Wind Integration Analysis for the Grain Belt Express HVDC Line

PREPARED FOR

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Table of Contents

Executive Summary

On February 11, 2015, the State of Missouri Public Service Commission issued an order requiring additional analyses of the potential economic effects of the proposed Grain Belt Express Clean Line project ("Project") on Missouri utilities and Missouri-owned or located generation. The Project is a high-voltage, direct current (HVDC) line that would connect wind resources in western Kansas to load in Missouri and Illinois/Indiana. To respond to the Commission's request, Clean Line Energy Partners LLC engaged The Brattle Group to analyze the effects of the Project on the ancillary service needs and costs in the Midcontinent Independent System Operator (MISO) system. In this report, we provide an analysis of the potential effects of importing approximately 500 MW of wind resources from western Kansas into MISO, considering MISO's ancillary service requirements and the statistical characteristics of wind resources from western Kansas relative to MISO's load.

Unlike traditional generators, the output of wind generators is both variable and uncertain. Power systems typically have existing capabilities to balance the grid considering the great variability and uncertainties associated with load levels. With the increasing deployment of wind generators, some systems have identified additional needs to help balance the combined effects of load and wind variability and uncertainty. When considering the potential needs of the system, one would need to analyze the characteristics of the wind resources to be added to the system. If new and existing wind generators' output is largely correlated with each other and that variability magnifies load-related variability, the potential need to balance the system could increase as more wind generators are being deployed. However, when the additional wind generation output is not well correlated with existing wind generation, the aggregate effect on system balancing needs can be minimal and even potentially reduce the costs of compensating for wind generation's variability and uncertainty.

Typically, as the distance between wind farms increases, the correlation of generation outputs across wind farms decreases. Thus, aggregating distant wind generators that have output that is not well-correlated with existing resources would be desirable and would not induce significant balancing needs from the rest of the system. Since the Grain Belt Express Project will connect wind generation from western Kansas to MISO, we find that the wind output it carries will be less correlated than if new wind generation was added within the MISO footprint. Therefore, wind resources from western Kansas will induce less of an increase in the aggregate variability of MISO wind generation than adding new wind generation to sites within MISO.

To date, MISO's ancillary services markets have enabled the installation of more than 12,000 MW of wind generation without causing significant system balancing or reliability issues. MISO currently sets requirements for spinning reserves and supplemental reserves based on the system's largest contingency. Integrating wind generation in MISO has not created system balancing challenges that required MISO to hold additional operating reserves. The Project will not change MISO's largest contingency, which means that MISO will not change the size of its spinning and supplemental reserves in response to integrating wind generation delivered over the Project. Thus, the Project will not cause any cost associated with increases in the need for spinning or supplemental reserves in MISO.

MISO also sets the requirement for regulating reserve, which is specifically designed to balance supply and demand on the system in real-time. MISO's regulating reserve procurements range from 300 MW during off-peak hours to 500 MW during ramping periods, with about 400 MW during peak hours. We understand that MISO has not and is not currently planning on procuring additional regulation reserves for the purpose of integrating additional wind generation. Even as more wind has been added to the MISO system over the last years, MISO has actually decreased its regulating reserve requirements. Unless MISO decides to change how it sets the magnitude of its regulating reserve requirement, the delivery of the wind generation from western Kansas to Missouri will not lead to additional regulating reserve needs. However, to err on the side of caution and to be responsive to the Missouri Commission's request, we estimate how adding wind resources could theoretically increase the need for regulating reserves in MISO by analyzing how wind generation from western Kansas would affect the overall variability and uncertainty of net load (the amount of load less the wind generation output) in MISO.

The Project would inject additional wind generation into MISO Reserve Zone 1, which covers a six-state area that extends from Iowa to Louisiana, including Missouri. Any incremental regulating reserve required as a result of the delivered wind generation by the Project would come from the most cost-effective resources across MISO, unless such incremental need would trigger a constraint on the system in such a way that only reserves from Zone 1 resources could meet the need. Historically, the price of regulating reserve has been uniform across MISO in more than 99% of all hours.

If MISO decides to procure more regulating reserves as a result of the wind resources added via the Project, we estimate that the incremental net load variability may increase to an extent that the additional regulating reserve requirement associated with integrating the wind resources delivered by the Project would be approximately 4.2 MW. We estimated this amount by analyzing the 5-minute variability and the 10-minute forecast uncertainty associated with the wind resources from western Kansas. Since 4.2 MW is small compared to the average of 400 MW of regulating reserves currently procured, the price of regulating reserves in MISO would not be affected significantly by the Project. With the theoretical 4.2 MW increase of regulating reserve need, we estimate that the high end of the range of the associated cost would be approximately $450,000 per year. Assuming procurement of regulating reserve remains largely unconstrained across MISO, and that the prices for regulating reserves remain uniform across MISO, as it has been historically, this cost would be shared across MISO's entire footprint and add on average about 0.1 cents per MWh of load in MISO. The analytical method used and the conclusions reached in this report are consistent with a majority of others' analyses on wind integration.

I. Introduction

Clean Line Energy Partners LLC ("Clean Line") has undertaken efforts to develop and build the Grain Belt Express Clean Line project ("Project"), a high-voltage, direct current (HVDC) line that would connect wind resources in western Kansas to load in Missouri and Illinois/Indiana. Grain Belt Express Clean Line LLC ("Grain Belt Express") is a wholly owned subsidiary of Clean Line. On March 26, 2014, Clean Line submitted an application to the State of Missouri Public Service Commission ("Commission") for a Certificate of Convenience and Necessity, authorizing Clean Line to construct, own, operate, control, manage, and maintain electric transmission facilities and a converter station in the state of Missouri.[1]

On February 11, 2015, the Commission issued an order directing Clean Line to file additional information and analyses before issuing a decision on Grain Belt Express' application.[2] Among the data the Commission ordered Grain Belt Express to provide were studies addressing the economic impact of the Project on the revenues and operational efficiency of Missouri utilities and Missouri-owned or located generation.

Clean Line has requested consultants at The Brattle Group to assist in analyzing the potential effects of the Project on the ancillary service needs and costs in the Midcontinent Independent System Operator (MISO) system. In that context, we analyze the potential effects of adding wind power generation delivered by the Project on the likely ancillary service needs and prices in MISO and the potential cost implications for Missouri load.

In this report, we provide an analysis of the potential effects of importing approximately 500 MW of wind resources from western Kansas into MISO, considering MISO's ancillary service requirements and the statistical characteristics of wind resources from western Kansas relative to MISO's load. We review the operations of MISO's ancillary service markets and estimate how the addition of wind could increase the quantity and price of each ancillary service procured. We then use historical wind and load data to measure the specific statistical properties of the wind imported through the Project and to estimate the potential impact, if any, on the ancillary service needs and costs to MISO and Missouri consumers.

