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Witness: Robert M. Zavadil
Sponsoring Party: Grain Belt Express
Clean Line LLC
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MISSOURI PUBLIC SERVICE COMMISSION

CASE NO. EA-2014-0207

SURREBUTTAL TESTIMONY OF

ROBERT M. ZAVADIL

ON BEHALF OF

GRAIN BELT EXPRESS CLEAN LINE LLC

October 14, 2014

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I. WITNESS INTRODUCTION AND PURPOSE OF TESTIMONY

Q. Please state your name and business address.

A. My name is Robert M. Zavadil, Executive Vice President and co-founder of EnerNex, LLC ("EnerNex"), and my primary business address is 620 Mabry Hood Road, Suite 300, Knoxville, Tennessee.

Q. Have you previously submitted prepared testimony and exhibits in this proceeding?

A. Yes, I have previously submitted direct testimony, which described the methodology and results of the loss of load expectation ("LOLE") analysis I performed to measure the Project's contribution to electric reliability in the State of Missouri.

Q. What is the purpose of this surrebuttal testimony?

A. I am responding to issues raised in the rebuttal testimonies of other parties in this proceeding, including witnesses representing Commission Staff and the Missouri Landowners Alliance ("MLA"). In Section II, I respond to objections to the LOLE analysis presented in my direct testimony and show why those objections should be rejected. In Section III, I respond to Commission Staff witness Sarah Kliethermes regarding the variability of the Project's energy injection into Missouri and the impact on ancillary services. I show why the Project will have a minimal impact on system variability, and, therefore, why it should have a minimal impact on ancillary services.

Q. What are your relevant qualifications to present this testimony?

A. My direct testimony summarizes my educational background, industry experience, and qualifications to perform LOLE analyses. With respect to Section III of this testimony, I also have substantial experience in analyzing the variability of wind generation and its impacts on electric system operations. My team and I at EnerNex have pioneered many of the techniques and methodologies that are almost universally employed to study the impacts of variable renewable generation on bulk power system scheduling, operation, and control. Over the past 15 years, I have conducted, led, and participated in over 30 renewable integration studies for electric utility and other clients in North America. A list of a portion of these studies is included in my curriculum vitae, Schedule RMZ-1, attached to my direct testimony.

II. MY LOLE ANALYSIS IS RELEVANT AND PROPERLY SUPPORTED

Q. At page 9 of his rebuttal testimony, MLA witness Jeffrey Gray asserts that your LOLE analysis "has little practical significance" because a decrease in LOLE is "only meaningful when resource adequacy is potentially unmet and reliability is at risk." What is your response?

A. Dr. Gray misses the point of an LOLE analysis. No electric system is so reliable that it is totally impossible (i.e., zero probability) for enough simultaneous generator outages to cause a loss of load. LOLE is a good reliability metric precisely because it recognizes that resource adequacy is not "met" or "unmet" in a binary sense. Rather, electric reliability is a continuum that can always be improved.

