real-time at a higher cost than day-ahead.

[11] Production cost can be negative overall when positions usually paid by the market, such as generation, experiences negative pricing and thereby pays into the market rather than takes payment from the market.

Virtual transactions can influence total production cost through violation costs and operating costs. Breaking down production cost into its component pieces, the data revealed that the difference in total production costs between the scenario without virtual transactions at interface locations and no virtual transactions at all is minute. As such, we focused solely on the no virtual transactions scenario when looking at how virtual transactions impact the individual components of production costs.

While violation costs were minimal during the comparison days, virtual transactions saved the market almost $22 million in violation costs during the winter weather event re-run days excluding February 18, or $19.5 million including February 18. Violation costs only account for around 3 to 4 percent of total production cost. Operating cost on the other hand, comprised of start-up, no load, energy, ancillary services, virtual offers, and interface transactions, as costs and virtual bids and price sensitive demand as credits, accounts for the majority of total production cost. During the comparison days, virtual bids were the largest source of savings at nearly $15 million. Virtual offers came next at $5.6 million.[12] The rest of the savings came from energy ($2.8 million), start-up ($31,000), and price sensitive demand ($9,000). Virtual transactions increased costs associated with no load, ancillary services, and transactions by $27,000, $49,000, and $10,000, respectively. Overall, virtual transactions saved the market around $23.4 million in the comparison days.

While virtual transactions during the winter weather event re-run days (excluding February 18) also reduced energy, virtual bids, and start-up costs ($53 million, $1.7 million, and $564,000, respectively), they also reduced the second largest component of operating costs – no load costs - by $2.7 million. However, these savings were fully offset by increases the cost of the virtual offers themselves ($111 million), ancillary services costs ($373,000) transaction costs ($56,000) and lower demand ($7,000). In total, virtual transactions cost the market an extra $53 million in operating costs (three percent).

[12]While generally, including during the winter weather event, virtual offers increase production costs since they are virtual energy, virtual offer costs were negative during these days (i.e. they paid into the day-ahead market).

Figure 4-3 Savings attributable to virtuals by component of total production cost

	Day	Operating savings =	Startup savings	No-load savings	Energy savings	Ancillary services savings	Virtual offer savings	Virtual bid savings	Transaction savings	Demand bid savings
Comparison days	Feb 2	$4,251,887	-$23,323	-$6,181	$860,631	$483	$798,290	-$2,614,931	$2,312	-$4,746
	Feb 3	$5,263,520	$47,126	$19,297	$690,089	$77	$1,225,630	-$3,275,545	$1,030	-$4,726
	Feb 4	$6,200,342	$24,325	-$44,862	-$88,048	-$23,191	$1,703,997	-$4,644,743	-$13,538	$3,085
	Feb 27	$3,503,488	-$2,717	$20,641	$879,209	-$20,159	$762,579	-$1,863,652	$0	-$283
	Feb 28	$4,191,838	-$14,406	-$15,488	$453,837	-$6,283	$1,186,885	-$2,584,634	$132	-$2,527
	Average	**$23,411,076**	**$31,005**	**-$26,593**	**$2,795,718**	**-$49,073**	**$5,677,381**	**-$14,983,506**	**-$10,065**	**-$9,197**
Winter weather event	Feb 15	-$6,192,294	$1,628	$206,229	$13,767,526	-$7,288	-$20,160,789	-$400	$0	$0
	Feb 16	-$23,940,535	-$57,442	$778,115	$17,098,918	-$365,193	-$41,448,686	-$53,752	$0	$0
	Feb 17	-$22,968,196	-$213	-$2,475	$1,027,628	$22,324	-$24,013,298	-$21,690	-$23,853	$0
	Feb 18	-$52,100,416	$0	$0	-$13,800	-$10	-$52,086,606	$0	$0	$0
	Feb 19	-$301,549	$620,292	$1,727,678	$21,296,654	-$23,047	-$25,539,080	-$1,655,190	-$32,036	$7,200
	Average	**-$21,100,598**	**$564,265**	**$2,709,548**	**$53,176,927**	**-$373,214**	**-$163,248,457**	**-$1,731,031**	**-$55,890**	**$7,200**
	Average w/o Feb 18	**-$53,401,575**	**$564,265**	**$2,709,548**	**$53,190,727**	**-$373,204**	**-$111,161,852**	**-$1,731,031**	**-$55,890**	**$7,200**

Including February 18, total operating cost increases by $105.5 million in operating costs (three percent). Including February 18, total operating cost increases by $105.5 million (5 percent), driven almost exclusively by an additional $52 million in virtual offer costs. A breakdown of savings by component of operating cost is available in Figure 4-2.

