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Demand Response Providing Ancillary Services

A Comparison of Opportunities and Challenges in the US Wholesale Markets

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Abstract

Interest in using demand response (DR) resources to supply low cost reliability products to the bulk electricity system is on the rise due to the uncertain impacts of increasing penetrations of intermittent generation and recent rulings supporting demand side participation in wholesale markets from the Federal Energy Regulatory Commission. However, organized electricity and ancillary services markets are just beginning to support DR resources for ancillary services, and the set of rules and requirements for participation are unique to each market. This paper discusses the opportunities that exist in the ancillary service markets in each US Independent System Operator territory and identifies challenges to market participation for demand response resources. It compares resource requirements, limits to aggregation, measurement and verification, bidding requirements, market timelines, and the types of organizations that can play in the markets. Additionally, it uses market clearing prices and market size to compare what value may be extracted from these markets, and identifies how these prices are currently determined. Using these criteria, PJM and ERCOT have the most favorable conditions for demand response participation in ancillary service markets, and changes to rules that effect aggregation and minimum resource size could promote more participation in other AS markets across the US.

1. INTRODUCTION

Ancillary services (AS) are support services in the power system and are essential in maintaining power quality, reliability and security. In the US, there are four typical products traded in ancillary services markets run by Independent System Operators/Regional Transmission Organizations (ISO/RTOs). From the faster to the slower acting, these services are: regulation, spinning reserves, non-spinning reserves, and supplemental reserves. Regulation is used to control system frequency by instantaneously maintaining the balance of supply and demand. Resources providing regulation products are certified by the ISOs to increase or decrease their output to follow an automatic generation control (AGC) signal sent by the system operator's energy management system. In some ISO/RTOs, regulation is split into two products, up and down. This means that the regulating resource will only be asked to provide a deviation from its normal operating point in one direction. Spinning reserves (sometimes called Synchronous or Responsive Reserves) are the portion of unloaded capacity of units already connected or synchronized to the grid that can be delivered in 10 minutes. Non-spinning reserve is capacity that can be synchronized and ramping to a specified load within 10 minutes. The last ancillary service in markets, supplemental reserve, is not available in all ISO/RTOs and is capacity that can be synchronized and delivered to the system within 30 minutes.

The adoption of state-level renewable portfolio standards is pushing the need for additional ancillary services and grid flexibility. The additional reserves needed depend on a variety of factors from location to adoption of different technologies. In California, an increase in the regulation capacity is expected [1, 2],while in ERCOT, studies suggest that the need for spinning reserves is growing [3].

As a result, there are many tools that ISO/RTOs are looking at to help alleviate the expected grid stress with increases in renewable generation, demand response being one of them. Additionally, the Federal Energy Regulatory Commission (FERC) has been passing rules in an attempt to level the playing field between traditional and alternative grid resources such as demand response [4, 5] and mandating that fast acting resources be compensated for the additional security that their flexibility brings the grid [6].

Conceptual studies have argued that demand response is ideally suited to provide AS to the grid [7, 8] and limited field tests [9-12] have examined their technical capability. The majority of DR literature focuses on its traditional uses such as emergency load relief, system peak management and price responsive demand [13, 14,15]. The major differences between traditional applications of DR and DR for AS are the reduction of notification time, and the increased speed and accuracy of measurements. Additionally, AS requirements vary geographically and they are typically needed year round.

With so much interest in flexible resources like demand response providing ancillary services to the grid, it is important to understand how much value a new market player can extract and which markets are best positioned to promote demand side participation. This analysis attempts to compare the value and rules of ISO/RTOs to help make the value proposition to demand side market participants more transparent. There will be a discussion of the market clearing price for the most valuable ancillary services in US ISO/RTOs, then some characterization of market size. This is followed by a comparison of market rules that are critical to demand participation. We will conclude with thoughts to bring together the effects of price, size and rules.

2. METHODS

The present analysis focuses on the six ISO/RTOs that are currently operating ancillary services markets in the US, shown in Figure 1. Those six are the California ISO (CAISO), Electric Reliability Council of Texas (ERCOT), Midwest ISO (MISO), Pennsylvania-New Jersey-Maryland Interconnection (PJM), New York ISO (NYISO), and ISO New England (ISO-NE). The analysis attempts to lay out relevant information for each ISO/RTO in order to highlight opportunities and challenges for industry to explore in these markets. This information is taken from publically available data on market clearing prices and procurement volumes from each of the ISO/RTO websites. Additionally, the ISO/RTO business manuals and tariffs were consulted to gain an understanding of the rules for market participation and how they differ between ISOs.

