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Issues: Generation Capacity and Reliability
Witness: Robert M. Zavadil
Sponsoring Party: Grain Belt Express Clean Line LLC
Type of Exhibit: Direct Testimony
Case No.: EA-2014-0207
Date Testimony Prepared: March 26, 2014

MISSOURI PUBLIC SERVICE COMMISSION

CASE NO. EA-2014-0207

DIRECT TESTIMONY OF

ROBERT M. ZAVADIL

ON BEHALF OF

GRAIN BELT EXPRESS CLEAN LINE, LLC

March 26, 2014

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I. WITNESS INTRODUCTION AND PURPOSE OF TESTIMONY

Q. Please state your name, present position and business address.

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

Q. What is the business of EnerNex?

A. EnerNex is a power system engineering consulting firm specializing in the analysis and application of electric power system equipment and technologies. EnerNex uses computer modeling and simulation tools to advise and serve clients, including electric transmission and distribution utilities, industrial end-users, generation project developers and operators, electrical equipment vendors, and research organizations.

Q. What are your duties and responsibilities as Executive Vice President at EnerNex?

A. I am responsible for developing and overseeing EnerNex's power system consulting business advising electric utilities, large industrial customers, power equipment vendors, research organizations, and project developers.

Q. Please describe your education and professional background.

A. I received a Bachelor of Science degree in electrical engineering (with highest honors) from South Dakota State University in 1982. I began my professional career in 1982 with Nebraska Public Power District as a technical support engineer in the Transmission and Distribution Engineering Division. In 1989 I joined Electrotek Concepts, a small consulting engineering company based in Knoxville, Tennessee. In 2003 I formed EnerNex with two partners. I have held a variety of positions at EnerNex and its sister company Dranetz-BMI. I have been a member of the Institute of Electrical and Electronic Engineers ("IEEE") for 32 years, and maintain registration in the Power and

Energy Society ("PES"), Power Electronics Society, and the Industrial Applications Society.

My career has centered on the application of various modeling, simulation, and other analytical techniques to a wide variety of power system engineering problems. I have extensive experience with new and emerging technologies for electric power generation, delivery, and utilization, including distributed generation and power electronics-based equipment. A copy of my curriculum vitae is attached as Schedule RMZ-1.

Q. Please describe your background in performing reliability benefit studies

A. I have been studying wind generation impacts on electric power systems for over 25 years. Over this time, I directed or contributed to approximately 20 different investigations into the effects of significant wind generation on power system operation and reliability. In several of these studies, the impact of wind generation on resource adequacy was a major topic of investigation.[1] I have also contributed substantially to the discussion of this topic in professional engineering circles. I have served as an officer of the IEEE Power and Energy Society's Wind and Solar Power Coordinating Committee since its establishment in 2006.

Q. What is the purpose of your direct testimony?

A. On behalf of Grain Belt Express Clean Line LLC ("Great Belt Express"), this testimony examines and measures the reliability impact of the Grain Belt Express transmission project ("Grain Belt Express Project" or "Project") on the State of Missouri. By applying

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[1] These include wind integration studies for Xcel Energy in Minnesota (2004) and Colorado (2005-2008, multiple studies), the Minnesota Public Utilities Commission (2006), the Nebraska Power Association (2009), the Eastern Wind Integration and Transmission Study for the U.S. Department of Energy through NREL(2010), and the PJM Interconnection (2013)

widely used techniques to assess resource adequacy, my testimony will demonstrate that the injection of wind energy via the Project improves the reliability of the Missouri bulk electric system.

II. <u>OVERVIEW OF LOSS OF LOAD EXPECTATION ("LOLE") ANALYSIS</u>

Q. Please define the reliability impact of the Project that is the subject of your testimony and analysis.

A. In order to maintain high levels of electric reliability, generating capacity must be available and able to produce power in sufficient quantities to meet the expected peak demand. This is often termed "resource adequacy." Because all generators experience forced outages or other times of unavailability, generation capacity must exceed expected peak load in order to maintain resource adequacy with a high level of certainty. The simplest measure of resource adequacy is the ratio of total generation capacity to expected peak load, sometimes termed the "planning" or "capacity" margin. However, a more rigorous assessment of resource adequacy is Loss of Load Expectation ("LOLE").