Our analysis does not include detailed production cost modeling of the MISO system. We understand that Clean Line has conducted detailed simulations of the MISO markets and will separately prepare responses to the Commission's questions.

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1 See Grain Belt Express (2014)

2 See Missouri PSC (2014)

II. Background of Grain Belt Express

The proposed Grain Belt Express Clean Line is an overhead, multi-terminal +/- 600 kV HVDC transmission line, of which approximately two hundred and six miles will be located in Missouri. The estimated capital cost for the Project is approximately $2.2 billion, excluding the costs of network upgrades required to interconnect the Project to the existing transmission grid. Costs will be recovered through selling transmission service to wind generators and/or power purchasers that use the line. The project will provide wholesale electric transmission service, but the cost of the project will not be subject to FERC's cost-of-service regulation or that of any state utility commission.[3] Instead, Grain Belt Express will be developed as a merchant transmission project and will enter into contracts with the purchasers of the transmission capacity at negotiated rates overseen by FERC.

The Project will connect to the existing alternating current ("AC") transmission system through three converter stations. The first station will be located in western Kansas, where wind farms will connect via AC lines. Grain Belt Express will construct a second converter station and the associated AC interconnecting facilities in Ralls County, Missouri to deliver 500 MW of power to Missouri. The terminal point of the line will be a third converter station in eastern Illinois that will connect to the Sullivan 765 kV substation in southwestern Indiana, near the Illinois/Indiana border. The project is designed to deliver up to approximately 500 MW of wind energy from western Kansas to Missouri, and up to 3,500 MW of wind energy to Illinois, Indiana, and locations further east.

In November 2013, Grain Belt Express issued a request for information that indicated that wind generators in western Kansas were ready to develop projects with the capacity to produce over 13,600 MW of renewable energy, more than three times the delivery capacity of the Project.[4] This information shows that there is likely sufficient demand for the transmission capacity offered by Grain Belt Express and that wind developers believe high capacity factor wind generation from western Kansas will be competitive with other alternatives for meeting energy needs, including other renewable and non-renewable energy resources in the MISO and potentially beyond, in the PJM market.

III. Drivers of Wind Integration Costs and Benefits

Unlike traditional generators, the output of wind generators is both variable and uncertain. Variability refers to changes in output caused by fluctuations in wind speed. The variability of wind generation can increase costs to the system if it increases the volatility of net load (load net of aggregate wind production) and thereby increases the need for flexible resources, such as natural gas combined-cycle, combustion turbines, or hydroelectric generators to adjust their

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[3] See Grain Belt Express (2014)

[4] See Grain Belt Express (2014), p. 7

generation output to meet the system's needs as wind energy output varies over time. Uncertainty refers to inaccuracies in forecasting wind generation output in advance of the delivery time frame. This source of uncertainty can increase system costs if it increases net load forecast error, requiring the system operator to hold more resources as reserves.

The potential costs of compensating for wind's variability and uncertainty are reduced by aggregating wind resources whose outputs are not highly correlated; the lower the correlation among wind resources, the lower the variability of their aggregate output. The degree of correlation among wind farm outputs depends on the distance between wind farm locations and other geographic features, particularly weather patterns at their varying locations. Typically, as the distance between wind farms increases, the correlation of energy outputs across the wind farms decreases, thus increasing the benefits of aggregation. This concept of "geographic smoothing" results from the fact that wind generators at different locations will face different wind conditions and wind speeds at any given time. The "geographic smoothing" across diverse wind resources would provide greater capacity value for the wind resources. Even though we do not estimate such increase in capacity value in this report, the value can be quite significant. In parallel, interconnecting regions with diverse load patterns can help reduce generation capacity needs and thereby provide significant value to the interconnected region. Considering both of these factors, transmission lines that connect regions with diverse electricity loads and/or renewable generation output can bring great value by reducing the cost of generation capacity necessary to support the interconnecting regions. While we do not directly link this diversity value to the Project's potential impact on ancillary service needs, it is important to recognize that any potential increase in cost associated with increase in ancillary services needs would be offset by the increase in capacity value (or the reduction of capacity needs) associated with interconnecting two regions with diverse load and wind generation.

A. Wind from Western Kansas is Not Well Correlated with Wind from MISO

Since the Project will connect wind generation from western Kansas to MISO, the wind output it carries will be less correlated than a new wind farm added within the MISO footprint. Figure 1 below illustrates the simulated historical wind output data for a sample 5-day period in 2009 (April 1–April 5) for approximately 500 MW of wind in western Kansas and approximately 500 MW of aggregated wind output from high-quality wind sites in MISO (Northern Illinois, Northern Iowa, Michigan, Minnesota, and North Dakota). [5]

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5 We represent aggregate MISO wind generation by combining the generation from several sites from areas of Iowa, Illinois, Michigan, Minnesota, and North Dakota with high amounts of installed wind capacity. These five states contain 90% of installed wind capacity in MISO. Sites were selected to have a combined capacity of approximately 500 MW, in order to directly compare with amount of western Kansas wind to be delivered by the Project. Installed wind capacity data from Ventyx was used to weigh the amount of installed capacity from each of the five states. Iowa, Illinois, Michigan, Minnesota, and North Dakota were found to represent 43.6%, 6.0%, 11.9%, 23.7%, and 14.8%

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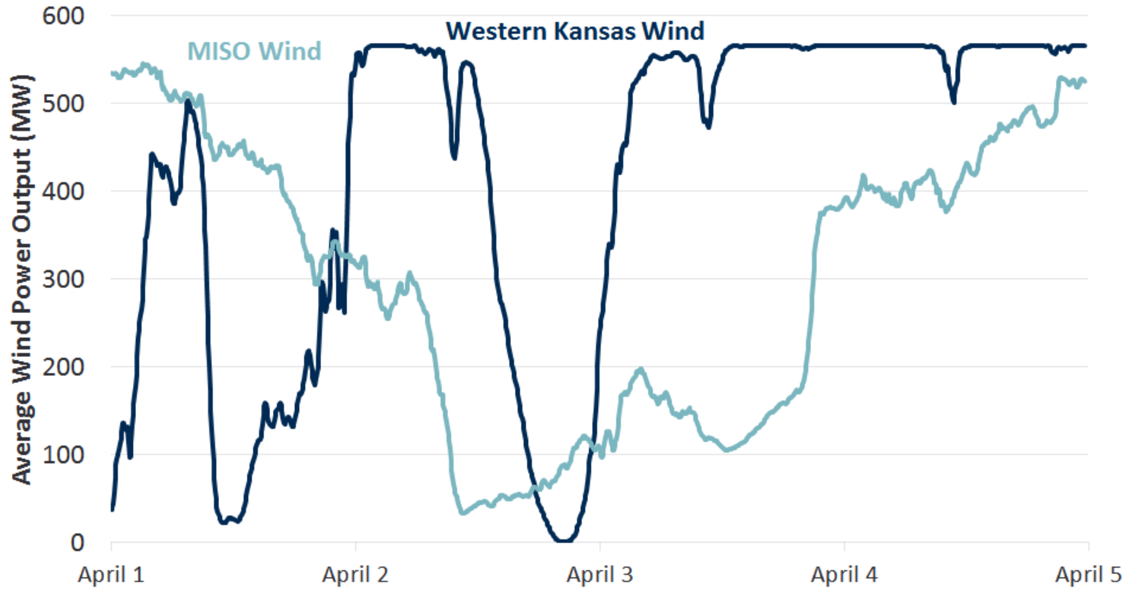
Figure 1
Wind Generation from Western Kansas and MISO Wind, April 1 – April 5, 2009