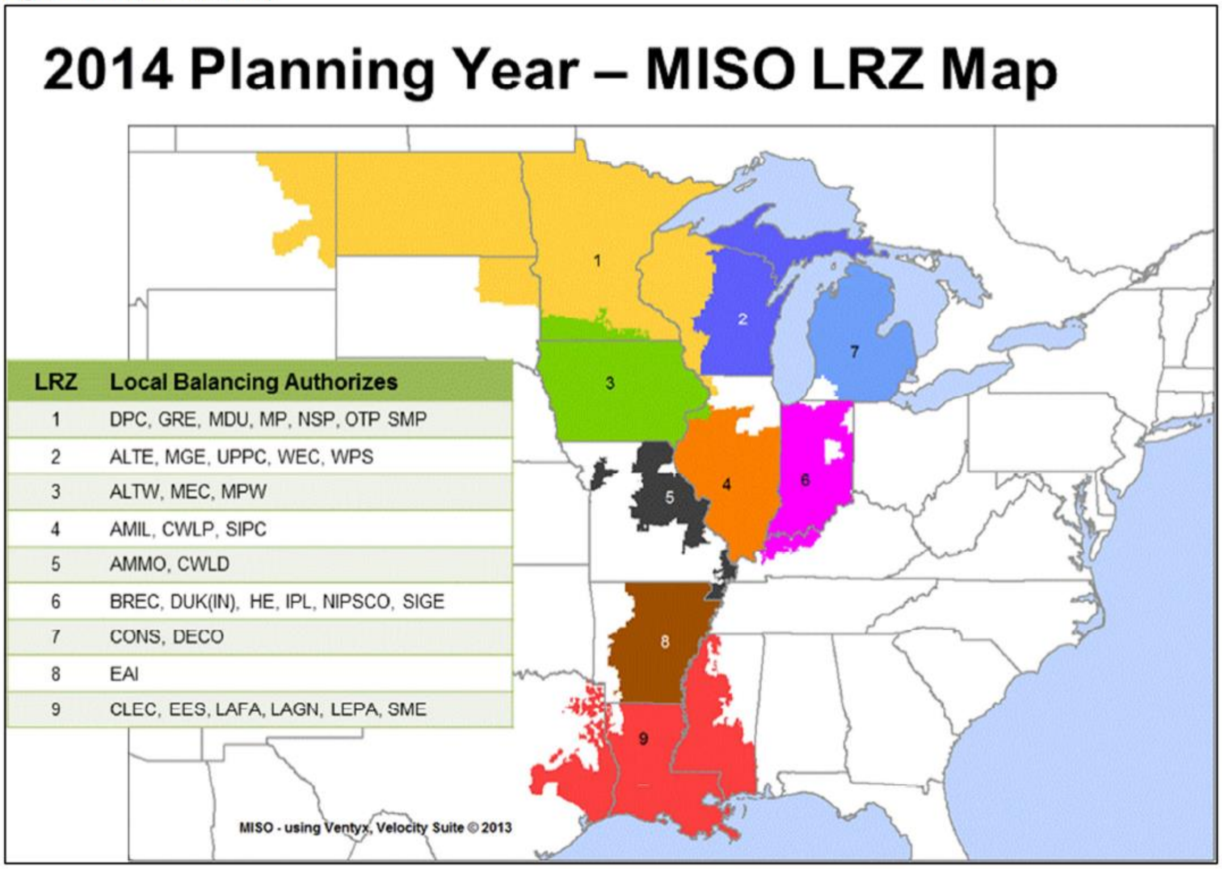
The capacity value of any new electric supply resource will depend on the adequacy of the existing resources at the time. If there is an excess of existing capacity, the contribution of the new resource would be small. For capacity-deficient systems, the contribution would obviously be higher. The assumption used in my analysis was that the adequacy of Missouri resources relative to Missouri load, at the time of the Grain Belt Express Project commissioning, resulted in the industry standard LOLE of 1 day in 10 years. From that baseline, the capacity value of the Project's wind energy injection was computed based on the incremental reduction in LOLE.

LOLE analysis measures the probability that load goes unmet. Based on the analysis presented in my direct testimony, the addition of the Project decreases the probability that load goes unmet – meaning resource adequacy and reliability improve. This improvement is a real benefit of the Project that Dr. Gray does not dispute.

Q. At page 8 and 9 of his rebuttal testimony, Dr. Gray asserts that your LOLE analysis "ignores the fact that the transmission grid is an integral part of the regional power grid." Is this true?

A. No. Dr. Gray's testimony appears to suggest that the LOLE study should have included all of the Midcontinent Independent System Operator ("MISO"). During peak load conditions, when resource adequacy is most likely to be tested, there are several transmission constraints within the MISO footprint that restrict which generators can serve load in specific locations. In analyzing resource adequacy, MISO defines local resource zones (LRZ) in which generators are eligible to serve load for resource adequacy purposes. These zones take into account transmission constraints and state borders since state public utility commissions have substantial jurisdiction over resource adequacy. The Ameren Missouri (AMMO) LRZ – as defined by MISO – includes only the portion of the MISO in Missouri.