LOLE analysis calculates the probability that a set of generating units or other supply options is insufficient to meet an expected level of electric demand. A higher LOLE indicates a higher probability of loss of load, whereas a lower LOLE value indicates a lower probability of loss of load and improved reliability in the bulk electric system.

Q. How does an LOLE analysis measure the reliability impacts of wind generation?

A. An LOLE analysis can incorporate meteorological data and wind generators' ability to generate during peak load hours. Hourly wind generation data are an input into the LOLE model. The techniques for the LOLE analysis of wind generation have been developed in part by the National Renewable Energy Laboratory ("NREL"). Several integration studies performed over the past decade, including those previously mentioned studies for the Minnesota Public Utilities Commission and the Eastern Wind Integration and Transmission Study ("EWITS"), have established some consensus techniques for the LOLE analysis of wind generation, and they form the basis of my analysis of the Grain Belt Express Project.

Closely related to LOLE is Effective Load Carrying Capability or ("ELCC"). ELCC measures the increase in load that can be served by the addition of a new supply resource to the portfolio. An ELCC calculation solves for the increase in load that can be accommodated while maintaining the same reliability level, expressed as a fixed LOLE. ELCC allows the ready comparison of wind generation's reliability contribution compared to that of other generation technologies.

III. STUDY METHODOLOGY AND INPUTS

Q. Please provide an overview of the study methodology for the study you performed.

A. In this study I first calculated the expected LOLE considering all Missouri electric demand and supply resources in the State. I then recalculated the LOLE considering the addition of the Project's hourly wind injection. The resulting LOLE reduction is one important measure of the reliability benefit of the Project. Finally, I calculated the increase in load, measured in megawatts ("MW") that the Project can support while maintaining the original level of reliability. This increase in load is the ELCC of the wind energy injection of the Grain Belt Express Project.

Q. Are the LOLE study and the methodology you describe in this testimony generally accepted in the electric industry as measures of reliability?

A. Yes, LOLE studies are routinely performed as part of long-term electric power system planning. They are a standard industry technique to assess the resource adequacy of the bulk electric system used by various regional reliability coordinators like Southwest Power Pool and Midcontinent Independent System Operator, and many utilities throughout the United States. The methodology employed in this analysis conforms to the accepted industry approach for measuring the probability of a supply resource shortfall.

Q. What software did you do to perform your LOLE and ELCC calculations?

A. I used the Multi-Area Reliability Simulation ("MARS") software developed and maintained by General Electric ("GE") Energy Consulting. MARS is a widely used model for LOLE and ELCC calculation. I have used MARS on several prior engagements including Xcel Energy in Minnesota and Colorado, the Minnesota Public Utilities Commission, and the EWITS. The GE MARS program employs a full sequential Monte Carlo simulation of available generation capacity and a chronological hourly simulation of the electric system. Such widely accepted simulations employ a broad class of computational algorithms that are used to calculate the probability of an event. In each hour, MARS compares the hourly load demand in each area to the total available generation in the area, which has been adjusted to account for planned maintenance and randomly occurring forced outages and, in the case of wind energy, meteorological conditions and the resulting wind energy output.

Q. What was the geographic scope of your analysis?

A. LOLE and other reliability studies are sometimes performed on a regional, rather than a state basis. The purpose of the study here, however, is to evaluate the contribution of the Grain Belt Express Project to Missouri supply resources. Therefore, I limited the scope of my analysis to the State of Missouri since this is the region of most concern to the Missouri Public Service Commission. This study takes a view of Missouri in isolation and gauges the impact of the Project's wind injection on the adequacy of the supply portfolio to meet Missouri electric loads.

Q. What are the primary inputs to an LOLE analysis?

A. The primary inputs to the LOLE calculation are peak electric demand or annual demand profiles, the inventory of generating units, generators' seasonal capacity ratings, and generators' scheduled maintenance periods. Other key parameters for generating units are their mechanical reliability expectations, including the probability of a failure or forced outage, and the average time to repair and restore the unit to service. For wind generation units, the hourly profile of generation, based on wind speeds and adjusted for any appropriate losses, is incorporated into the model.