Sources and Notes:
5-minute simulated wind generation from NREL WIND toolkit, see NREL (2015). Western Kansas wind represents an aggregation of 70 simulated sites (566 MW installed capacity) in west Kansas. MISO wind represents an aggregation of sites in Illinois, Iowa, Michigan, Minnesota, and North Dakota (566 MW installed capacity), see footnote 5

B. Integrating Wind from Western Kansas Would Require Less Ancillary Services Than Additional Wind From MISO

Aggregating the output of many wind generators with diverse locations reduces the total variability of their generation output. Because wind generators in western Kansas are distant from the wind generators within the MISO footprint, the wind power delivered by the Project will be less correlated with existing aggregate MISO wind power than if new wind was developed inside the MISO footprint.

To estimate the correlation between the 5-minute changes in output between western Kansas wind and MISO's existing wind, we simulate adding approximately 100 MW of new wind generation from six locations: western Kansas and five states in MISO that have high quality wind resources (Illinois, Iowa, Michigan, Minnesota, and North Dakota). This means that we

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respectively of the aggregate wind capacity in these states. Therefore, Iowa, Illinois, Michigan, Minnesota, and North Dakota sites were assigned to contribute 240 MW, 34 MW, 68 MW, 144 MW, and 80 MW respectively. Clean Line anticipates that approximately 566 MW of installed wind capacity will subscribe to the Project to deliver to Missouri. The line losses on the Project are expected to reduce the amount of power delivered to MISO by about 5%–7% less than the 566 MW of maximum generation capacity we used in the analysis. A maximum of 500 MW would be delivered to Missouri at any one time. However, we have ignored the line losses in our analyses since it is not expected to affect the results in any significant manner.

compared the 5-minute variability associated with adding wind generators from western Kansas with adding *new* wind resources from the five states in MISO. These *new* wind resources are from different sites (even if from the same states) as the existing aggregate MISO wind resources. For each state, we aggregated wind generation from sites such that the simulated new generation capacity is approximately 100 MW. We then estimate the 5-minute output variability from each of the 100 MW of *new* capacity, and tested the correlation of these 5-minute changes to the 5-minute changes in aggregate MISO wind generation (see footnote 5 for details on how aggregate MISO generation was represented).

Table 1 below shows the correlation coefficients (by season) of 5-minute changes in generation between *new* wind resources and MISO's aggregate wind generation. A correlation coefficient of 1.0 would signify a perfect correlation between the 5-minute movements of the wind between western Kansas and MISO wind. A correlation coefficient of negative 1.0 would signify that the outputs from the different locations are exactly negatively correlated (or whenever the wind in one location increases, the wind from another location decreases by the same magnitude.) A correlation coefficient of 0 would signify that there is no relationship between the changes in the generation output from the two resources. We analyze the correlation of 100 MW of new wind capacity added from each of the six locations (western Kansas, Illinois, Iowa, Michigan, Minnesota, and North Dakota) to the representative bundle of existing MISO wind generation. As shown, due to geographic smoothing, the 5-minute changes of wind generation output from western Kansas is almost fully uncorrelated to the wind in MISO (with close to 0 correlation coefficient).

Table 1
Correlation Between 5-Minute Variability of New Wind Generation Added in Six Locations to Aggregate MISO Wind

	Summer	Winter	Annual
Western Kansas	**0.06**	**0.14**	**0.09**
Illinois	0.12	0.21	0.16
Iowa	0.60	0.72	0.63
Michigan	0.14	0.23	0.16
Minnesota	0.42	0.62	0.46
North Dakota	0.17	0.29	0.19

Sources and Notes:

This table illustrates the effect of adding 100 MW of newly installed wind capacity from each of the six locations (KS, IL, IA, MI, MN, and ND) to the aggregate existing MISO wind resources. Aggregate MISO wind generation is estimated as the combined generation from sites in IL, IA, MI, MN, and ND (566 MW total capacity). Newly installed wind capacities are from sites different than those included in the aggregate MISO wind generation capacity. For more details, see footnote 5. Wind data from NREL WIND Toolkit (NREL 2015).

Such correlation analysis shows that when combining wind from western Kansas with existing wind resources in MISO, the variability of the combined set of wind resources will exhibit less variability than had the new wind resources been added from one of the windy MISO states. This also means that adding approximately 500 MW of wind resources from western Kansas to MISO would likely have less effect on the variability of net load in MISO than adding wind from within MISO. Thus, when Grain Belt Express delivers wind resources from western Kansas, any additional ancillary services needed to support such new wind resources would be less than had the same amount of wind resources been added from within MISO states.

IV. Estimation of Needs to Integrate New Wind Resources in the MISO Market

The Project will deliver wind generation in western Kansas to a converter station in Ralls County, Missouri, where it will connect to the existing AC transmission system of the Ameren Missouri. MISO operates the Ameren Missouri's transmission grid and MISO's electricity markets. As a part of the operator's responsibility, MISO procures the ancillary services needed to help integrate the generation resources delivered to Missouri via the Project.

A. MISO's Ancillary Service Products and Markets Are Used to Integrate Renewable Resources

To date, MISO's ancillary services markets have enabled the installation of more than 12,000 MW of wind generation without causing reliability issues.[6] MISO manages several ancillary service products through its ancillary services markets that are designed to efficiently price the services needed to maintain system reliability in the face of variable and uncertain load and generation patterns. Both in day-ahead and in real-time, generators submit offers to MISO of the quantities and prices at which they are willing to provide energy and ancillary services. MISO then schedules and dispatches generators by co-optimizing the provision of energy and ancillary services from the lowest-cost combination of generators. Such market operations ensure that suppliers that have a competitive advantage in providing ancillary services are selected to do so. For example, a combined-cycle or combustion turbine unit that can quickly and cost-effectively ramp to meet load in five minutes will be dispatched to provide regulation, while a nuclear or other baseload plant that cannot ramp quickly but can provide energy cost effectively will be dispatched primarily to meet the energy needs in the market.