Figure 1: MISO LRZ Map



Source: MISO, 2014

Given this zonal definition by MISO, my original study defined its boundaries in a reasonable fashion. In addition, the purpose of the study was to show the reliability benefits from the Project specifically to the State of Missouri, not for MISO in general. Therefore, the definition of boundaries was appropriate for the purpose of the study.

III. <u>THE VARIABILITY OF THE PROJECT'S WIND ENERGY INJECTION IS SMALL</u>

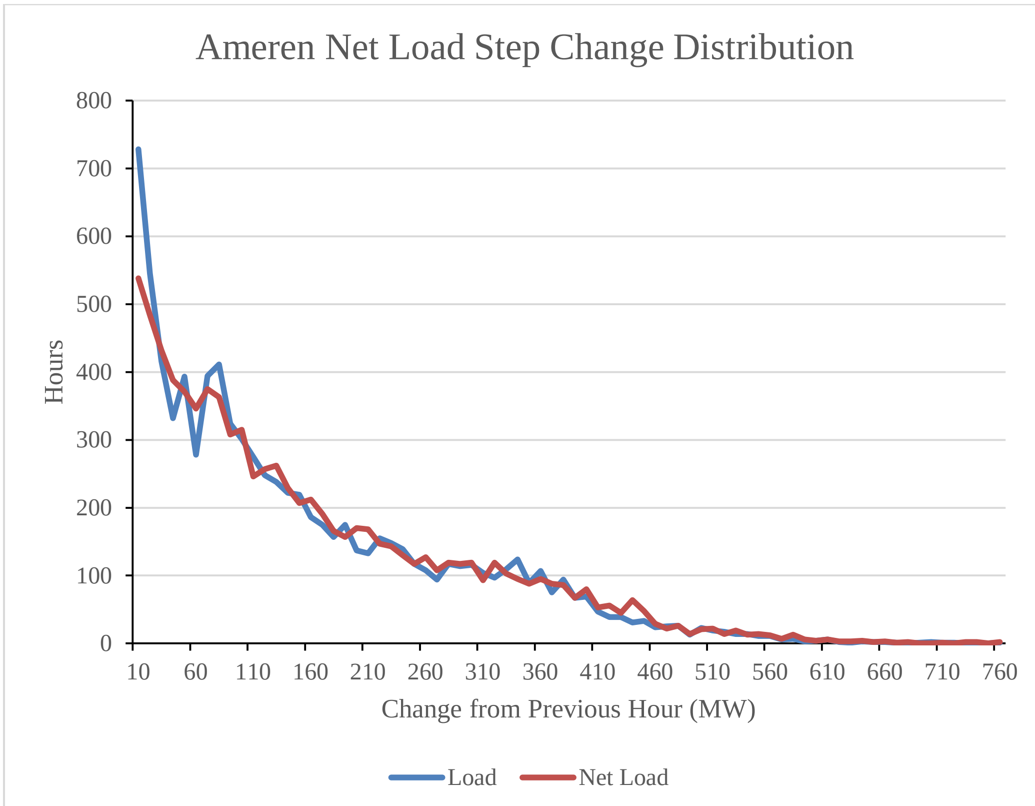
Q. In her rebuttal testimony at pages 14, 15, 23 and 24, Staff witness Sarah Kliethermes expresses concern that the variability of the Project's wind energy injection will drive a need for additional ancillary services or ramping capability. Is it possible to estimate the impact of the Project on system variability?