Generator and load data for the study was derived primarily from the Ventyx Powerbase data set. This is a widely used data set also used by witness Gary Moland in his direct testimony on behalf of Grain Belt Express. I have used this same database for some of my prior engagements to perform LOLE analysis. From the Ventyx database, hourly load and generating unit data were extracted for Missouri. Peak load and load energy levels represented forecast calendar year 2019 conditions. Generating unit forced outage information extracted from the Ventyx Powerbase data was derived from the NERC Generator Availability Data System ("GADS").[2]

In addition to the generators in the Ventyx database, I added generation capacity to the model so that the base case LOLE value was the industry-standard one day in ten

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[2] NERC's GADS Services group manages the Generating Availability Data System. This unique series of databases is used to collect, record, and retrieve operating information for improving the performance of electric generating equipment. It also provides assistance to those researching the vast amounts of information on power plant availability stored in its database. The information is used to support equipment reliability and availability analyses, and decision-making by GADS data users.

years (0.1 day per year, or 2.4 hours/year). This modification is justified since the objective of this study is to calculate the reliability of the Project, not to assess the baseline sufficiency of Missouri generating resources. Between now and 2019, if it is necessary for Missouri to add generation to compensate for coal plant retirements or load growth, it is safe to assume that this generation will be added. Further, this additional generation may reflect the fact that some Missouri load serving entities have contracts with out-of-state generation, which are used to serve their load and meet reliability targets but are not included in the Ventyx database.

The hourly profile of wind injection representing the Grain Belt Express Project's converter station facility in Missouri is based on modeled hourly generation from western Kansas sites. The data source is the EWITS, led by NREL. The hourly profiles are based on numerical weather models developed by AWS Truepower, LLC, a leading meteorology consulting firm, and the National Weather Service. In my experience, EWITS is an appropriate and reliable data source for hourly wind generation profiles in ELCC analysis.

IV. STUDY RESULTS

Q. What cases were developed for the LOLE study?

A. The cases defined for this study included a base or benchmark consisting of forecast hourly profiles for electric load within Missouri and the resources serving Missouri load. This base case did not include the Grain Belt Express Project or its wind energy injection into Missouri.

A second set of cases include hourly wind injection from the Project's converter station or tap located in Missouri. The initial case in this set utilized the hourly wind profile described above. To account for inter-annual meteorological variations that could affect the correlation between periods of high electric demand (which are more likely to stress the electric power system in terms of supply resource availability and adequacy), an additional eight cases were generated by shifting this profile by one or more weeks either forward or backward in time, for a total of nine cases. Each of these cases was executed with the GE MARS program to develop a set of numerical results from which annual LOLE values are calculated.

By comparing the base case LOLE to the LOLE with the Project, I measured the LOLE improvement from the Project. Similarly, by adding load to the "with Project" case until the LOLE returns to the base case value, I measured the ELCC contribution of the Project's injection in Missouri

Q. What are the expected reliability benefits provided by the Project and the wind energy it will deliver to Missouri?

A. The addition of wind energy from the Project reduces the LOLE in all of the scenarios analyzed. The average reduction in LOLE is 23%, or a reduction of 0.023 days/year from the assumed baseline of 0.1 days/year. In terms of firm capacity, the results of the cases show an annual ELCC that ranges from a low of 28 MW to a high of 450 MW, which is an average of 165 MW over the nine individual scenarios. The 33% average capacity benefit (capacity value divided by the nameplate rating of the Project's tap) is consistent with what has been calculated for high-quality wind resources in previous studies. In other words, the Grain Belt Express Project's wind energy injection in Missouri would have approximately the same reliability benefit of a single medium-sized natural gas power plant.

A copy of my study is attached as Schedule RMZ-2.

Q. Based on the results of your LOLE study, what is your conclusion as to whether installation of the Grain Belt Express Project and the wind generating facilities that will be connected to it in western Kansas will increase the reliability of electric service in Missouri?

A. Wind energy injection from the Grain Belt Express Project into Missouri will positively impact resource adequacy and electric reliability in the state, based on reduced LOLE metrics from the addition of the Project.