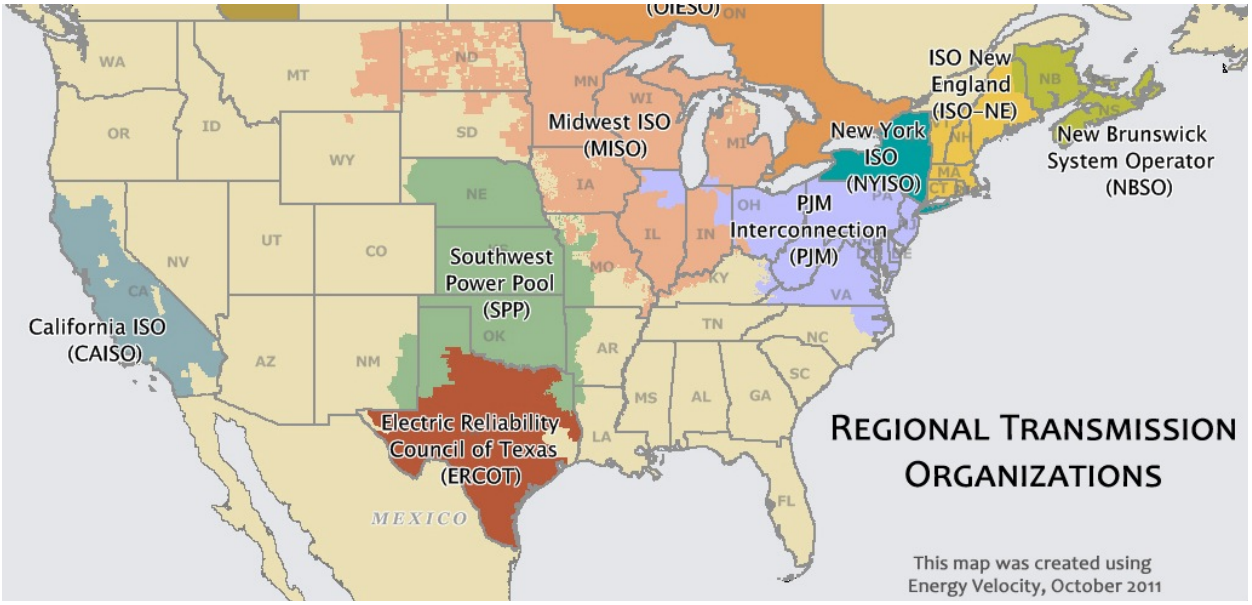

Figure 1: Map of ISO/RTO Balancing Areas in the US [16]

ISO/RTO Markets were evaluated using hourly price and procurement data. Hourly ISO/RTO Market Clearing Prices (MCP) for the years 2009-2011 were gathered using Ventyx's Velocity Suites data base, which queries the individual ISO/RTO sites. MCP is a product of a balancing area's system optimization and is the sum of the availability bid and opportunity cost (generally determined through co-optimization with the energy markets) of the most expensive resource awarded ancillary service capacity for each hour. In most markets, all awarded resources are paid the MCP regardless of how much less the sum of their bid and opportunity costs were. MCP is recorded in units of $/MW-h, where MW-h represents the value of a MW of capacity held in reserve for an hour. Where available, data on hourly AS procurement volumes was collected for the years 2009-2011. These values, in MW-h, were gathered either through Velocity Suites or through the individual ISO/RTO sites themselves. They represent the amount of capacity procured in AS markets, but do not include capacity that was self-supplied or contracted out of market.

With the data collected, an analysis was performed using Matlab® to understand the market value of each service and the size of the AS markets. This was done by examining average prices and procurement for years, seasons, and months to give a sense of magnitude and trends in market prices. Additionally, variation across the hours of the day was examined. Finally, the size of the markets in dollars was determined through the product of MCP and capacity procurement volume.

3. MARKET VALUE OF ANCILLARY SERVICES

Two important factors in evaluating ancillary services markets are the market clearing price and the size of the markets. The market clearing price indicates what a new entrant into the market could expect to make in the near term. However, the effects of a large penetration of new low cost entrants into the market are uncertain and may have the effect of lowering the clearing price [17]. The volume of capacity procured in a market is one indicator of how robust it will be to these new entrants. When analyzed together, the market volume and the price paid for a service in that market indicate how much money is at stake. This analysis focuses on the two most valuable ancillary services: Regulation and spinning reserves. For reference, non-spinning reserves tend to be about 7% to 50% of the value as spinning reserves, depending on the ISO/RTO, and any 30-minute supplemental reserves are less valuable than non-spinning reserves.

3.1. Market Clearing Price

The market clearing price is set by the highest priced resource that is awarded. All units in a reserve zone are paid the same MCP.

Table 1 shows the annual average MCP for regulation and spinning reserves for each ISO/RTO with AS markets. Annual average MCP for regulation has been between \$37/MW-h and \$7/MW-h, with a median value of \$16.28/MW-h. If we assume that a resource provides these services for all hours of a 30-day month, these MCP values yield revenues between \$5 and \$26.5 per kW-mo, with a median of about \$11.7/kW-mo. The annual average MCP for spinning reserve among ISO/RTOs is between \$3/MW-h and \$10/MW-h, and a median value of \$5.24/MW-h. The ERCOT region in 2011 experienced brief periods of high prices that produced an anomalously high annual average of nearly \$23/MW-h. This range for the value of spinning reserve can be converted to typical DR value units, giving us a median value of spinning reserve at \$3.8/kW-mo. While analysis of the market clearing price for regulation provides a relative understanding of the value of the product, FERC Order 755 has fundamentally changed the way regulation will be compensated in the future by including payments for amount and quality of performance of the resource. This is expected to improve the market value of fast resources, such as demand response.