While virtual transactions during the winter weather event re-run days (excluding February 18) also reduced energy, virtual bids, and start-up costs ($53 million, $1.7 million, and $564,000, respectively), they also reduced the second largest component of operating costs – no load costs - by $2.7 million. However, these savings were fully offset by increases the cost of the virtual offers themselves ($111 million), ancillary services costs ($373,000) transaction costs ($56,000) and lower demand ($7,000). In total, virtual transactions cost the exclusively by an additional $52 million in virtual offer costs. A breakdown of savings by component of operating cost is available in Figure 4-2.

The fact that virtual transactions were shown to increase total production costs during the four analytically valid winter weather event re-run days versus decrease production costs during the comparison days demonstrates that virtual transactions had a significantly different effect on the market during the winter weather event re-run days. This was primarily driven by net virtual cost being positive (as stated before, net virtual cost is typically negative) and larger than their aggregate impact on lowering other costs, such as energy. In 2021, net virtual transactions as part of total production costs was negative at a daily level every day except February 15, 16, 17, 18, and 19. During the remaining days, virtual bids exceeded virtual offers and, in 65 percent of days, total virtual offer costs were also negative, both leading to negative overall virtual costs.[13] The combination of extremely tight supply conditions leading to few virtual bids clearing, very large day-ahead prices, and a shift from virtual offers being placed largely at dispatchable variable energy resource settlement locations that typically have very low if not negative prices to interface locations caused this sudden shift in virtual costs.

---

[13] A high proportion of virtual offer transactions at wind resource locations where prices are often negative drive the frequency at which virtual offers are negatively priced and hence, reduce production cost overall.

Aside from having a markedly different impact on total production cost on the aggregate, virtual transactions also performed differently on a per-megawatt and per-dollar of virtual cost basis. During the comparison days, operating costs decreased $1.13 for every dollar *paid in* by virtual transactions (virtual transactions on net paid into the market, decreasing operating costs). During the winter weather event, operating costs *increased* by $0.49 for every dollar of virtual cost. On a per-megawatt hour basis, every megawatt hour of virtual transactions (bids and offers) displaced $25 of operating costs whereas during the winter weather event re-run days, every megawatt hour of virtual transactions *increased* operating costs by $324.

The efficiency at which virtual transactions lowered operating cost during the comparison days, outside of the direct impact of virtual transactions themselves, is attributable mainly to their impact on energy. And while virtual transactions increased operating costs overall during the winter weather event re-run days, here too they lowered energy costs significantly. During the comparison days, virtual transactions paid the market $68 for every megawatt hour of energy displaced and paid the market roughly $7 per $1 of cost displaced. On a per-megawatt hour basis, it took three virtual megawatt hours to displace each physical megawatt hour or roughly 1/3 megawatt hour of virtual energy to displace $1 in energy costs. During the winter weather event re-run days, it cost $736 in virtual cost per megawatt hour of physical energy displaced owing to higher prices but only $2 in virtual cost to displace every $1 of energy cost. This indicates that virtual transactions represented a much more attractive offer of energy (or reduction in demand) compared to physical energy available during the winter weather event than during the comparison days. Intuitively this makes sense given generation was extremely tight and fuel costs drove day-ahead energy offers to and often above the $1,000/MWh offer cap during the height of the emergency. However, this also demonstrates that during the winter weather event, virtual transactions were an expensive offset for energy costs.