Q. Does this conclude your direct testimony?

A. Yes, it does.

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of the Application of Grain Belt Express Clean Line LLC for a Certificate of Convenience and Necessity Authorizing it to Construct, Own, Control, Manage, Operate and Maintain a High Voltage, Direct Current Transmission Line and an Associated Converter Station Providing an Interconnection on the Maywood 345 kV Transmission Line	)))))))	Case No. EA-2014-0207

AFFIDAVIT OF ROBERT M. ZAVADIL

STATE OF Tennessee)
) ss
COUNTY OF Knox)

Robert M. Zavadil, being first duly sworn on his oath, states:

1. My name is Robert M. Zavadil, Executive Vice President and co-founder of EnerNex, LLC.

2. Attached hereto and made a part hereof for all purposes is my Direct Testimony on behalf of Grain Belt Express Clean Line LLC consisting of 9 pages, having been prepared in written form for introduction into evidence in the above-captioned docket.

3. I have knowledge of the matters set forth therein. I hereby swear and affirm that my answers contained in the attached testimony to the questions therein propounded, including any attachments thereto, are true and accurate to the best of my knowledge, information and belief.

[signature]
Robert M. Zavadil

Subscribed and sworn before me this 25 day of March, 2014.

[signature]
Notary Public

PATTI D LIVESEY STATE OF TENNESSEE NOTARY PUBLIC COUNTY OF KNOX

My commission expires: 12-26-2017

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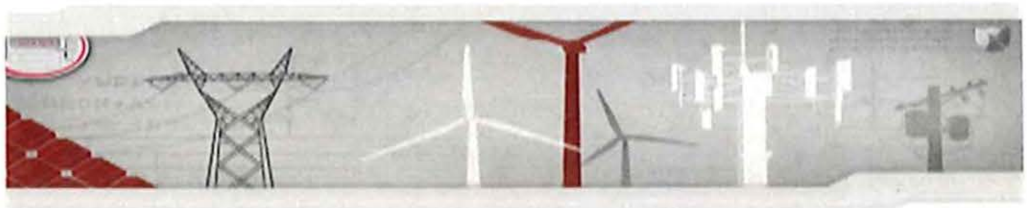
EnerNex



Robert M. Zavadil, P.E.

Executive Vice President of Power Systems Consulting, Co-Founder

Education
B.S. Electrical Engineering, South Dakota State University

Registrations
Registered Professional Electrical Engineer, Nebraska

Affiliations
Member, IEEE Power Engineering Society

Member, IEEE Power Electronics Society

Member, IEEE Industrial Applications Society

Secretary, IEEE PES Wind and Solar Power Coordinating Committee

Experience
36 years

Biography

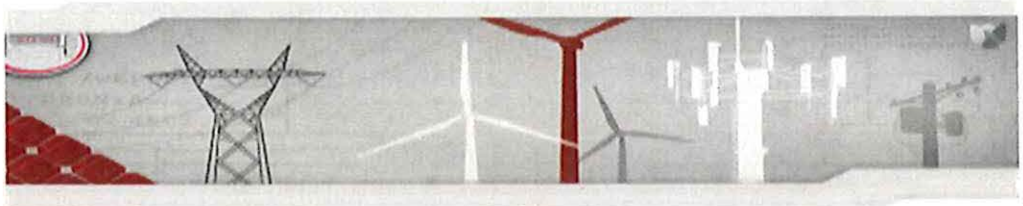
Bob Zavadil is responsible for developing and overseeing EnerNex's power system engineering and consulting business. Bob is a nationally recognized expert in electric power system issues for wind generation. His clients in the wind generation industry range from turbine designers and manufacturers to project developers and operators, along with transmission service providers and independent transmission system operators. He has extensive experience with new and emerging technologies for electric power generation, delivery and utilization including distributed generation and power electronics-based equipment. Bob has over twenty-five years of experience with advanced modeling and simulation tools for electric power systems, which he routinely uses in his consulting engagements to provide a comprehensive technical and analytical foundation for advice and recommendations to clients.