Table 1: Annual average market clearing prices (\$/MW-h) for regulation and spinning reserves in US ISO/RTOs (Darker cell shades indicate real-time markets, lighter are day-ahead markets)

ISO (Reserve Zone)	Regulation (Combined or Up/Dn)			10-min Spinning Reserves		
	2009	2010	2011	2009	2010	2011
CAISO (South)	NA	8.06/ 6.75	11.93/ 7.27	NA	5.24	9.45
CAISO (North)	NA	5.64/ 4.98	9.21/ 6.93	NA	4.07	7.23
ERCOT	9.70/ 7.25	9.81/ 8.27	22.67/ 8.58	9.95	9.09	22.92
MISO	12.43	12.17	10.83	4.03	4.02	4.03
PJM*	23.51	17.95	16.42	4.83	5.72	7.91
NYISO (East)	37.20	28.80	11.80	5.13	6.23	7.41
NYISO (West)	37.20	28.80	11.80	4.15	4.41	3.37
ISO-NE	9.26	7.07	7.16			

* MCP for spinning reserve is for Mid-Atlantic reserve zone in PJM, while regulation MCP is for all of PJM

In all eastern ISO/RTOs, regulation prices have fallen by varying degrees in the last three years (MISO, PJM, NYISO, and ISO-NE), particularly in NYISO, where the average MCP in 2011 is less than a third of the 2009 MCP. Conversely, spinning reserve MCPs have largely risen in the same period. However, the trends in the annual average should be confirmed by examining plots of monthly averages, like those of Figure 2 and Figure 3 used here as illustrative examples.

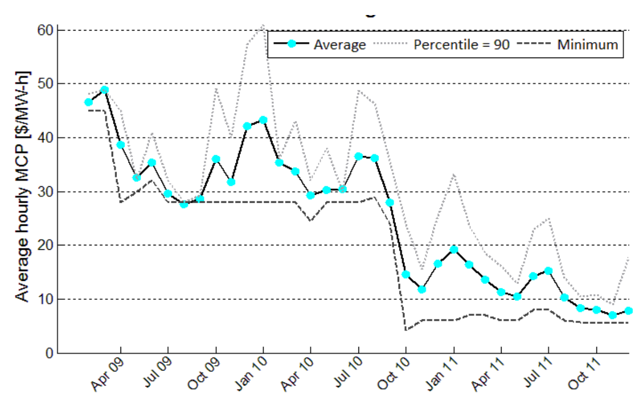

Figure 2: Monthly MCP statistics for NYISO regulation

Figure 2 shows a distinct downward trend in MCP over the three year period examined. This is similar to the trend in the average annual values in

Table 1. In contrast, Figure 3 provides a somewhat different picture of the meaning of the annual averages, as there is not necessarily a clear overall trend in the data, but

rather a seasonal effect, in which prices begin to rise in the spring in early summer. In fact, the rise in value of spinning reserve in CAISO in 2011 can be attributed to abnormally high amounts of rainfall, leading to a higher utilization of hydro power in the region for energy rather than ancillary services [18].

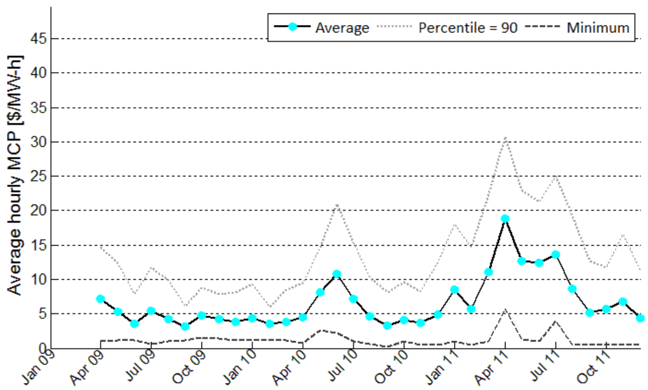

Figure 3: Monthly MCP statistics for Spinning Reserve in Southern CAISO

The difference between Figure 2 and Figure 3 demonstrate why it is important to consider a more granular historical price signal when considering the value available to new market entrants, especially for demand response entrants. Demand side resources are not available in the same quantities year round or even throughout the day [19]. In order to demonstrate the value to demand resources in providing ancillary services, an understanding of both the seasonal effects and the daily effects on prices are necessary. Figure 4 illustrates some of these daily and seasonal effects on MCP using the regulation up product in CAISO South as an example.