In summary, during the comparison days, virtual transactions ultimately saved the market $23 million in operating costs, mostly from energy savings and because of negative virtual costs and slight savings in demand and start-up costs. However, these savings came at a price in the form of increased no load, ancillary services, and transaction costs. During the winter weather event re-run, not only did virtual transactions increase operating costs overall, but they shifted where those costs were realized away from physical energy, start-up, no load, and transaction costs into ancillary services, demand, and virtual energy costs.

4.3 PRICE CONVERGENCE

The second way virtual transactions tend to benefit the market is through better price formation in day-ahead, ultimately leading to narrower price spreads between day-ahead and real-time. Average day-ahead prices during the five day re-run period stayed consistently high; prices stayed above $2,000 per megawatt on average until tapering off to just over $1,000/MWh on average on February 19. Average real-time prices, by contrast, did not exceed $200 per megawatt-hour and decreased steadily across the five days until reaching $8/MWh on February 19[14]. This led to large spreads between day-ahead and real-time prices across the five re-run days, averaging $2,449/MWh with the greatest average spread occurring on the February 18 when, on average, day-ahead prices exceeded real-time prices by $3,700/MWh. By contrast, average prices during the five comparison days in February were $15.41/MWh in the day-ahead market and $0.79/MWh in real-time, with the price spread averaging $14.63/MWh.

During the five winter weather event re-run days, virtual transactions generally lowered price spreads. Illustrated in Figure 4-3, the base scenario had the lowest day-ahead versus real-time price spreads while removing either all virtual transactions or just those at interface locations increased day-ahead versus real-time price spreads. This indicates that virtual transactions on these days did aid price convergence and moreover, that most of this influence came from virtual transactions at interface locations. However, this trend reversed on February 18 when the base scenario, which included all virtual transactions, had higher average day-ahead prices and a greater spread between day-ahead and real-time prices. Correspondingly, February 18 saw the highest total virtual profit and profit per megawatt.

[14] This figure is an average across all settlement locations across hours; some settlement locations saw prices well above or below these figures during certain hours.

Excluding February 18, the addition of virtual transactions improved price convergence on average by $284/MWh, or 13 percent ($217 or 10 percent including February 18). During the five comparison days, the addition of virtual transactions improved price convergence on average by $4.14/MWh, or 21 percent. Comparing these results to the winter weather event, the impact virtual transactions had on price during the winter weather event was larger in raw dollar amount but had a little more than half the proportional impact.