EnerNex Project Experience

Eastern Wind Integration and Transmission Study (EWITS) – Led the culmination of an effort that spanned two and one-half years. The study team began by modeling wind resources in a large part of the Eastern Interconnection and finished by conducting a detailed wind integration study and top-down transmission analysis. The study resulted in information that can be used to guide future work. A number of other studies have already examined similar wind integration issues, but the breadth and depth of the analysis in EWITS is unique. EWITS builds on the work of previous integration studies, which looked at considerably smaller geographic footprints, focused almost exclusively on wind integration, and did not include transmission. EWITS took the next step by expanding the study area and including conceptual transmission overlays.

Cape Wind Offshore Wind Farm Modeling, Cape Wind Associates – Provided support in developing a custom model for an off-shore wind farm to be built in Nantucket Sound, the first-ever facility in the United States. The model will be used by NSTAR, the local utility, to perform steady-state power flow and dynamic stability studies using the PSS/E analysis software. The model incorporates control and protection functions specific to the turbine technology utilized, in this case the GE Wind 3.6 MW turbine, as well as the associated underwater collection system. In addition to facilitating the construction of this pioneering wind generation facility, the model should serve as a basis for the development of future land-based and offshore wind projects.

Wind Integration Study, Xcel Energy/Minnesota Department of Commerce – Served as the project and technical lead for this study, which focuses on the potential technical and



economic impacts of operating up to 1,500 MW of wind generation on Xcel Energy's system in Minnesota, North Dakota, South Dakota, Wisconsin and Michigan. Building on a previous wind integration study conducted by the Utility Variable-Generation Integration Group (UVIG), this project is analyzing the impacts of significant amounts of large-scale wind generation on the real-time operations and short-term planning of Xcel Energy's electric power system. These functions are critical to reliable and economic operation of interconnected power systems and represent tangible costs to the utility. Key components of the project include accurate modeling and forecasting of wind patterns with simulation and analysis of power system operations. The overall effort began with a thorough science-based investigation of the wind patterns in Xcel Energy's control area in the Upper Midwest to yield the most accurate models possible. Wind generation forecast accuracy was also evaluated with the results forming a basis for the power system operational analysis.

Wind Integration Study, Xcel Energy/Public Service Company of Colorado (PSCo) – Directed a wind integration study for Xcel Energy's control area in Colorado. Techniques developed in the 2004 study for Xcel Energy were augmented and expanded to consider the impacts of significant wind generation on the scheduling and operation of PSCo's supply portfolio. Of particular interest was the effect of wind variability and uncertainty on the day ahead nomination of natural gas for PSCo's gas-heavy generation portfolio. As with the earlier Xcel study, a formal technical review team was assembled to guide and critique the project as it unfolded.

Wind Plant Interconnection Support, Nebraska Public Power District (NPPD) – Provided support on a number of tasks to facilitate the interconnection of a proposed 60 MW wind farm. Reviewed NPPD's interconnection guidelines and process for conducting interconnection studies, recommended changes to address technical issues relating to the intermittent nature of wind generation and provided support for modeling and simulation activities to support the interconnection study process. Also analyzed like dynamic reactive power compensation schemes that might come into play for various interconnection scenarios.

Wind Integration Study, New York State Energy Research and Development Authority (NYSERDA) – Provided consulting support to the NYSERDA on a high penetration wind integration study for New York State. Offered advice and recommendations on study scope and approach, wind turbine and wind plant models to be used by the study contractor and provided ongoing support on analysis of the study results.

Study of Wind Power Impacts on Power System Operation, Utility Variable-Generation Integration Group (UVIG) – Played a key role in this research project to determine the impact wind generation has on the real-time operations and short-term planning of electric power systems. Funded by UVIG, the Electric Power Research Institute (EPRI), Xcel Energy, Western Area Power Administration (WAPA), the American Public Power Association and the National Rural Cooperative Association, this study examined this impact, which can compel utilities to charge wind plant owner/operators for the perceived cost of additional cost capacity, an economic barrier to broader deployment of wind as a generation source. The study focused particularly on the Bonneville Power Administration and Northern States Power (Xcel Energy) power systems. The study calculated costs of ancillary services due to additional regulation duty load following and operating reserve requirements.