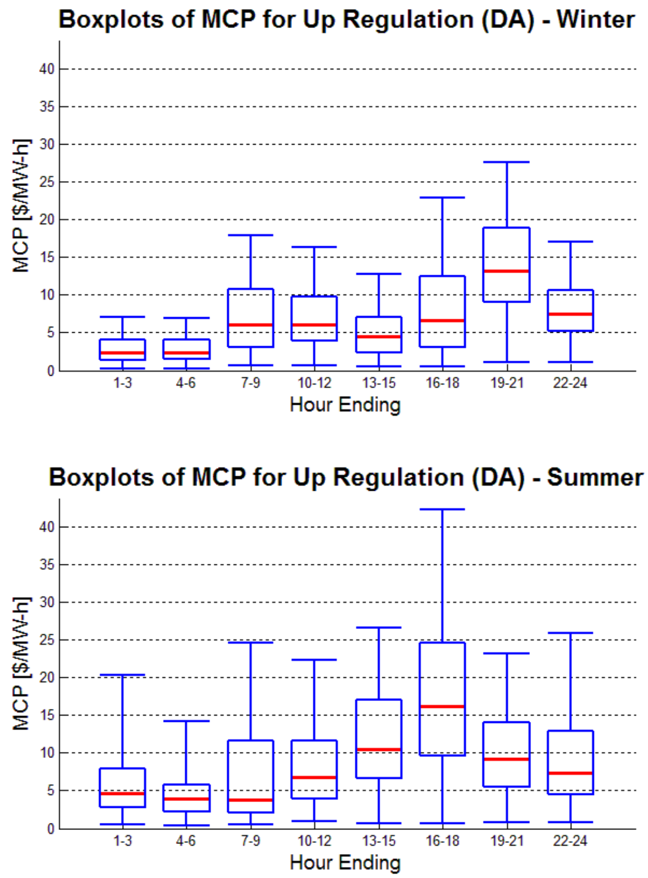

Figure 4: Boxplots indicating the daily and seasonal trends in CAISO South Regulation Up markets

The boxplots in Figure 4 represent all hourly MCP data for three hour blocks for all months of a season. The bold line in the center of each boxplot is the median; the box represents the data range from the 25th percentile to the 75th percentile. The whiskers are the minimum data point and the 90th percentile. In this particular example, the winter months appear to have a large price peak in the evening hours between 6 and 9 PM, with a slight peak in the morning hours as well in the 6 to 9 AM hour block. The early morning hours have much less value than other hours, causing a daily change in the medians of around $10/MW-h. This change in value throughout the hours of the day could indicate an opportunity for flexible loads able to provide services when they are most valuable.

The example given for summer months in Figure 4 shows a slightly different characteristic shape in the medians. There appears to be a single peak in the 3 to 6 PM block of data with the early morning hours still being the least profitable, yielding a larger daily change in the medians of approximately $12/MW-h. The shapes in Figure

4 indicate that some more seasonal loads may be ideally poised to take advantage of high prices in different markets. The following section will qualitatively describe the trends seen in the US ISO/RTO ancillary service markets based on analyses similar to those described here.

3.1.1. Trends in MCP in US ISO/RTOs

CAISO

A transmission line known as Path 26 is the divider between the major North and South Reserve Zones for CAISO. The MCPs in CAISO South are always greater or equal to those of the North because the MCP is the sum of the shadow prices caused by relaxing regional constraints. As a result, there are very similar trends in the MCP for ASs in North and South and only the south will be outlined here.

While there does not appear to be any clear overall trend in MCP for any of the products in CAISO, there does appear to be some seasonal variation, with spring and summer months displaying higher MCPs than Winter and Fall for all products. When looking at daily trends in the medians of regulation up and spinning reserve, summer and fall have shapes with a single peak, while there are two peaks in both winter and spring. The dominant peaks for these products tend to be in the 6 to 9PM 3-hour block, although during summer that shifts to 3-6PM. The minor secondary peaks are in the mornings and early afternoons. Early morning periods (midnight to 6AM) have much lower MCPs than any other times in the day, yielding daily fluctuations in the medians between \$6/MW-h (fall) up to \$12/MW-h (winter). Regulation down has very different daily trends that may be complementary to regulation up. Regulation down has the highest MCP during the early morning hours, from 3-9AM, in all seasons. The rest of a day tends to be relatively flat, with a slight dip in the medians to a minimum between 6PM and 9PM. However, the overall daily change in MCP is generally no more than \$3/MW-h, although the summer sees a larger change of \$6/MW-h. These trends suggest that for a flexible demand side resource, the most successful strategy may be to provide regulation down (load increases) as the demand ramps up, and then when the demand should be at its peak, the value of regulation up (load reductions) is at maximum. This seems complimentary to the natural state of most load profiles as when the load is low, there is more flexibility to increase consumption and when load is high, the most flexibility is in decreasing consumption.

ERCOT

While

Table 1 implies that there is a significant trend upward in the MCP of AS in ERCOT, closer inspection of the monthly average MCP suggests that there were only two months in 2011 that were outliers (and only about 10% of the hours of those two months) that have driven the average price of AS so high. If those two months are ignored, then there does not appear to be a clear trend over time in the price of ancillary services.