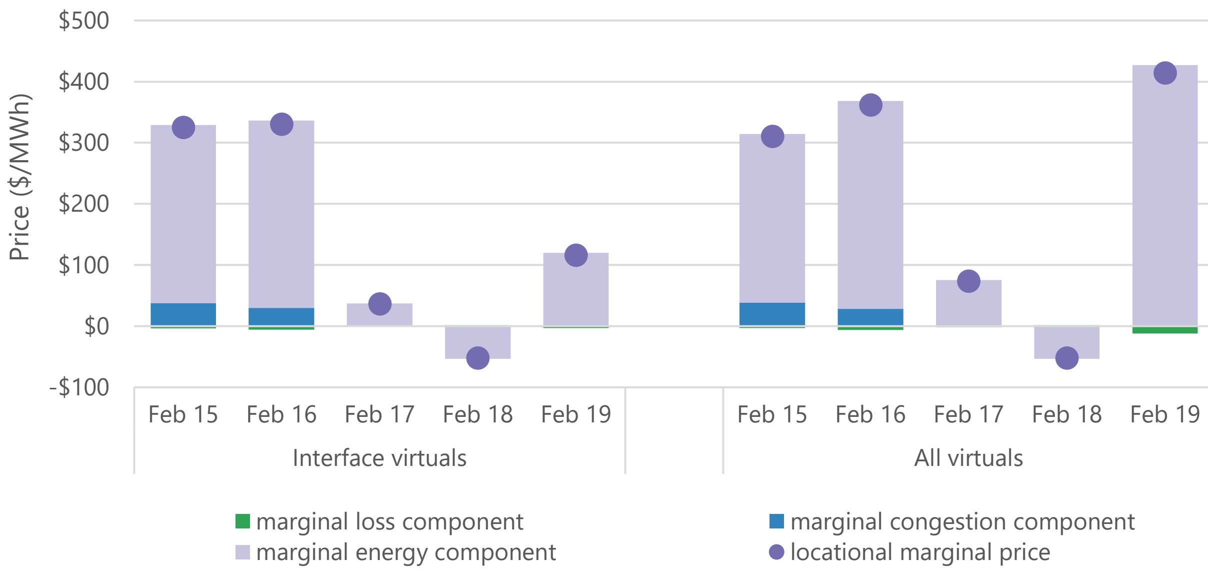
Figure 4-4 Average prices by scenario

				No interface virtuals			No virtuals		
	Day	Real-time LMP	Day-ahead LMP	LMP	LMP change	Percent change	LMP	LMP change	Percent change
Comparison days	Feb 2	$2.55	$17.59	—	—	—	$22.35	$4.77	+21%
	Feb 3	$0.51	$14.92	—	—	—	$19.65	$4.72	+24%
	Feb 4	$0.25	$15.30	—	—	—	$19.19	$3.88	+20%
	Feb 27	$1.21	$15.99	—	—	—	$18.85	$2.86	+15%
	Feb 28	-$0.60	$13.26	—	—	—	$17.74	$4.48	+25%
	Average	**$0.79**	**$15.41**	—	—	—	**$19.55**	**$4.14**	+21%
Winter weather event	Feb 15	$177	$2,912	$3,204	$292	+10%	$3,192	$280	+9%
	Feb 16	$117	$2,722	$3,053	$332	+12%	$3,091	$369	+12%
	Feb 17	$82	$2,192	$2,227	$35	+2%	$2,264	$73	+3%
	Feb 18	$25	$3,707	$3,657	-$50	-1%	$3,657	-$50	-1%
	Feb 19	$8	$1,121	$1,239	$118	+11%	$1,537	$416	+27%
	Average	**$82**	**$2,531**	**$2,676**	**$145**	**+7%**	**$2,748**	**$217**	**+10%**
	Average w/o Feb 18	**$96**	**$2,237**	**$2,431**	**$194**	**+9%**	**$2,521**	**$284**	**+13%**

Breaking prices down by individual component, virtual transactions impacted price convergence primarily by influencing the marginal energy component (MEC) and secondarily through the marginal congestion component (MCC) of locational marginal prices (LMP). Figure 4-4 shows the daily average dollar improvement in price convergence by component, where the higher the dollar value, the closer day-ahead prices converged toward real-time prices and vice-a-versa. Here again, the data highlight how on the February 18, virtual transactions exacerbated price spreads, *adding* about $50 of divergence between day-ahead and real-time. It also shows that the way that virtual transactions impact price convergence is primarily (90 percent of total impact) through lowering marginal energy cost (MEC). This indicates that during the winter weather event, *how* virtual transactions impact prices did not change significantly, only the extent to which they impacted prices did.

Overall, the inclusion of virtual transactions tended to aid price convergence during the winter weather event. Accounting for the difference in volume of all virtual transactions cleared, during the comparison days, there were over 45,000 megawatt hours of virtual energy cleared per dollar of spread improvement. By contrast, every 145 megawatt hours of virtual energy had the same impact during the winter weather event (190 if we include February 18).

Figure 4-5 Average price convergence improvement by component by scenario



Another way to look at the efficiency at which virtual transactions converged price is to compare dollars of virtual cost per dollar of price spread improvement. During the comparison days, the market **received**, on average, almost $1 million per dollar of price spread improvement while during the winter weather event, the market **paid**, on average, $148,500 per dollar of price spread improvement ($96,000 including February 18). This indicates that while each megawatt hour of virtual transactions had a larger impact on price convergence during the winter weather event, on a cost basis, virtual transactions were a much less cost effective tool for price convergence.