Table 2 below summarizes the various types of MISO's ancillary service products, and illustrates how the addition of wind could affect the quantity of each product. Both spinning reserve and supplemental reserve are referred to as contingency reserve (shown in Figure 2 below), and are designed to protect MISO from facing the largest contingency in the system.[7] Because the wind delivered via the Project will not change the single largest contingency for MISO, it will not

6 See MISO (2013a), p. 4

7 See MISO (2015a), p. 48

increase procurements of spinning reserve or supplemental reserve or affect the prices of these products.[8]

Regulating reserve is designed to balance supply and demand in real-time. According to the MISO Business Practices Manual, MISO procures sufficient regulating reserve to "ensure acceptable compliance levels with Electric Reliability Organization standards and applicable Regional Entity standards related to control performance."[9]

MISO's regulating reserve procurements range from 300 MW during off-peak hours to 500 MW during ramping periods, with about 400 MW during peak hours.[10] MISO staff has communicated that these levels are based on historical system information and are intentionally somewhat higher than what is required to meet the North American Electric Reliability Corporation's ("NERC") Control Performance Standard 1 ("CPS1"). CPS1 is a reliability standard with which Balancing Authorities must comply by controlling steady-state Interconnection frequency. As such, CPS1 measures each Balancing Authority's contribution to deviations from an Interconnection's target frequency.[11]

We understand that MISO has not and is not currently planning on procuring additional regulation reserves to integrate new wind resources added to its system. This means that it is likely that the current level of regulating reserve requirement is conservatively higher than what is necessary to meet the CPS1 reliability requirement. Even as more wind has been added to the MISO system over the past few years, MISO has decreased its regulating reserve requirements.

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8 The largest single contingency in the MISO system is the Riel-Forbes 500 kV line connecting MISO to Manitoba Hydro. See Cronier and Marvig, (2013), p. 20. MISO typically clears approximately 2,000 MW total of spinning and supplemental reserve, of which half to a third is from Reserve Zone 1, see MISO (2015b).

9 See MISO (2015a), p. 46

10 See MISO (2015b)

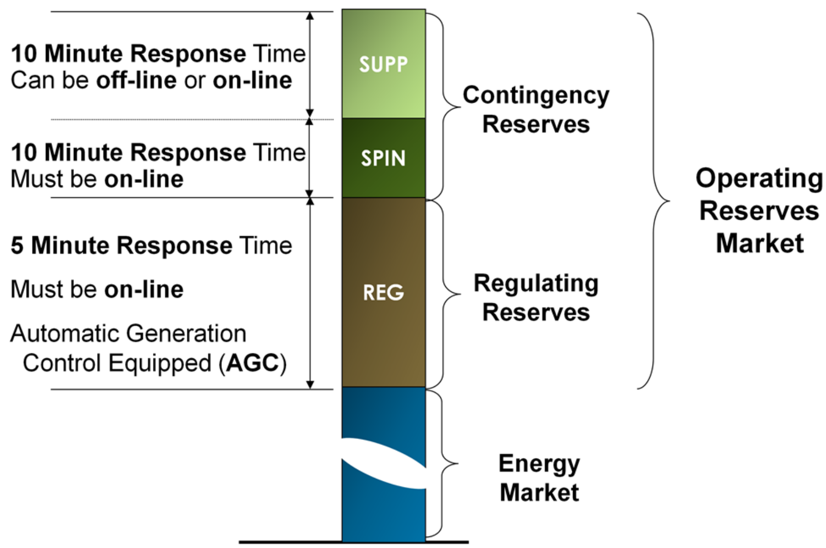
11 See NERC (2011) p. 33

Table 2
MISO's Ancillary Service Markets

Market	Description/Purpose	How Are Requirements Set?	Effect of Wind
Regulating Reserve	• Used to physically balance supply and demand in real-time • Resources need to be on line and be able to respond within 5 minutes	• At discretion of MISO system operators to maintain system reliability	• Wind could increase 5-minute variability of the net load and therefore could increase MISO's regulation reserve needs in the future • However, MISO has not and does not intend to procure more regulation reserves based on wind on the MISO system
Spinning Reserve	• Used to meet demand in the event of an unexpected loss of a generation or transmission resource • Resources must be synchronized and be able to respond within 10 minutes	• Based on single largest contingency	• Unless wind that is well correlated becomes the single-largest contingency, the requirement will not be affected by wind resources
Supplemental Reserve	• Used to meet demand in the event of unexpected loss of a generator or transmission resource, • Similar to spinning reserve, but resource can be offline and be able to respond in 10 minutes	• Based on single largest contingency	• Unless wind that is well correlated becomes the single-largest contingency, the requirement will not be affected by wind resources

Sources:
MISO (2014b), MISO (2015a), and communications with MISO staff.

Figure 2
Relationship between MISO's Ancillary Services and Energy Markets



Source:
MISO (2014b), p. 20

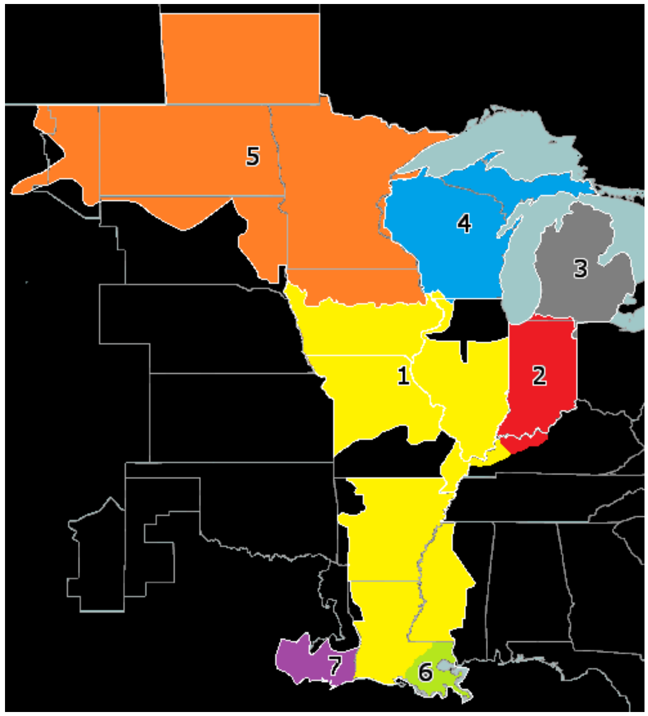
B. Historical Prices in MISO's Ancillary Services Markets

Through the day-ahead and real-time dispatch process, MISO procures sufficient regulating reserves, spinning reserves, and supplemental reserves to meet both market-wide reliability requirements and reliability requirements within each of seven MISO reserve zones (shown in Figure 3).[12] MISO dispatches generators to meet the overall requirements of MISO and the requirements of each zone simultaneously. If a particular zone's requirements will need to be met by a higher-cost resource than in another zone, the prices would differ between zones.