ERCOT is the only other ISO/RTO that splits regulation into two products, regulation up and regulation down. Like CAISO, regulation down is more valuable in the morning hours, particularly during the summer. The shape of the median MCPs for spinning reserve and regulation up are very similar to that of CAISO as well; however, the daily change in the median can be a bit more drastic. For regulation up, the medians suggest a daily variation of up to \$20/MW-h.

MISO

The MCP for regulation seems to be declining from 2009 to 2011, based on the monthly averages. It started around \$13/MW-h and ended at around \$10/MW-h. The same can be said of spinning reserve, falling from nearly \$4/MW-h down to almost \$2/MW-h.

For both spinning reserve and regulation, the median MCP for each three hour block displays two clear price peaks for all seasons but summer. These peaks are from 9AM to noon, and 6PM to 9PM. In summer the peak is in the 3PM to 6PM block. The lowest prices for either service are in the early morning hours from 3PM to 6PM. The difference between the minimum and maximum medians for spinning reserve MCP is between \$6 and \$8 per MW-h, and \$6 and \$13 per MW-h for regulation.

PJM

Market clearing prices for regulation in PJM fell between 2009 and 2011, and in this case the drop displayed in the annual averages, from about \$23.5/MW-h to \$16.4/MW-h well represents the trend. Additionally, MCP of regulation appears to be highest during the summer months and lowest during the winter. The MCP of spinning reserve trended slightly upward, with some seasonality indicating slightly lower prices during summer months. The MCP of spinning reserve for PJM used in this analysis corresponds to the Mid Atlantic reserve region; other reserve regions in PJM have very low MCPs for spinning reserve. The low MCPs throughout the rest of PJM may be due to an abundance of self-scheduled reserves, or to PJM's unique tiered structure to spinning reserves. PJM considers all capacity that is not fully loaded do to economic energy dispatch to satisfy their reserve requirement, so there may not be much need to deploy any additional spinning reserve through their markets.

There does not appear to be significant variation in the median MCP for regulation throughout the day in all seasons but summer in PJM. However, the distribution of

MCPs during the early morning hours appears to be much wider, and skewed toward values higher than the median, indicating more variability and higher average prices in those hours. The summer has some significant variability, with peak hours between 4-6AM, and a daily variation in the medians of approximately $10/MW-h with afternoon hours being the least valuable. The shape of median MCPs for regulation in PJM indicate that very different types of end use loads may be better suited to extract value from this market than CAISO, ERCOT, and MISO. The daily trends for spinning reserve had very similar daily trends in the medians as was seen in other ISOs, with summer showing the largest variation at nearly $7/MW-h in the medians.

NYISO

New York ISO has two reserve zones, East and West of the Central East interface. Regulation is shared among these reserve zones, but spinning reserves are not. When examining the trends in monthly average MCP, it is very clear that regulation fell significantly between 2009 and 2011, from above $45/MW-h for the first few months of 2009 down to below $10/MW-h for the last few of 2011. The average MCP of Spinning Reserve in NYISO East may have a slightly positive trend from 2009 to 2011. In the West, MCP for spinning reserve fell in price, particularly in the last 6 months of 2011.

Examining daily variation of the median price for Regulation shows that Spring and Summer months have relatively stable MCPs throughout the day, while winter and fall see wider variation with a two peak shape, both before and after typical work hours. Spinning Reserve MCP in the East has a very similar shape to most other ISO spinning reserve markets, with daily variation of the medians of near $10/MW-h. However, in the west there does not appear to be much seasonality at all in the shape. For all seasons, the early morning hours have prices near zero and nearly half of the day has an almost constant price of $7/MW-h.

ISO-NE

In ISO New England, the only product examined in this analysis is regulation. From 2009 to 2011, ISO-NE's Regulation MCP generally trends downward, beginning 2009 near $11/MW-h and falling down below $7/MW-h by for most of 2011. The medians of the three-hour block box plots suggest that ISO-NE maintains a fairly consistent MCP for Regulation throughout a day, with the Winter and Spring being slightly higher priced than Summer and Fall.

3.2. Market Capacity Volume

Capacity volumes in ISO/RTO administered ancillary services markets vary by the size of a balancing area and how the balancing area determines its reserve requirements. Some balancing areas determine their requirements based on the forecasted load, while others base it on time of day. Table 2 lists the average hourly capacity procurement in markets in which data was available. This data represents only the capacity that was purchased in the markets, and does not include any capacity that was self-scheduled or contracted for. In the table, CAISO is broken into North and South, and the capacity reported for PJM's Spinning Reserve Market is only representative of the Mid-Atlantic Reserve Zone. The table indicates that ERCOT holds the most spinning reserve procured in its markets, and that PJM has the largest amount of Regulation. The hourly capacity procurement data was not available for NYISO or ISO-NE, so these two ISOs will be omitted.