Figure 4-6 Price spread improvement efficiency comparison

	Day	Virtual spread improvement	Cleared virtual MWhs	Cleared virtual cost	MWh efficiency (MWh/$ improvement)	Cost efficiency ($/$ improvement)
Comparison days	Feb 2	$4.77	172,778	-$3,413,221	36,255	-$716,209
	Feb 3	$4.72	223,532	-$4,501,175	47,309	-$952,651
	Feb 4	$3.88	225,522	-$6,348,741	58,054	-$1,634,309
	Feb 27	$2.86	156,228	-$2,626,231	54,642	-$918,549
	Feb 28	$4.48	166,701	-$3,771,518	37,212	-$841,892
	Average	**$4.14**	**188,952**	**-$4,132,177**	**45,609**	**-$997,428**
Winter weather event	Feb 15	$279.82	58,941	$20,160,389	211	$72,047
	Feb 16	$369.35	52,420	$41,394,934	142	$112,074
	Feb 17	$72.86	17,587	$23,991,608	241	$329,304
	Feb 18	-$50.17	42,236	$52,086,606	(842)	-$1,038,178
	Feb 19	$415.57	35,852	$23,883,890	86	$57,473
	Average	**$217.49**	**41,407**	**$32,303,485**	**190**	**$148,531**
	Average w/o Feb 18th	**$284.40**	**41,200**	**$27,357,705**	**145**	**$96,194**

4.4 MARKET CONVERGENCE

Traditionally, discussions and evaluations of the value of virtual transactions as a market product center on increased liquidity and competition that lead to greater price convergence and, as a result, more efficient unit commitments in the day-ahead market. However, Figure 4-1 and 4-2 indicate virtual transactions had a wider influence on the day-ahead market. Focusing solely on price convergence and production alone does not fully capture the extent of this influence and the cost and/or benefits resulting from it.

The first notable impact seen from the re-runs is how virtual transactions influenced the quantity of ancillary services that could clear in the day-ahead market. Virtual transactions provided generating capacity when the system was otherwise extremely tight. On February 15, 16, and 19, the additional virtual energy allowed the market to clear 200 to 300 more megawatts of ancillary services per hour. This equates to 15 to 20 percent of total ancillary services that cleared. The addition of more ancillary services clearing provided the system greater stability but also raised production cost since, without virtual transactions, fewer ancillary services would have cleared. Excluding February 18 and 19, the additional cost of ancillary services accounted for about one percent of the total increase in production cost. Virtual transactions also shifted ancillary services during the comparison days, but the effect was much smaller and they did not significantly impact the quantity of ancillary services able to clear in the day-ahead market.

The market was tightest on February 18 and 19 when nearly all available generation was already committed before including virtual transactions. As a result, the addition of virtual energy had a negligible impact on ancillary services commitments. When including February 18 and 19, the additional cost of ancillary services drops to 0.4 percent of the total increase in production cost attributable to virtual transactions. However, particularly on February 18, virtual transactions had an additional benefit related to the scarcity of energy.

Going back to Figure 4-1, the re-run results demonstrate a second notable impact: removing virtual transactions on February 18 led to nearly no change in generation and a significant decrease in fixed demand. Fixed demand also decreased, albeit to much smaller extent, on February 19, when virtual transactions were removed from the market. This indicates that under these specific grid circumstances, virtual transactions were an important stand-in for physical generation and the difference between serving load versus shedding load. The best way to value avoiding load shedding would be to use a value of lost load (VOLL). While SPP has not adopted a value of lost load, in MISO, the adopted value is $3,500 per MWh and in ERCOT, $9,000 per MWh. However, for the benefit of clearing more load in the day-ahead market to just equal the $376 million in virtual profit, the value of lost load used in SPP would have to be at least $10,000 per MWh, which exceeds even ERCOT's established value of lost load.[15]

As discussed at length, virtual transactions shifted steeply in favor of offers (both in volume offered and volume and percent cleared) and away from resource locations to interface

---

[15] As a thought experiment, we re-ran just February 18 adding non-existent "pseudo" generators in each reliability zone with offers as high as $50,000 per megawatt hour, SPP's current VRL for global power balance, in order to see if the market clearing engine logic would choose to clear this expensive generation over shedding load. With its current logic, the market clearing engine solution utilized even this high cost generation to make up the megawatt hours virtual transactions covered in order to avoid cutting fixed demand during that day. However, it is unlikely SPP members or the RTO would ever approve a value of lost load this high.

locations. This led to a third notable impact: Instead of representing real-time generation, virtual transactions largely shifted to represent imports, which are generally underrepresented in the day-ahead market. While the market participants with the largest virtual import positions only supplied a fraction of this power in real-time, other market participants stepped in in real-time and imported physical imports in excess of the total quantity represented by virtual offers at interface locations.