We understand that the wind resources delivered via the Project into MISO will be injected into MISO Reserve Zone 1, which covers a six-state area that extends from Iowa to Louisiana, including Missouri. If any additional ancillary services would be needed to support the new wind, it is possible that MISO would designate that the reserves be procured locally from Zone 1.

12 For details on the minimum zonal requirements, see MISO (2015a), pp. 51–53.

Figure 3
MISO Reserve Zones



Sources and Notes:
MISO (2014a)

Historically, the prices for ancillary services have been relatively uniform throughout MISO with little price differentials between the Reserve Zones. This means that even if different zones have different levels of requirements, the marginal resource used to meet the needs across all zones have the same cost. Table 3 shows the average annual MISO regulating reserve prices for 2011 – 2014. The average price is between $8.9/MWh to $12.1/MWh. Following that, Table 4 below shows the frequency and magnitude of the price differentials for regulating reserves across the seven zones in 2014. The first row shows that in 2014, Zone 6 had the highest number of hours among all other zones where its regulating reserves' prices were different from Zone 1's and those price deviations only occurred in 64 hours, or less than 1% of the hours. Row 2 in Table 4 shows that even in those 64 hours, the average difference was minimal, yielding almost identical average annual and seasonal regulating reserve prices for all zones. The historical uniform prices across the zones suggest that the regulating reserve requirement for each zone has been met through a common pool of resources for all zones. If such a price pattern continues into the future, we expect that resources across the entire MISO footprint would continue to be used to integrate wind from the Grain Belt Express.

Table 3
MISO Historical Annual Average Regulating Reserve Prices, 2011 - 2014

	Average Regulating Reserve Price ($/MWh)
2011	$12.0
2012	$8.9
2013	$10.2
2014	$12.1

Sources and Notes:

Regulating reserve prices tend to increase as energy prices increase due to the opportunity costs of providing ancillary services. See Potomac Economics (2013), p. 30, Potomac Economics (2014), p. 32 and MISO (2014a).

Table 4
Price Differentials between Each MISO Reserve Zone and Zone 1, for Regulating Reserves (2014)

		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Total Hours Different	[1]	0	14	32	43	38	64	39
Average Difference ($/MWh)	[2]	$0.000	$0.005	-$0.592	$0.031	$0.037	-$1.029	-$0.969
Average Annual Price ($/MWh)	[3]	$12.1	$12.1	$12.1	$12.1	$12.1	$12.1	$12.1
Average Summer Price ($/MWh)	[4]	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0
Average Winter Price ($/MWh)	[5]	$15.0	$15.0	$15.0	$15.0	$15.0	$15.0	$15.0

Sources and Notes: Ventyx (2015)

[1]: Number of hours (out of 8760) the price deviates from Zone 1 prices
[2]: Average price difference in the hours included in [1]
[3]: Average annual price
[4]: Average price in June, July, and August
[5]: Average price in December, January, and February

As required by the Federal Energy Regulatory Commission ("FERC") Order 755, issued in late 2012, MISO restructured the regulating reserve market by adding a payment for Regulation Mileage to compensate resources for how much they move to follow the regulation signal.[13] This "mileage" payment is in addition to traditional payments for regulating capacity, or the amount of capacity reserved to participate in the regulating reserve market. Figure 4 below shows the prices for the three types of reserves that MISO procures. As shown in the left-most panel, regulation mileage makes up a significant proportion of regulation price. However, according to MISO's 2013 State of the Market Report, the total regulating reserve prices were not materially affected by the addition of a mileage payment and the prices reported in Figure 4 still represent the typical price pattern for regulating reserves in MISO.

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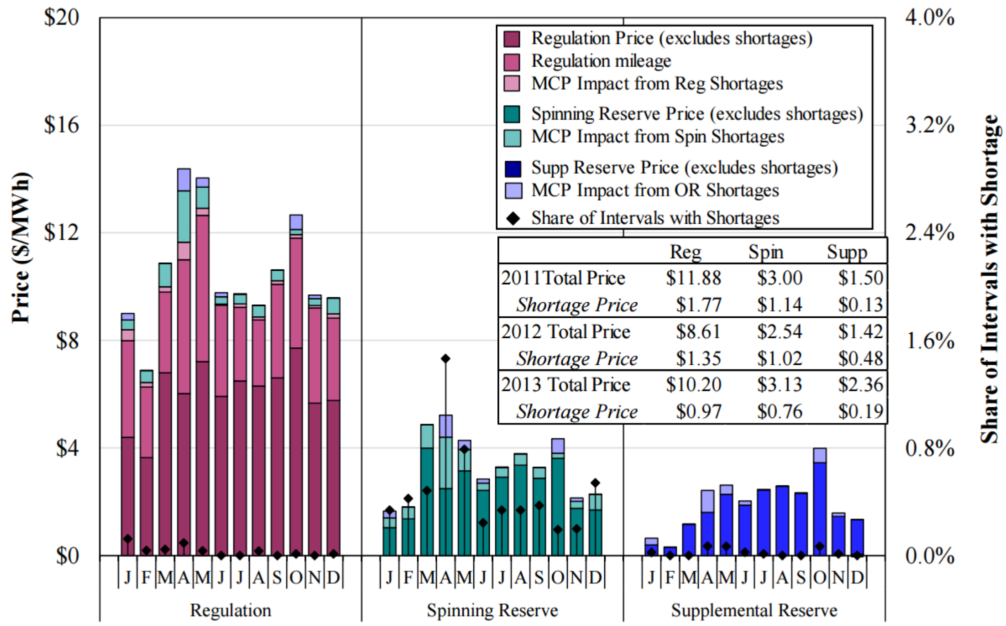
13 See MISO (2013c)

Figure 4
2013 Prices for MISO's Regulation, Spinning and Supplemental Reserves



Sources and Notes:
From the MISO 2013 State of the Market Report, see Potomac Economics (2014)

C. MISO's Dispatchable Intermittent Resource Program Allows MISO to Increase Its Efficiency By Managing the Output of the Wind Resources

In June 2011, MISO established the Dispatchable Intermittent Resource ("DIR") program, designed to improve MISO's ability to efficiently integrate and manage wind energy.[14] Under this program, wind resources are placed under the control of the system operator to respond economically to dispatch instructions.[15] Wind generators would need to provide MISO with their Forecast Maximum Limits, which are estimates of the maximum output the resources could produce given the short-term wind forecast data.[16] Based on the price and quantity of the wind generators' bid offers, MISO could dispatch the wind resources based on the economics of their bid offers and the price of energy in the market.[17] Wind resources under the DIR program are eligible to provide energy, but not operating reserves (regulating, spinning, or supplemental).[18] The implementation of the DIR program has improved MISO's ability to respond efficiently and