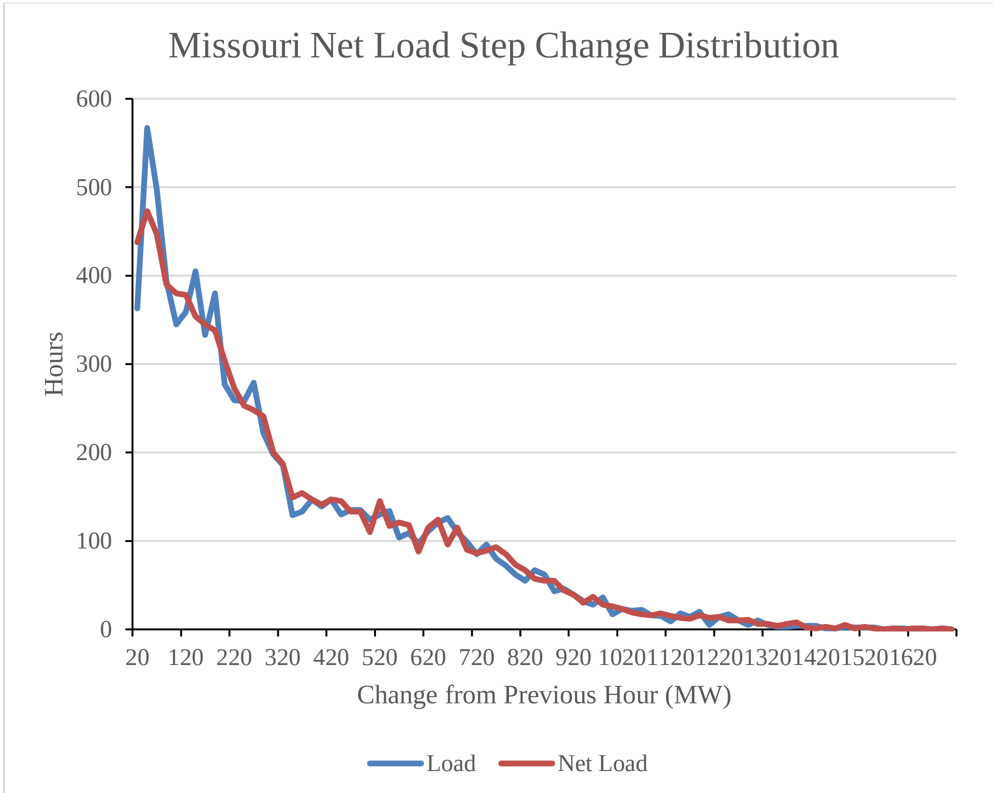
A. Yes. The expected impact of the additional variability introduced by the Project's injection can be conservatively estimated using a standard modeling technique called a net load analysis.

A net load analysis starts with the existing variability of system load. Electric load continually varies, and therefore dispatchable generation must respond to ensure generation equals load at all times. Load variability serves as a baseline for the amount of system flexibility required.

Load variability is then compared with "net load" variability. Net load is equal to load minus wind output. For this purpose, it is appropriate to treat wind power as a reduction in load because it reduces the amount of dispatchable generation needed to meet system demand. Like changes in load, changes in net load must be met by generators capable of ramping over the time interval of the change. Larger changes in net load mean more flexible capacity is needed. If there is no increase in net load variability from a wind energy injection, then there is no need for additional flexible resource or ancillary services.

The two graphs below show the comparisons of (1) load variability without the Project's injection and (2) net load variability with the Project's energy injection. The comparison is shown for Ameren Missouri, and, separately, for all of the state of Missouri. The graph shows the frequency of one hour changes in load (in blue) or net load (in red). The y-axis represents the frequency of changes, while the x-axis represents the size of the change. The difference between the red (net load with Project) and blue (load without Project) represents the increased or decreased frequency of a system ramp of a certain size due to the Grain Belt Express Project's wind energy injection. No major change is seen.