While this element-by-element analysis is enlightening, it does not fully capture whether these shifts in prices and quantities increased or decreased total market convergence overall – i.e., how close the day-ahead market was to the real-time market in all respects – during the comparison days and the winter weather event. To capture the effect of virtual transactions on total market convergence, we measured the total change in price and quantities at each settlement location between the day-ahead market and real-time market and compared that to the total change in prices and quantities at each settlement location during the re-run scenario removing all virtual transactions and the real-time market. If virtual transactions, on the whole, increased the efficiency of the day-ahead market, the spread between the re-run scenario and real-time should be greater than the spread between the day-ahead and real-time markets. We treated this difference, minus virtual profits after fees, as the benefit virtual transactions provided in terms of total market convergence. We then performed the same analysis for ancillary services.

During the comparison days, virtual transactions improved the efficiency of the day-ahead market as they decreased the total spread between the day-ahead and real-time markets by around $8 million. With a virtual cost of -$20 million, every $2.50 virtuals paid into the market brought the day-ahead market $1 closer to the real-time market. Virtual transactions decreased the efficiency of the day-ahead market during the winter weather event re-run days, increasing total spread by $104 million. This decrease in convergence came at a cost of nearly $165 million, equating to every $1.58 in virtual cost diverging the market by $1.[16]

---

[16] We also calculated this metric altering real-time prices during EEA2 and EEA3 intervals to $1,000 if below $1,000 and $3,500 if below $3,500, respectively, to see if unduly low real-time prices during

Computing the same metric for ancillary services yields significantly different results. Instead of promoting convergence, virtual transactions actually exacerbated spreads between day-ahead and real-time markets in both the comparison days ($1.6 million increase in spread) and the winter weather event re-run days ($74 million increase in spread). During the comparison days and winter weather event re-run days (excluding February 18 when virtual transactions had almost no effect on ancillary services), every $3 of virtual profit, on average, diverged the ancillary services market by $1. The lack of a significant difference in convergence between the comparison days and winter weather event re-run days and because in both cases, virtual transactions allowed more ancillary services to clear, there is no evidence virtual transactions influenced the ancillary services market differently during the exceptional grid conditions of the winter weather event.

---

declared system emergencies had any impact on the cost effectiveness of virtual transactions on market convergence. These higher real-time prices did not change the outcome.

Figure 4-7 Market convergence improvement efficiency comparison

	Day	Virtuals spread improvement	Virtual cost	Cost/$ spread improvement
Comparison days	Feb 2	$1,167,177	-$3,413,221	-$2.92
	Feb 3	$1,891,242	-$4,501,175	-$2.38
	Feb 4	$2,089,711	-$6,348,741	-$3.04
	Feb 27	$1,199,972	-$2,626,231	-$2.19
	Feb 28	$1,924,271	-$3,771,518	-$1.96
	Total	**$8,272,374**	**-$20,660,886**	**-$2.50**
Winter weather event	Feb 15	-$44,867,782	$20,160,389	$0.45
	Feb 16	-$6,600,786	$41,394,934	$6.27
	Feb 17	-$54,517,289	$23,991,608	$0.44
	Feb 18	-$9,597,850	$52,086,606	$5.43
	Feb 19	$11,424,586	$23,883,890	$2.09
	Total	**-$104,159,120**	**$164,979,489**	**$1.58**
	Total w/o Feb 18	**-$94,561,271**	**$109,430,821**	**$1.16**