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14 See Potomac Economics (2014)

15 See MISO (2011b), pp. 2 - 3

16 Registered DIR resources provide a rolling forecast of 12 five-minute forecasts of their Forecast Maximum Limit, see MISO (2011a), p. 9

17 See MISO (2015a), p. 157

18 See MISO (2015a), p. 157

reliably to the variability and uncertainty of wind generation within the MISO footprint, and the program almost entirely has eliminated manual wind curtailments.[19]

D. Estimated Incremental Regulating Reserve Needs Are Minimal

In this section, we provide a first-order approximation of the potential integration costs of wind delivered via Grain Belt Express into MISO Reserve Zone 1. We use publicly available data from MISO and simulated wind energy data from the NREL WIND Toolkit. As discussed above, in Section IV.A, spinning and supplemental reserves are designed to protect against the failure of the largest contingency in the MISO system and therefore will not change due to the addition of the wind delivered via Grain Belt Express. Thus, we focus our efforts on estimating the potential costs associated with the potential need for additional regulating reserves to compensate for the variability and uncertainty of wind delivered by the Project.

Also as discussed in Section IV.A, MISO currently does not intend to its increase regulating reserve requirements based on the amount of wind resources on its system. Nevertheless, to err on the side of caution and to be responsive to the Missouri Commission's request, we estimate how adding wind resources theoretically may increase the need for regulating reserves in MISO.

Below, we analyze the potential effect of added wind on regulating reserves by estimating the increase in short-term overall net load variability and uncertainty that 500 MW of wind delivered by the Project may induce on the MISO system.[20] Specifically, we estimate the variability of wind from western Kansas as the 5-minute change in wind output, using simulated wind data from the NREL WIND Toolkit.[21] We also estimate the short-term forecast error for the wind resources by assuming that the wind generation forecast for each 5-minute period is based on the actual generation output 10 minutes prior. Using such a 10-minute "persistence" forecast approach is consistent with common industry practice and with the time frame MISO uses to estimate the Maximum Forecast Output level of the resources in its DIR program discussed above.[22]

Because we do not have access to MISO's 5-minute load data, we are unable to estimate the variability and uncertainty associated with MISO's load at the same 5 minute granularity. Instead, we make the common assumption that short-term wind generation variability and uncertainty are statistically independent from the short-term variability and uncertainty of load.

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19 See Potomac Economics (2014), p. 49

20 Although 500 MW of wind will be delivered by the Project, our estimates of variability and unpredictability are based on the 566 MW of installed wind capacity that is anticipated to subscribe to the Project.

21 See NREL (2015)

22 MISO uses the 10-minute ahead wind generation forecast to estimate the Maximum Forecast Output level of Dispatchable Intermittent Resources (DIR), see MISO (2011a), p. 4. 10-minute persistence forecasting is assumed by many wind integration analyses, see Milligan *et al.* (2010)

With this simplifying assumption, we use the formula shown in Equation 1 below to estimate the combined variability of load and wind.[23] Equation 1 shows that the variance of the "net load" is equal to the sum of the variance of the load before the wind is added and the variance of the wind.

$$Var(net\ load) = Var(load) + Var(wind) \qquad \text{(Eq. 1)}$$

Variance is a statistical term that is equal to the square of the standard deviation of a distribution. Standard deviation is a measure of the spread of the distribution from the mean of the distribution. For the purpose of our analysis, we use a commonly-used method to measure system variability, which is the "3-sigma," or the "three standard deviation" threshold for changes in the five-minute load.[24] Three standard deviations of a normal distribution would account for about 99.7% of the distribution. Thus, when one says that MISO would procure enough regulating reserve to account for 99.7% of the load variance, it means that MISO would measure the distribution of the load variations and procure sufficient regulating reserves to account for 99.7% of the level of 5-minute changes in load levels (in MW).

MISO on average procures approximately 400 MW of regulating reserves, with procurements varying from 300 MW to 500 MW depending on the time of day.[25] Assuming that MISO currently procures 400 MW of regulating reserves to cover three standard deviations in the load variability, measured by changes across 5-minute load levels, we estimate that the standard deviation of MISO's 5-minute net load is roughly 133.3 MW (or 400 MW divided by 3 standard deviations). The variance is the square of the standard deviation; therefore we estimate that the variance associated with the 5-minute MISO load levels is roughly 17,777 MW^2.[26] Our estimate for the standard deviation for the 5-minute load variations includes several simplifying assumptions because we do not have access to actual historical 5-minute net load data from MISO.

Next, we estimate the variance of wind generation output and the wind forecast errors associated with the western Kansas wind resources. We estimate the variance of generation output based on the changes in the wind output for every five minutes. For the wind forecast errors, we estimate the variance across 5-minute periods based on the "persistence forecast" of the wind output from ten minutes prior. For both estimations, we use the simulated NREL WIND Toolkit data for approximately 500 MW of nameplate capacity of wind from western Kansas.[27] Because

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23 See Hudson *et al.* (2001) and Chang and Hanser (2010).

24 See Zavadil (2014) and EnerNex (2011)

25 See MISO (2015b)

26 The variance is the square of the standard deviation, therefore we estimate that the variance associated with the 5-minute MISO load levels to be roughly $(133.3\ MW)^2$ or 17,777 MW^2.

27 We use simulated data because 5-minute measured data was not available. Our analysis is therefore limited to the extent that the simulated wind data does not accurately capture the actual variability of

Continued on next page

wind variability and forecast error are not statistically independent, we also consider the covariance between the two. The equation of such estimation is shown in Equation 2 below.

$$Var(wind) = Var(wind_{5-\min changes}) + Var(wind_{ForecastError}) + 2Cov(wind_{5-\min changes}, wind_{ForecastError}) \quad \text{(Eq. 2)}$$

Based on statistical analyses of the wind data, we find that the standard deviation for the 5-minute wind output is 4.7 MW. With the same calculation, the standard deviation of the wind forecast errors is approximately 9.1 MW. Including the covariance of the two terms (approximately 137.7 MW^2), the overall variance of western Kansas wind is roughly 380 MW^2, with the majority of the variance being driven by the forecast error.[28]

Using Equation 1 above and the assumption that the variance for MISO's net load today is about 17,777 MW^2, and the estimated 380 MW^2 for wind, the combined variance is 18,157 MW^2.[29] Converting the variance back to standard deviation, we find that the resulting standard deviation in load plus wind is the square root of 18,157 MW^2, or approximately 134.7 MW.[30] Given that, we estimate that the incremental change in the standard deviation of net MISO load, calculated as the change from the prior 133.3 MW to the new 134.7 MW is about 1.4 MW.[31] If we assume that MISO will procure enough regulating reserves to meet 3-standard deviation of the net load with the wind from western Kansas added to MISO, we estimate the incremental regulating reserve requirement would be in the range of 4.2 MW (or 3 times 1.4 MW).[32]

This small amount of regulating reserve estimation means that *if* MISO currently procures exactly the right amount to meet the current variability and uncertainty around net load today, the 500 MW of wind resources delivered via the Project *could* increase MISO's regulating reserve requirement by about 4.2 MW. This finding is based on the assumption that the current 400 MW of regulating reserves is just sufficient to meet MISO's needs. However, as MISO staff has indicated to us, MISO is actually procuring slightly more than it needs to conservatively operate the system, leaving sufficient room to accommodate additional wind resources to be added to the system without actually having to revise the levels of its regulating reserve requirements. Thus,

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Continued from previous page

wind. For example, if the simulated wind data underestimates or overestimates the likelihood of very large changes in 5-minute generation, our results will also result in an underestimation or overestimation of the wind variability and regulating reserve requirements.