Table 2: Average hourly in-market capacity procurement volume [MW-h] for some US ISO/RTOs from 2009-2011 (Darker cell shades indicate real-time markets, lighter are day-ahead markets)

[MW-h]	Regulation			Spinning Reserves
	Up	Down	Combined	
CAISO-S	91	94		227
CAISO-N	92	98		289
ERCOT	628	606		1715
MISO			396	978
PJM			824	418

To put the average size of these AS markets into perspective, it is helpful to consider the average loads in the ISO/RTOs. In 2011, the average load in CAISO was 25.8 GW [18], making the total regulation (up or down) and spinning reserves procurement in market approximately 0.7% and 2.0%, respectively, of average load. In ERCOT, regulation (up or down) and spinning reserve are 1.6% and 4.5% of the 2011 average load of 38.2 GW [20]. In MISO, 0.6% and 1.5% of the 2011 average load of 64.6 GW [21]. And in PJM, regulation is 1.0% of the 2011 average load of 82.5GW [22]. As the spinning reserves reported are only for one of three reserve zones in PJM, they are only 0.5% of the 2011 average load. The variation in the relative size of the market volume is likely due to varying levels of self-scheduled AS that are not awarded via market mechanisms. The ancillary services markets are very small when compared to the energy markets in ISO/RTOs, but there is some uncertainty into the effects of this size. Traditional economic logic would suggest that a small market would not have a robust price, but due to the co-optimization of energy and ancillary services, it is possible that the ancillary services markets will be fairly robust to changes in a portion of their resources precisely because it is so small compared to the energy market. However, if the latter is true, then there will likely be a tipping point of low cost resource penetration in which the MCP begins to fall precipitously to zero (or whatever the availability bid will be).

3.3. Market Size

Using the data for MCP and the capacity procurement volumes, an estimate of annual market size in dollars was calculated for some of the ISO/RTOs. Table 3 displays the annual market size of regulation and spinning reserve markets in the US in millions of dollars per year. The market size for 2009 for both CAISO and MISO could not be calculated because of incomplete data. The data suggests that the deepest markets are in ERCOT's, although the spike in 2011 is largely due to a single month's extremely high prices.

Table 3: Annual market size (M$/yr) of US ISO/RTO Regulation and Spinning Reserve Markets (Darker cell shades indicate real-time markets, lighter are day-ahead markets)

[M$/yr]		CAISO-S	CAISO-N	ERCOT	MISO	PJM
Regulation	2009	NA	NA	105	NA	160
	2010	12	12	118	43	126
	2011	18	12	152	38	123
Spinning Reserve	2009	NA	NA	119	NA	24
	2010	11	14	122	33	32
	2011	19	18	462	23	51

4. MARKET RULES AFFECTING DR PARTICIPATION

Understanding the value of demand response in ISO/RTO markets is an important indicator of the opportunities that exist in the markets. Other important factors affecting market participation include the market rules as well as the regulatory and retail environments that these markets reside in. In the present paper, we consider some of the market rules at the wholesale level that affect DR participation in AS, but do not focus on the retail and regulatory context which can greatly influence the desire for these pro.

Rules and requirements that define ancillary services and dictate resource participation in ancillary service markets are not consistent across all ISO/RTOs. In this section, rules that effect demand response participation are compared across all markets. These rules are grouped into those that affect the size of the resource, the measurement of the resource, and who and when resources are bid into the markets. These rules were gathered from the business practice manuals, tariffs, and protocols of the various ISO/RTOs [23-34].

The magnitude of the effect of each market rule on participation varies. Rules that effect resource size tend to be the most important, because these exclude market participation for many resources. Rules effecting metering and telemetry may be the next most important, as they effect the capital investment required to enable a resource for market participation. Next, the possible exclusion of certain business types from being able to directly interact with markets can impact profit streams and exclude innovation by start-up organizations. Lastly, the discussion of bidding timelines is also important, but likely not the most critical, as these rules will impact the forecasting capability and the uncertainty inherent in resource capacity that is bid.

While these rules can have large impacts on the participation levels of DR, there are other influences to participation not covered in this analysis. Retail and regulatory environments may play a large role. In ERCOT, for example, the business model for demand response providers has the added challenge of a highly competitive retail energy market with considerable uncertainty in customer retention for retail energy providers. The risk that customers could change providers from month to month makes a DR enablement investment less appealing. In areas with regulated utilities, the cost of ancillary services is often a pass through. This provides little incentive for the utilities to pursue less expensive means to provide these services outside of regulatory intervention. Opening the ISO/RTO market rules up to demand response is important, but are not the only things preventing it from participation in these markets.

4.1. Resource Size

Demand response and other demand side resources will be smaller than traditional generators, and may be limited in the contiguous period in which they deliver a service. Table 4 and Table 5 describe the rules that affect the size of resources in Regulation and Spinning Reserve markets, respectively. These rules include the minimum resource capacity, whether or not aggregation of independently metered demand side resources is allowed, and limits on capacity for continuous energy delivery. Additionally, all ISO/RTOs but CAISO and ERCOT require that Regulation be supplied symmetrically in the up and down direction.