Missouri River Wind/Hydro Integration Analysis, US Department of Energy National Renewable Energy Laboratory (NREL) – Bob is leading this project to qualitatively assess the impact of significant wind generation on the operation of the WAPA's control area, especially considering the economic impacts on hydropower, which constitutes a significant amount of the generation base. EnerNex is determining the level of wind generation that can be accommodated by the current generation deployment scenario for ancillary services such as regulation and load following or real-time balancing. A key goal of this project is to identify the constraints on the Missouri River system that could further limit wind generation deployment due to control area operating issues, explore ways to maximize availability of the hydroelectric system to provide ancillary services for wind generation and to provide recommendations on how the study findings can be utilized to investigate transmission capacity within and outside the WAPA control area.

System Analysis and Expert Testimony Support – ISO New England and Northeast Utilities – EnerNex played a key role in this effort to perform extensive harmonic and transient analysis of the southwest Connecticut power system on behalf of ISO-New England and Northeast Utilities (the operating companies) to evaluate the maximum amount of underground 345-kV cable that could safely be used in a major expansion of that system. The analysis required running tens of thousands of cases and developing the automation systems to validate and process the results. Bob provided expert testimony on the results to the Connecticut Siting Council which is the body with the authority to approve the expansion of project design. Key elements of the testimony included devising a method to graphically and intuitively describe complex electromagnetic phenomena to an audience of widely varying backgrounds. The Connecticut Siting Council ultimately approved the project as recommended by the operating companies, EnerNex, and the other consultants involved in the project (GE Power Systems and PB Power).

Later, Bob conducted a feasibility study for ISO-New England on a proposed generator expansion in the area, which involved an additional 345-kV cable. Electromechanical dynamic models of these generators, including the excitation systems, were included in the transient overvoltage studies.

Expert Testimony for Patent Infringement Suit – Provided expert witness testimony in a patent infringement suit (Kenetech Corporation vs. Enercon GMB, United States International Trade Commission, Investigation No. 337-TA-376) for a domestic wind turbine manufacturer.

Previous Professional Experience

Electrotek

At Electrotek, Bob consulted for a number of Electrotek clients, including EPRI, the NREL, major U.S. electric utilities, and private corporations. His technical responsibilities included distribution system and end-user power quality and power electronics, motor and drive technology and applications, power quality and power quantity measurements and renewable energy applications. Bob managed technical operations in Electrotek's Mountain View, California office from late 1992 until 1996, when he transferred to a sister company, Basic Measuring Instruments (BMI). In 1997, he returned to Electrotek. In addition to consulting, Bob's responsibilities included new corporate product development, sales and marketing of Electrotek products and services and development of new business areas and ventures. Highlights of consulting activities at Electrotek included:

- Contributor to a series of projects directed at determining the impacts of substantial amounts of intermittent wind generation on the real-time operations and short-term operations planning functions of utility control areas. The basic analytical and simulation methodologies were extended to cover the full range of possible impacts (from unit governor operations to weekly unit commitment) or application to the Big Island of Hawaii.
- Served as Secretary of EPRI-sponsored National Motor and Drives Steering Committee. This committee was founded by EPRI to provide a forum for electric motor and drive users, researchers and manufacturers to discuss and exchange information on motor drive market needs, technology, research and applications. As Secretary, Bob was responsible for coordinating all aspects of the committee's activities, including meetings, technical presentations and working group activities (1991 - 1995).

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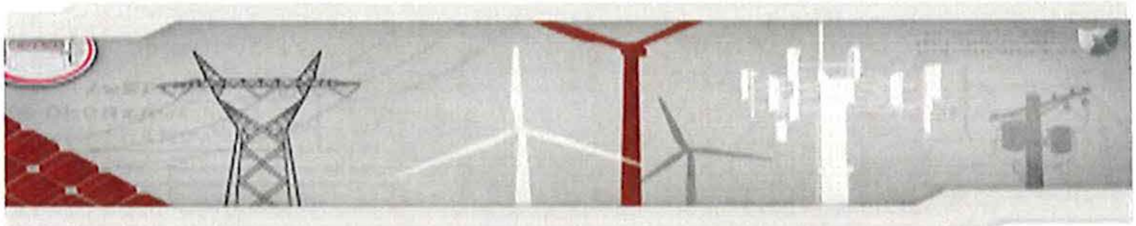

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QUANTIFYING RELIABILITY BENEFITS OF PROPOSED GRAIN BELT EXPRESS HVDC TERMINAL IN MISSOURI

OBJECTIVE

The purpose of this analysis is to quantify the reliability benefits of the proposed Grain Belt Express HVDC transmission project ("Grain Belt Express Project" or "Project") which will deliver 500 megawatts ("MW") of power to the state of Missouri.