One way to measure the magnitude of increased system variability is the increase in 3-sigma changes in net load. This is the value of hourly step change (in MW) which is greater than or equal to the step changes in 99.7% of all hours. The 3-sigma change increases by 9 MW for just Ameren Missouri and 5 MW for the entire state.[1] In other words, potential additional system flexibility (in the form of fast-ramping generation or another technology) of only 9 MW in Ameren Missouri and 5 MW for the entire state may be needed to accommodate the wind generation injected by the Grain Belt Express Project, assuming that transmission constraints would require MISO to utilize local resources for this duty.

[1] A previous version of this analysis was provided in the response of Grain Belt Express to Staff DR-04. The analysis presented above has been updated based on a more complete Missouri load forecast.

Q. You stated that your estimate of the Project's impact on system variability is conservative. In what ways is your estimate conservative?

A. The simple net load analysis I performed above does not take wind forecasting into consideration. Wind forecasting can often predict a change in wind output in advance of it occurring, so existing generators have more time to adjust their output. As a result, many kinds of generators, even those that take more than one hour to ramp their output, can respond to net load variability. In addition, MISO procures ancillary services on a system-wide basis. Considering the variability of a wind energy injection over a larger footprint (rather than just in Missouri) with more load generally reduces the impact on ancillary services.

Q. What is the impact of the Project's injection on the system over shorter time intervals, such as those for regulation and operating reserve ancillary services?

A. The variability of wind power over time intervals of one minute or less, the traditional unit of time for regulation and operating reserves, is very low. One recent paper examined a 300 MW wind plant in Colorado and found that the standard deviation of output over one minute was only 2 MW. The same study found that one minute ramps across individual wind turbines, even at the same wind farm, were almost entirely uncorrelated, with a correlation coefficient of 0.05.[2] A correlation coefficient of zero indicates complete statistical independence, whereas a correlation coefficient of 1.0 indicates a perfect correlation. Because of this lack of correlation, short-term output ramps of individual turbines are smoothed across one or more wind farms, and therefore aggregate one-minute ramps typically become quite insignificant. As discussed below,

[2] B. Hodge, S. Shedd, and A. Fiorita Examining the Variability of Wind Power Output in the Regulation Time Frame (2012), available at http://www.nrel.gov/docs/fy12osti/55967.pdf.

MISO has actually decreased its use of regulation reserves despite a large increase in wind generation.

Q. At pages 23 and 24 of her rebuttal testimony, Staff witness Sarah Kliethermes states her opinion that additional ramping capability would be needed in "the already-constrained area" around the Project's planned Missouri converter station. Do providers of ancillary services need to be located in the same place as a variable energy injection?

A. No. Conventional generators that balance the variability of wind generation do not typically need to be located in the same location as the variable energy injection. I understand that MISO has completed a Feasibility Study of the Project at its full 500 MW injection showing the output is deliverable to load. Therefore, I would expect that any generator that already can deliver power to the same load within the MISO system can balance the variability of the Project's injection, and it is unlikely that additional ramping resources would need to be located near the Project's delivery point.

Q. Could the Grain Belt Express Project actually lead to decreased variability in wind energy generation?

A. Yes. If you compare adding wind generation from western Kansas to additional wind generation in MISO states that already have substantial wind generation like Iowa, Minnesota and South Dakota, the Kansas wind generation will likely cause variability to decrease. Adding Kansas wind generators introduces more geographic diversity in the wind generation serving MISO's load. Dispersing the locations of wind farms is a very effective way of reducing the variability of their energy output. Because the wind does not blow heavily at the same time in all places, a diversified group of wind plants generates electricity in a more consistent manner than a geographically concentrated group. Meteorological events that cause an increase or decrease in wind speed and a corresponding increase or decrease in power output affect different areas of the country at different times. Consequently, the combined energy output of geographically diverse wind farms is less variable and has fewer wind integration costs than the output of geographically concentrated wind farms.

Q: Are there studies that confirm your conclusions?