28 $(4.7\text{ MW})^2 + (9.1\text{ MW})^2 + (2 \times 137.7\text{ MW}^2) = 380.3\text{ MW}^2$

29 $17{,}777\text{ MW}^2 + 380.3\text{ MW}^2 = 18{,}157\text{ MW}^2$

30 $\sqrt{18{,}157\text{ MW}^2} = 134.75\text{ MW}$

31 134.74 MW – 133.33 MW = 1.41 MW

32 Our statistical analyses follow common industry practice and assume that 5-minute variations and forecast errors are normally distributed. If actual 5-minute variations and forecast errors are not normally distributed, but have a higher probability of large deviations, we will somewhat underestimate the variance of wind and therefore underestimate the regulation requirements of the Project.

our estimation represents a theoretical upper bound of the range of future regulating reserve requirement that could be attributable to adding additional wind delivered via the Project. Since we could not obtain 5-minute *net* MISO load data, we also could not estimate by how much the diversity of the western Kansas wind could actually offset the system's regulating reserve needs by "smoothing" out some of the variability of the existing net load, and thereby reduce the theoretical magnitude of the incremental regulating reserve requirement.

The incremental need for regulating reserves in MISO associated with the wind resources that the Project would deliver is sensitive to the wind forecast accuracy. Our analysis assumes that 10-minute persistence forecasts are used to forecast real-time wind generation output. However, if forecasts could predict wind generation twice as well as a 10-minute persistence forecast (i.e. the forecast errors were reduced by half), the overall variance of wind would fall from 380 MW^2 to 180 MW^2, due to reductions in the variance of forecast error and covariance between forecast error and the 5-minute change in wind.[33] If that is the case, the incremental regulation requirement would fall from approximately 4.2 MW to 2.0 MW.[34]

Further, because the wind from western Kansas is not well correlated and the variance of the wind generation output is not well correlated with the existing or future additional wind resources within the MISO footprint, we expect that adding the wind from western Kansas actually would have less impact on the need for additional regulating reserves than what might be needed to support additional wind resources from MISO (See Section III.B).

E. Cost of Additional Regulating Reserves IS Also Minimal

Based on the analysis described above, the upper bound on the regulating reserve requirement associated with the wind generation delivered via the Project would be approximately 4.2 MW. As we indicated above, since historical prices for regulating reserves have not shown significant price differences across the MISO zones, we anticipate that all resources in MISO can help meet that incremental need. Since 4.2 MW is small compared to the average of 400 MW of regulating reserves currently procured, we assume that this incremental amount will not increase prices for the services. Table 4 above shows that the regulating reserves market's clearing prices in Regulation Zone 1 during 2014 were the same as in the rest of MISO in almost all of the hours. The average hourly regulating reserve market clearing price in 2014 was $12.1/MWh, with a distribution that ranged from $1.8/MWh to $1,360/MWh, with prices below $60/MWh in about 99% of hours. If indeed MISO decides to procure additional 4.2 MW in regulating reserves in every hour, the estimated cost of this upper bound of the potential cost range would be approximately $450,000 per year. Assuming that the incremental cost will be distributed across

33 Halving forecast error would reduce the standard deviation of the forecast error from to 9.1 MW to 4.5 MW and covariance to 68.8 MW^2. 180 $MW^2 = (4.7\ MW)^2 + (4.5\ MW)^2 + (2 \times 68.8\ MW^2)$

34 Wind standard deviation = 134 MW = $\sqrt{17{,}777\ MW^2 + 180\ MW^2}$.
Incremental increase in system standard deviation = 0.67 MW = 134.00 MW – 133.33 MW
3-sigma increase in regulation requirement = 2 MW = 3 x 0.67 MW

all of MISO's load, which amounts to approximately 690,000 GWh per year,[35] on average, this cost would add about 0.1 cent per MWh of load in MISO. Again, this is the upper bound of the potential impact because we have not offset this estimate by the degree that the western Kansas wind is diverse from the rest of the wind in MISO and therefore likely to reduce the aggregate system's regulating reserve requirement.

MISO has sufficient supply of cost-effective ancillary service resources to aid in wind integration. One such future additional resource is the increase of use of hydroelectric resources via the addition of a 500 kV line between Manitoba to MISO that would allow MISO access to additional resources to help balance the system when additional intermittent resources are added. The new hydro resources, if connected to MISO through the proposed 500 kV line, could add to the supply of regulating reserves and thereby decrease their prices and costs.[36] Thus, the future prices for MISO's ancillary services may actually be lower than it has been historically, all else equal.

V. Review of Wind Integration Literature

Wind generation integration analyses have become increasingly important as the amount of wind deployed on power systems has increased. A large body of literature examines and provides analyses of the potential costs and requirements of integrating wind generation onto power systems. Many wind integration studies evaluate the effect of wind generation on reserve requirements. The findings of these studies are sensitive to variations in how ancillary service products are defined on a given system, the existing availability of reserves, and the geographic diversity and quality of wind generation added. Most wind integration studies use statistical analyses to evaluate how the addition of wind will increase reserve requirements. The studies generally consider the effects of adding large amounts of installed wind capacity, up to 25% of peak load. In contrast, the 500 MW of installed wind capacity we evaluate in this report would only represent about 0.5% of MISO's 2013 peak load of 94,000 MW.[37]

In 2008, the Electric Reliability Council of Texas (ERCOT) evaluated the regulation requirements of integrating 5,000 MW, 10,000 MW, and 15,000 MW of new wind resources.[38] This wind capacity addition would have represented of 8%, 16%, and 24% of ERCOT's 2008 peak load of 62,000 MW, respectively.[39] The study included simulations of the ERCOT's regulation requirement on a minute-by-minute basis and found that to integrate 15,000 MW of new wind

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35 MISO 2014 net generation, SNL (2015)