4.5 SUMMARY

During the five winter weather event re-run days, virtual transactions made just under $376 million in profit, equating to $1,815 per megawatt hour. Excluding February 18, these figures are nearly $243 million or $1,473 per megawatt hour. This compares to only $4.8 million in virtual transaction profit or $5.08 in profit per megawatt hour during the comparison days. Looking at these figures relative to the benefits and costs virtual transactions imposed on the market, $4.8 million in virtual transaction profit saved the market $23 million in production costs (1:5 cost to benefit) and brought day-ahead and real-time prices $4.14 or 28 percent closer during the comparison days. During the winter weather event re-run days, $376 million in virtual transaction profit cost the market an additional $8.6 million in production costs, but brought day-ahead an real-time prices roughly $284 or 13 percent closer. These numbers indicate that the effect of virtual transactions on price convergence was, proportionally speaking, muted during the winter weather event and came at the cost of both higher production costs and nearly $400 million in profits by virtual transactions, which are ultimately a cost to the market.

The results also indicate virtual transactions were less efficient and cost effective with regard to total market convergence. Virtual transactions during both time periods decreased the overall spread between the day-ahead and real-time markets, but taking into account differences in total virtual profitability, it cost $0.43 per $1 of market convergence during the comparison days versus a staggering $12 to achieve the same effect during the winter weather event re-run days. As a result, the cost/profit of virtual transactions during the winter weather event was not justified in terms of their benefit to converging the market.

Virtual transactions did have the unusual benefit of, in theory, allowing the day-ahead market to solve without shedding load on February 18. The benefit of solving the day-ahead market should be the additional megawatt hours cleared multiplied by an established value of lost load; however, SPP has yet to set a value of lost load. Given virtual profit less fees during the five re-run days totaled almost $376 million, the value of lost load needed to balance that level of profit against an additional 38,560 MWh of demand clearing would be just under $10,000 per MWh. This is almost three times higher than the established value of lost load in MISO ($3,500 per MWh) and 11 percent higher than ERCOT's $9,000 per MWh, the highest established value of lost load value. As such, it is unlikely that a value of lost load value, had SPP established one, be high enough to make virtual transactions a cost effective solution for clearing additional fixed demand.

5 RECOMMENDATIONS

Based on the results of this study along with insights gained from the MMU's Report on February 2021 Winter Weather Event, the MMU makes the following three recommendations:

1) **The RTO and SPP members should consider suspending virtual trading during scarcity events.** Data from the winter weather event suggests that while virtual transactions still aid in price and overall market convergence, they are no longer cost-effective when day-ahead prices exceed the $1,000/MWh offer cap. At this level of scarcity and resulting price spreads (and hence, profit), virtual transactions are much less likely to displace a significant quantity of expensive generation to have a significant enough impact on price to be a cost-effective tool for market convergence.
2) **The RTO and/or MMU should conduct further analysis to determine at what level of average day-ahead prices, price spreads, and virtual volume to load ratios virtual transactions typically no longer become a cost-effective tool for aiding price and market convergence.** This will potentially reveal other circumstances, other than scarcity pricing / energy emergency events, that warrant a suspension of virtual trading. This could include suspending virtual trading when virtual bids are no longer clearing since without the offset of virtual bids, virtual transactions on the whole are more likely to cost the market more than the value they provide in price or total market convergence.
3) **The RTO and our members should consider studying how violation relaxation limits (VRLs) interact with the profitability and cost-effectiveness of virtual transactions under different levels of scarcity.** Violation relaxation limits, by design, relax market requirements during times of shortage, which fundamentally alters price formation and can, in many cases, cause prices to be lower than if the shortage did not exist. This can cause price spreads between the day-ahead and real-time markets to grow, potentially impacting the efficacy of virtual transactions in aiding price and market convergence. This recommendation is in line with the MMU's Annual State of the Market in which the MMU recommended that the RTO and its members review price formation during

scarcity events and adopt graduated demand curves to avoid distorted or even perverse market incentives caused by VRLs.

4) **The RTO should partner with our member load-serving entities to research potential reasons real-time load deviated from net load forecast during the winter weather event and during other times when the system was experiencing stress.** A better understanding of factors such as consumer conservation behaviors and behind the meter demand response could allow SPP to improve net load forecasting during extreme events and in turn, improve day-ahead commitments.