Table 4: Rules effecting size of Regulation Resources

	Min. Size (MW)	Aggregation Allowed	Symmetric Bid	Continuous Energy Period
CAISO**	0.5	No	No	60 min
ERCOT	0.1	No***	No	NA
MISO	1	No	Yes	60 min
PJM	0.1	Yes*	Yes	NA
NYISO	1	No	Yes	NA
ISO-NE	NA***	NA	NA	NA

*Requires approval.
** Forthcoming, WECC does not currently allow demand side resources to provide this product.
*** Pilots are underway to examine the ability to change this rule.

ISO-NE is the only ISO/RTO that prohibits demand response resources in their regulation market, although it has been running the Alternative Technologies Regulation Pilot Program to examine including other resources, including DR. CAISO is developing a market model to allow demand side resources into the regulation and spinning reserve markets, in spite of the fact that the Western Electricity Coordinating Council (WECC), the reliability regulatory body that CAISO's territory is in, does not currently allow demand side resources to participate in either market.

Splitting the regulation market into two parts, up and down, as was done in ERCOT and CAISO, may lead to more participation than in the other symmetric ISO/RTO regulation markets as loads and those who run programs for them are more familiar and capable of reducing load than increasing it.

In CAISO and MISO, there is a requirement that a resource providing AS must maintain its full AS capacity for a specified time in order to be certified and to bid into their AS markets. This continuous energy delivery requirement does not exist in the other ISOs for regulation. In most cases, certification is accomplished by demonstrating that the resource can follow a test AGC signal over a specific period of time. This requirement has the effect of artificially limiting the participation of some energy limited resources, such as demand response and storage.

Rules for allowing aggregation are believed to be of critical importance, because allowing aggregation can greatly increase the size of available resources to the market and lead to a more reliable, consistent response [8].

Table 5: Rules effecting size of Spinning Reserve resources

	Min. Size (MW)	Aggregation Allowed	Continuous Energy Period
CAISO**	0.5	No	30 min
ERCOT	0.1	No***	NA
MISO	1	Yes	60 min
PJM	0.1	Yes*	NA
NYISO	1	No	60 min
ISO-NE	1	Yes	NA

*Requires approval.
** Forthcoming, WECC does not currently allow demand side resources to provide this product.
*** Pilots are underway to examine the ability to change this rule.

4.2. Metering and Visibility

Metering and visibility refer to the metering and telemetry requirements for both settlement and operator visibility purposes levied on participants in an ISO/RTO. Telemetry refers to real-time meter data that is sent to the ISO/RTO over a secure connection with rapid periodicity for operational visibility. In this analysis, metering refers to revenue metering, sent to the ISO/RTO for settlement purposes, at much slower periodicities. As demand side resources are considerably smaller than traditional generators, metering and telemetry can be a large expense when enabling a resource to participate in AS markets relative to the value they receive from providing such services. Table 6 displays some rules that may be particularly relevant for demand side resources.

Metering accuracy affects the cost of the meter. As accuracy improves, costs increase. Requirements for revenue metering accuracy (in Table 6) are generally greater than telemetry metering accuracy in ISO/RTOs.

Telemetry is always required for regulation and in some ISO/RTOs it is also required for spinning reserve (SR in the table). By removing that requirement, the business case for DR is improved. In PJM, the data granularity is 2 seconds for telemetry, but it can be batch sent once every minute for DR resources which is a much less stringent requirement, particular for aggregated resources that utilize some front end computation in order to send their telemetered data.

In MISO, metering accuracy is not specified at the ISO level, but rather MISO accepts the requirements of individual states. This is in stark contrast to all the other ISO/RTOs who set the requirements themselves.

Some ISO/RTOs require there to be actual data collected and reported all the way to each individual resource, while others are content with verifiable aggregate level data for all of the resources in aggregation. The ability to provide aggregate data opens the door for advanced modeling techniques of aggregations that may reduce overall costs to provide telemetered ASs.

Table 6: A selection of ISO/RTO metering and telemetry rules

	Metering Accuracy	Telemetry Rate	Telemetry for SR	Data Level
CAISO	+/- 0.25%	4 sec	Yes	Resource
ERCOT	+/- 2%	3-5 sec	No	Aggregate
MISO	State Spec	4 sec	Yes	Resource
PJM	+/- 2%	2 sec	No	Aggregate
NYISO	+/- 2%	6 sec	Yes	Resource
ISO-NE	+/- 0.5%	10 sec	Yes	Resource

4.3. Market Bidding

The last set of rules indicates when and who can bid into the markets. Table 7 indicates the bid timeline for each ISO/RTO. For the real-time markets, '-1D' indicates the day before, 'OH' indicates operating hour, and 'OI' indicates Operating Interval (15 minute rolling intervals in CAISO, and 5 minute in MISO). ISO-NE uses the results of its Forward Reserve Market in its energy market to dispatch its Spinning Reserves, and thus does not have a separate reserve market. As most ancillary services are procured in the day ahead markets, demand side resources will want to participate in those markets. In some demand side applications, these bid times could increase the level of uncertainty in the available capacity of demand available to provide the ancillary service. Thus, earlier bid times may reduce the amount of resources in the market.