APPROACH

The North American Electric Reliability Corporation ("NERC") definition of reliability for the Bulk Electric System (BES) is based on two principles. The first is operational reliability, which is achieved by always operating the BES in a state where it is able to recover from and continue functioning after defined disturbances such as the loss of generators or transmission lines. The second principle is adequacy, defined as the ability to meet the aggregate power and energy demands of electric consumers. A key component of adequacy is the availability of generating capacity sufficient to meet the expected peak demand, also known as resource adequacy.

Since generation equipment is subject to failures and must be periodically removed from service for maintenance, achieving specific adequacy levels requires the availability of generation capacity in excess of peak loads. And, because "perfect" reliability (practically defined as some infinitesimally small probability that available generation capacity would not be adequate to meet peak demand) is not economically feasible, generation capacity is planned to meet some value that exceeds expected peak load. Resource Adequacy is sometimes simply gauged as the ratio of maximum generation capacity to expected peak load, expressed as "planning" or "capacity" margin.

A more rigorous assessment of adequacy incorporates a probabilistic target, or Loss of Load Expectation (LOLE). A LOLE analysis calculates the probability that a given set of generating units or other supply options (such as demand-side resources and firm capacity purchase contracts) would be insufficient to meet an expected level of electric demand. Primary inputs to the calculation of LOLE are peak electric demand or annual demand profiles, the inventory of generating units and their seasonal capacity ratings along with scheduled maintenance periods. Other key parameters for generating units are their mechanical reliability expectations, including the probability of a failure or forced outage and the average time to repair and restore the unit to service.

Wind generation is primarily considered an energy source, but there has been significant research over the past three decades into exploring its influence on bulk system reliability and resource adequacy. The National Renewable Energy Laboratory (NREL) has been especially active in this area. Through the integration studies performed over the past decade, some consensus techniques have emerged on the analytical approach for calculating the capacity value of a variable renewable energy resource, such as wind. The approach used in this study, which is described here, is based on those consensus techniques, and utilizes the concept of "Effective Load Carrying Capability" or ELCC.

ELCC measures the increase in load that can be met at the target reliability level, expressed as LOLE, by the addition of a new supply resource to the portfolio. In this study, a case with the expected LOLE considering all Missouri electric demand and supply resources serving this demand was calculated (base case), and then compared with a case where the LOLE considering the addition of the Grain Belt Express Project hourly wind injection was calculated. The increase in load, measured in MW, that can be met with the same target reliability as the base case is attributed to the addition of the wind energy injection.

LOLE studies are routinely performed as part of the long term electric power system planning process. Due to the critical role that the high voltage transmission system plays in maintaining system reliability, LOLE and other reliability-focused studies are performed on a regional, rather than state, basis. The purpose of the study described here, however, is to evaluate only the Missouri electric demand and supply resources, since the jurisdiction over resource adequacy is not part of the NERC charter.

Consequently, this study takes a view of Missouri as an electric island and gauges the impact of the Grain Belt Express Project wind injection on the adequacy of the supply portfolio for Missouri electric loads.

For purposes of this calculation, the profile of hourly load within the Missouri state borders was not treated probabilistically. Instead, sequential Multi-Area Reliability Simulations ("MARS") were run for scaled load profiles derived from 0.90 or 90% up to 110% of the original load level. This approach allows the LOLE for each case to be aggregated into a curve (see Figures 1 and Figure 2 below), with peak hourly load on the horizontal axis and LOLE (in days/year) on the horizontal axis. This method of presentation shows the relationship of varying reliability targets and changes in peak load. It should be noted that the scaling process involves all hours of the annual profile, not just the peak hour.