A. Yes. Several studies have corroborated the benefits of geographic diversity in a wind energy portfolio. Xcel Energy engaged my firm to perform a study on the feasibility and cost of integrating two gigawatts ("GW") and three GW of wind into the Public Service Company of Colorado's electric system. The study compared multiple portfolios of wind farms with greater and lesser geographic diversity, a similar methodology to the analysis presented below. The study found that "the degree of geographic diversity in the wind facilities added to grow the wind penetration level from 2 GW to 3 GW produced changes [decreases] in average system operations integration cost in the range of 4-16%."[3] Additionally, a report by the Electric Power Research Institute summarized industry knowledge of wind integration. In this report, a team of experts reviewed wind integration studies conducted by utilities around the country. The report observed: "There are several options for increasing flexibility of power system [including] …

[3] Xcel Energy, *Public Service Company of Colorado 2 GW and 3 GW Wind Integration Cost Study*, August 19, 2011, p. 20. Available at: http://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/11M-710E_2G-3GReport_Final.pdf (last accessed October 14, 2014).

increased transmission between regions, which allows greater sharing of flexibility and reduces the need for balancing due to geographic diversity."[4]

Q: How will the Grain Belt Express Project affect the diversity of wind generation serving Missouri and the MISO system?

A. The addition of wind energy delivered by the Project will help increase the geographic diversity of Missouri's and MISO's renewable energy portfolios. The source of the energy is several hundred or more miles from other wind resources in MISO. This extends the geographic scope of the wind production that must be integrated by the MISO market and its operators. The Project's wind power production resource in western Kansas is – to a high degree – statistically independent from when the wind blows in the best wind resource locations in Missouri, Iowa and Minnesota.

Schedule RMZ-3, which is a correlation analysis I created using data from the NREL's Eastern Wind Integration and Transmission Study (the "EWITS" study), demonstrates the diversification enabled by the Project. Using numerical weather models that capture the way weather patterns move across the United States, the EWITS study developed a time series of the output at wind farms across the United States. The exhibit shows the correlations between wind power generated at modeled wind farms situated near the Project's origination point in western Kansas and modeled wind farms situated in the best wind resource areas in Missouri, Iowa, Minnesota and South Dakota. A lower number implies a lower correlation between the geographic areas, i.e., wind blows and power is produced at one site when the wind is not blowing at the other site, and vice versa. As can be seen from the chart, the western Kansas wind resource that will be

[4] Electric Power Research Institute, *Impacts of Wind Generation*, April 2011, p. 4. Available at: http://www.uwig.org/EPRI-1023166.pdf (last accessed October 14, 2014).

connected to the Project has a very low correlation with wind in the best wind resource areas in Missouri, Iowa, Minnesota and South Dakota. Consequently, adding wind farms in western Kansas to a portfolio of wind farms physically interconnected in MISO will create a geographically diverse portfolio that is likely to result in steadier production and smaller ramps by fossil-fueled generation sources than a portfolio of wind farms all situated in the same geographic location.

Q. Does MISO have a track record of successfully integrating the variability of wind energy generation without a large additional cost?

A. As of May 2014, MISO had over 13,000 MW[5] of registered wind capacity in its market and reliability footprints and has to date experienced no significant operational challenges. Because of the substantial geographic diversity in wind generation, MISO has actually been able to reduce the amount of regulation capacity it carries from an average of 1,105 MW to less than 500 MW with the introduction of the ancillary service market in 2009.[6] The primary challenge for MISO operators has been manual curtailment of individual wind resources due to transmission congestion. In response, MISO implemented its Dispatchable Intermittent Resource (DIR) automated tool which better enables the market to manage curtailments due to transmission congestion by allowing wind generators to participate in the market dispatch. This allows wind generators to respond to market price signals so that market economics determine which

[5] https://www.misoenergy.org/Library/Repository/Meeting%20Material/Stakeholder/Informational%20Forum/2014/20140617%20Informational%20Forum%20Presentation.pdf (last accessed October 14, 2014).