Table 7: Bid Timelines for ISO/RTO AS Markets

	Day-Ahead		Real-Time	
	Bid Closes	Awards	Bid Closes	Awards
CAISO	10:00 AM	1:00 PM	OH-75min	OI-7.5 min
ERCOT	10:00 AM	2:30 PM	OH-60 min	OH-30min
MISO	11:00 AM	3:00 PM	OH-30 min	OI-5min
PJM	NA	NA	6PM -1D	OH-30min
NYISO	5:00 AM	11:00 AM	OH -90min	OH-30min
ISO-NE	NA	NA	NA	NA

In addition to the timeline of the markets, the markets also limit who can bid demand side resources into the markets. In both ERCOT and CAISO, all market participants must be represented by a specific entity (a Qualified Scheduling Entity in ERCOT, or a Scheduling Coordinator in CAISO) that is financially responsible for all interactions with the market and undergoes special certification. For demand side resources in their AS markets, CAISO requires that the scheduling coordinator must be the Load Serving Entity (LSE) which precludes Curtailment Service Providers (CSPs) from participation. Although all of the other ISO/RTOs allow CSPs to participate in their markets, several of the states within the MISO footprint preclude CSPs from offering programs. CSPs who want to participate in the NYISO programs have an additional layer of complexity as they must interact with the transmission owner, who generally is the provider of telemetry data directly to the NYISO.

5. CONCLUDING REMARKS

The interest in fostering demand response participation in ancillary services markets requires a clear financial incentive and the market structures to capture it. This paper attempts to bring more transparency to the incentives available in each of the ISO/RTO AS markets. In addition, it identifies some rules that may make certain markets more favorable than others for demand response participation.

Two markets stand out as clear locations with potentially the best demand response opportunities. PJM has the most favorable market rules for demand response participation, particularly because its telemetry requirements are the most flexible, the bid is closest to real time, and they allow aggregation in all products. The market value in PJM is fairly consistent, with typically average MCP and some of the largest markets in the US. The one challenge in PJM may be the symmetric bid requirements for providing regulation.

ERCOT also seems to be a good fit for demand response participation. Prices in ERCOT are typically high and the volumes are large relative to the size of the system. Additionally, the market rules are more favorable for promoting demand side resource participation than most other ISOs, and they have split regulation up and regulation down products, allowing for asymmetric regulation bids which should be good for demand response resources. Once aggregation is allowed in ERCOT, this may be the best ancillary service market opportunities for DR in the US.

To further promote participation of demand response in ancillary service markets, other ISO/RTOs should consider reducing the minimum capacity for participation and allowing aggregated demand response resources. CAISO appears to have the closest to favorable market rules in those respects.

While PJM and ERCOT do appear to have the most opportunity for demand response, the regulatory and retail context of these markets was ignored in this discussion. This will likely play a large role in actual participation of demand side resources in ancillary services markets. Future work examining the interaction between retail and wholesale environments would be very valuable.

The market clearing prices for ancillary services display clear daily patterns in some markets that some demand response resources may be able to profit from. The flexibility and availability of some resources may correspond to high prices, allowing them to capture more revenue, especially in markets that have separate regulation up and down products. This result suggests that analysis of the value of ancillary service participation for demand response markets should include daily and seasonal variation in market clearing prices.

The analysis presented here assumes that market prices will be relatively consistent despite addition of new resources to the markets (e.g., demand response). This assumption may not hold given how small these markets are relative to the size of the overall energy market. Additionally, the mechanisms by which regulation will be compensated are changing as a result of FERC order 755. These changes should improve the business case for fast, accurate resources that can provide ancillary services, like demand response.

Future work is planned to augment the present analysis. This includes an examination of measurement and verification standards, including baseline calculation methods, as they are substantially different for demand response in ancillary services markets than other types of DR and an analysis of the operational models developed for the inclusion of demand response in ISO/RTO unit commitment and dispatch.

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Biography

Jason MacDonald, a Senior Scientific Engineering Associate at Lawrence Berkeley National Laboratory, has spent the majority of his career in distributed energy resources. As a member of the Grid Integration Group in the Environmental Energy Technologies Division at LBNL, Jason researches fast, automated demand response for bidding into bulk power system ancillary service markets. This work includes analyses of market and policy barriers to DR's market entry into ISO/RTO markets, and pilots to test control paradigms for resource aggregation of thermostatically controlled loads and PEVs for AS participation. Prior to joining LBNL, he pursued his graduate work in Mechanical Engineering and Sustainable Systems in the University of Michigan's Engineering Sustainable Systems dual degree program. As a student researcher, Jason examined the electricity consumption profile, fleet marginal electricity demand and environmental impacts of PEVs. He has held positions as a system engineer for a photovoltaic integrator in Southern California, and as a systems integration engineer on the Chevy Volt powertrain at General Motors.

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