36 See MISO (2013b)

37 See SNL (2015)

38 See GE (2008), pp. 6-1 to 6-42

39 See SNL (2015)

(24% of ERCOT's peak load), ERCOT would need to increase regulation procurements by 285.8 MW for up-regulation and -281.2 MW for down-regulation.[40]

In 2010, PacifiCorp conducted a wind generation integration analysis that evaluated how the addition of up to 1,833 MW of new wind capacity would increase operating reserve and load following reserves.[41] This wind capacity addition would represent 20% of PacifiCorp's 2010 peak load of 9,418 MW.[42] The study used concurrent 10-minute interval wind generation and load data from 2007–2009 to estimate the amount of operating reserve, both up and down, needed to manage wind and load variability. Three levels of wind addition were considered: 425 MW, 1,372 MW, and 1,833 MW. The addition of 425 MW was found to increase the total regulation up requirement by 10 MW and regulation down requirement by 15 MW. The addition of 1,833 MW was found to increase total regulation up requirement by 132 MW and regulation down requirement by 164 MW. Total wind generation integration costs for the 1,833 MW scenario were found to be $9.70/MWh. However, a subsequent 2012 update to the analysis of the same system revised the cost estimate down to $1.89/MWh due to refinements to the analyses.[43]

A 2010 report by NREL summarized the findings of nine different wind generation integration analyses for a variety of U.S. and international systems.[44] The majority of studies quantified reserve requirements with statistical methods using the standard deviation of wind variability, similar to the approach used in our analysis. In general, the studies found that integrating wind would not require large increases in operating reserves. For example, a 2005 New York wind integration study found that the addition of 3,300 MW of wind power, or 10% of peak load, would require an additional 36 MW of regulating reserve.[45] In Minnesota, a 2006 study estimated that the addition of 5,688 MW of wind capacity would increase regulating reserve requirements by 20 MW.

We have used consistent analytical methodologies as those used in other wind energy integration analyses in the industry. While the precise ranges of the additional regulating reserve requirements associated with adding wind resources are sensitive to the statistical features of the wind resources and load on the system, and the relative size of the wind generation addition, the findings in this report are within the reasonable range of other analytical findings. Generally, the magnitude and costs of additional regulating reserve requirements to help integrate wind

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40 This regulation procurement would cover wind variability in 98.8% of hours, see GE (2008), pp. 6-9 to 6-10

41 See PacifiCorp (2010)

42 See SNL (2015)

43 See PacifiCorp (2012)

44 See Milligan *et al.* (2010). The study evaluated the effect of wind integration on systems including Minnesota, New York, the U.S. Eastern Interconnect, Western Interconnect, Ireland, Spain, the Netherlands, Denmark, and Quebec.

45 NYISO 2005 peak load was 32,000 MW, see SNL (2015)

resources would not be substantial. As the industry moves toward much improved wind energy forecasting and as system operators have more tools to manage changes on the system, such as MISO's practice of dispatching the system on a 5-minute basis, the cost of integrating intermittent resources will decrease. However, if the system integrates an increasing amount of wind resources that are well-correlated such that when the wind stops blowing or is blowing too strongly, a very large amount of generating resources simultaneously would drop off of the system, MISO may need to change the requirements for contingency reserves (spinning and non-spin reserves). As we pointed out earlier, because the wind from western Kansas is much less correlated with wind resources from MISO, such a lack of correlation should help reduce any potential future need for additional contingency reserves compared to adding wind from the same area as the existing resources on the system.

VI. Conclusions

While adding intermittent wind resources to a system has been shown to increase the need for ancillary services that help balance the system, the amount of incremental need depends greatly on the characteristics of the system and of the wind resources being added. The intermittency of wind resources can be described to include "variability" and "uncertainty." "Variability" of wind resources stems from changes in output that occur over time due to changes in wind speed. The "uncertainty" of wind relates to the difference between the forecast levels of energy output from wind generation versus the actual energy output during real-time operations. Because of the variability and uncertainty, adding wind resources to a system can require using other dispatchable supply or demand resources on the system to maintain system balance.

Our analysis shows that the output of wind farms located in western Kansas is not well correlated with the output of other wind generators on the MISO system. This lack of correlation provides geographic diversity value to the MISO system and decreases the additional generating capacity that MISO would need. Further, since the wind resources from western Kansas are not well-correlated with the existing or new wind resources to be added within MISO, adding wind resources from western Kansas will help counterbalance some of the variability of the wind resources that the MISO system currently experiences. Thus, the ancillary services needed to accommodate the incremental wind resources delivered by the Project will be less than the amount of ancillary services needed to accommodate incremental wind resources added from MISO's footprint.

MISO procures three ancillary services to compensate for short-term variability and uncertainty: regulating reserve, spinning reserve, and supplemental reserve. Spinning and supplemental reserve are ancillary services that MISO procures to ensure that the system can reliably operate even when the system encounters the largest contingency. Since neither the Project nor the wind resources carried by the Project will be the single largest MISO contingency, MISO will not need to procure spinning or supplemental reserves to support the wind resources delivered by the Project, thus no additional integration cost associated with contingency reserves will be incurred by MISO load.

MISO procures regulating reserves to manage variability and uncertainty in net amount of load (that is, load net of the amount met by wind generation) served by MISO that occurs on the timeframe of less than five minutes. In MISO, the system operator procures adequate amounts of regulating reserves to maintain system reliability according to NERC standards. MISO currently does not intend to increase its regulating reserve requirements based on the amount of wind resources on its system.

We estimate that if MISO were to procure regulating reserve to accommodate the variability and forecast uncertainty associated with 500 MW of wind delivered from western Kansas, MISO may need to increase the regulating reserves by approximately 4.2 MW, if the amount MISO currently procures is precisely the amount needed for the existing system. This small amount of incremental regulation need would be inconsequential compared to the regulation need to support the existing system's net load variability and forecast uncertainties. Further, because of such small amount of incremental need, the price of regulation in MISO would not be affected significantly. Thus, we estimate that the high range of the cost estimate would be approximately 37,000 MWh of annual regulating reserve multiplied by the average price of regulation in the range of $12.1/MWh, resulting in approximately $450,000 per year. In the vast majority of hours the prices for the regulating reserves are uniform across MISO. Thus, assuming that Zone 1 does not procure more than other region proportionally to the zone's load, the costs associated with any such incremental regulation, if procured by MISO, would be similar to being shared by all electricity consumers in MISO, and on average only add 0.1 cents/MWh to the average wholesale cost of electricity in MISO.

The analytical method used and the conclusions reached in this report are consistent with a majority of others' analyses on wind integration. With increasing improvements in wind energy forecasting and system operators' ability to dispatch resources on a 5-minute basis, the estimates of the likely cost of integrating intermittent resources have been decreasing. Additional flexible resources such as the possibility of interconnecting additional hydroelectric resources from Manitoba with MISO also present opportunities for MISO to reduce the potential cost of integrating renewable resources.

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