[6] https://www.misoenergy.org/Library/Repository/Communication%20Material/Value%20Proposition/2013VP/ValueProposition_2013.pdf (last accessed October 14, 2014)

generators run. The DIR has reduced the manual curtailments of wind generation dramatically.[7]

Q. Have the wind integration studies in which you have been involved confirmed that variable wind generation can be integrated at a reasonable cost?

A. Yes. The electric power industry has been addressing how to best integrate variable renewable energy resources for over a decade now. In many of these studies, the increased operational costs were estimated. While these estimates varied due to assumptions, methods, and characteristics of the systems and renewables being studied, they were found to be relatively modest, on the order of around $5/MWh of delivered wind energy.[8]

To provide context for this estimate, it must be noted that most of the studies conducted to date considered relative amounts of renewable generation that are far larger than the current reality in any Balancing Authority Area in the U.S., and much larger than what Grain Belt Express is proposing to deliver to Missouri. For example, a study for the State of Minnesota in 2006 examined up to 5,000 MW of wind generation in the state and assumed that the utilities in the state were operated as a single entity, which yielded integration costs of around $5/MWH.[9] The current reality is that the Minnesota utilities are MISO participants, and the size of the balancing area is over five times as large – meaning wind integration costs are almost certainly lower than the estimate.

[7] https://www.misoenergy.org/Library/Repository/Meeting%20Material/Stakeholder/RSC/2013/20130514/20130514%20RSC%20Item%2011%20Wind%20Curtailment%20Data.pdf, slide #5 (last accessed October 14, 2014).

[8] http://variablegen.org/wp-content/uploads/2013/01/EPRI-1023166.pdf (last accessed October 14, 2014).

[9] http://mn.gov/puc/documents/pdf_files/000666.pdf (last accessed October 14, 2014)

Q. At page 40 of her rebuttal testimony, Ms. Kliethermes suggests that the Commission require Grain Belt Express to provide additional modeling to determine ancillary prices paid by load and received by Missouri generators. Have you been involved in this type of analysis?

A. Yes. Many of the wind integration studies listed on Schedule RMZ-1 include a detailed analysis on the effects of wind generation on ancillary services in the relevant study area.

Q. In your professional opinion, is it reasonable to require Grain Belt Express to perform such detailed studies of ancillary service impacts?

A. I understand that Grain Belt Express witness David Berry will address Ms. Kliethermes' proposed requirement on behalf of the Company. Therefore, I will limit my response to a discussion of the technical aspects of such a detailed wind integration study based on my extensive experience in performing them.

In light of the (1) complexity, (2) regional nature, (3) multi-party nature, (4) long time frame, and (4) prohibitive data requirements described below, in my judgment it is not feasible for Grain Belt Express to perform the kind of detailed study of ancillary services that Ms. Kliethermes appears to be suggesting as a requirement. Far more appropriate is the kind of net load analysis presented in this testimony, which should provide comfort to the Commission that the variability of the Project's energy injection should have a minimal impact on ancillary services and system variability.

All of the detailed wind integration analyses of which I am aware studied a major expansion of wind generation in a state, utility footprint or RTO. I am unaware that any wind farm owner or single project transmission owner has ever performed such a study, much less been required to perform one. Ancillary services requirements and prices cannot be understood by looking at a single wind energy injection in isolation. Ancillary services are required to deal with changes in electric demand, forced generator outages, and the aggregated variability of the renewable energy generation throughout the area studied. Given all of these factors, it makes little sense to study a single project, and much more sense to perform a comprehensive study of a large region.

However, such regional studies require a huge effort. The wind integration studies in which I have participated are almost never performed by a single party. Rather, they are performed by a large coalition that can include parties such as generators, transmission owners, grid operators, national laboratories, meteorology firms and others. Detailed wind integration studies often take more than a year to perform. The data requirements to perform such studies are tremendous, and furthermore, the necessary data are often proprietary. Without the adequate data, performing the kind of analysis suggested by Staff is impossible.

Q. Does this conclude your surrebuttal testimony?

A. Yes, it does.