This presentation of the results is also important when applied to variable renewable energy, such as wind, since it allows the effects of the renewable energy injection to be calculated by comparing two cases: 1) a case without renewable energy injection, and 2) a case where renewable energy delivery to the system is defined each hour of the study year. The distance between the two plotted curves (in MW) at the target reliability level (generally taken as 0.1 days/year or 1 day in 10 years) is the ELCC of the wind energy injection.

Input data for the study and the General Electric ("GE") MARS cases were derived primarily from the Ventyx Powerbase data. Hourly load and generating unit data were extracted for defined operating areas within the state of Missouri. Peak load and load energy levels represented forecast calendar year 2019 conditions.

The hourly profile of wind injection representing the Project facility in Missouri was developed by Clean Line Energy Partners LLC ("Clean Line") from measurement data and numerical weather simulations.

Generating unit forced outage information extracted from the Ventyx Powerbase data was derived from the NERC Generator Availability Data System ("GADS") system.

The cases defined for this study included a base or benchmark consisting of forecast hourly profiles for electric load within the state of Missouri and resources serving Missouri load, as taken from the Ventyx Powerbase dataset, and a second set of cases including hourly wind injection from the Project tap located in Missouri. The initial case in this set utilized an annual hourly profile of wind delivery, provided by Clean Line, developed from measurement data and representative of calendar year 2013. An additional eight (8) cases were generated by shifting this profile by one or more weeks either forward or backward in time. Each of these cases was executed with the GE MARS program to develop a set of numerical results and curves from which annual ELCC is calculated for each case.

Adjusting the wind profile via time shifting is a technique that has been used in previous integration studies to account for inter-annual meteorological variations that could affect the correlation between periods of high electric demand – which are more likely to stress the electric power system in terms of supply resource availability and adequacy – and high levels of wind generation. Marked inter-annual variation in annual ELCC for wind generation resources has been observed in several of the previous major integration studies that used up to only three years of annual data.

RESULTS

Results from the initial GE MARS case showed that the LOLE for the forecast peak load was in excess of 0.7 days/year. This was, in all likelihood, entirely a consequence of the assumptions used to frame the computation for this study. While all supply resources designated to Missouri operating areas in the Ventyx Powerbase data were included in the calculation, this does not necessarily reflect the entirety of the capacity available to Missouri utilities. Firm capacity contracts with neighboring utilities outside of Missouri, for example, are a common mechanism for supplementing capacity needs.

To account for the other sources of capacity not represented by the portfolio of Missouri generating resources in the Ventyx Powerbase data, the initial case was modified by adding additional capacity until the LOLE for the annual case was the industry-standard of 1 day in 10 years (0.1 day per year, or 2.4 hours/year). This modification is well justified since the primary objective of this study is to calculate the ELCC of the new – Project wind energy – resource, rather than to support a commentary on the sufficiency of Missouri generating resources.

Additionally, the ELCC of an incremental resource can be dependent on the starting LOLE of the system being examined. If the system is short of capacity – meaning that the LOLE is higher than the target of 0.1 days per year – the capacity value of the new resource will tend to be amplified. Conversely, if the LOLE is already very low, the capacity benefit from additional resources will be small. In the wind integration studies mentioned above, the standard approach has been to adjust the LOLE of the underlying system so as not to overstate or discount the capacity value of the wind resources being studied.

The quantitative results from the study show that the Grain Belt Express Project wind energy injection in Missouri would have the capacity benefit of a single-medium sized natural gas power plant. For the nine (9) scenarios of wind constructed for the study, the annual ELCC averaged 165 MW, with a low annual value of 28 MW and a high value of 450 MW. The 33% average capacity benefit (capacity value divided by the nameplate rating of the Grain Belt

Express Project tap) is consistent with what has been calculated for high quality wind resources in previous studies. Similarly, the reduction in LOLE from the assumed baseline is 0.023 days/year, or a 23% reduction from the assumed baseline of 0.1 days/year. The complete set of ELCC and LOLE results for each of the nine (9) scenarios is provided in Table 1 below.

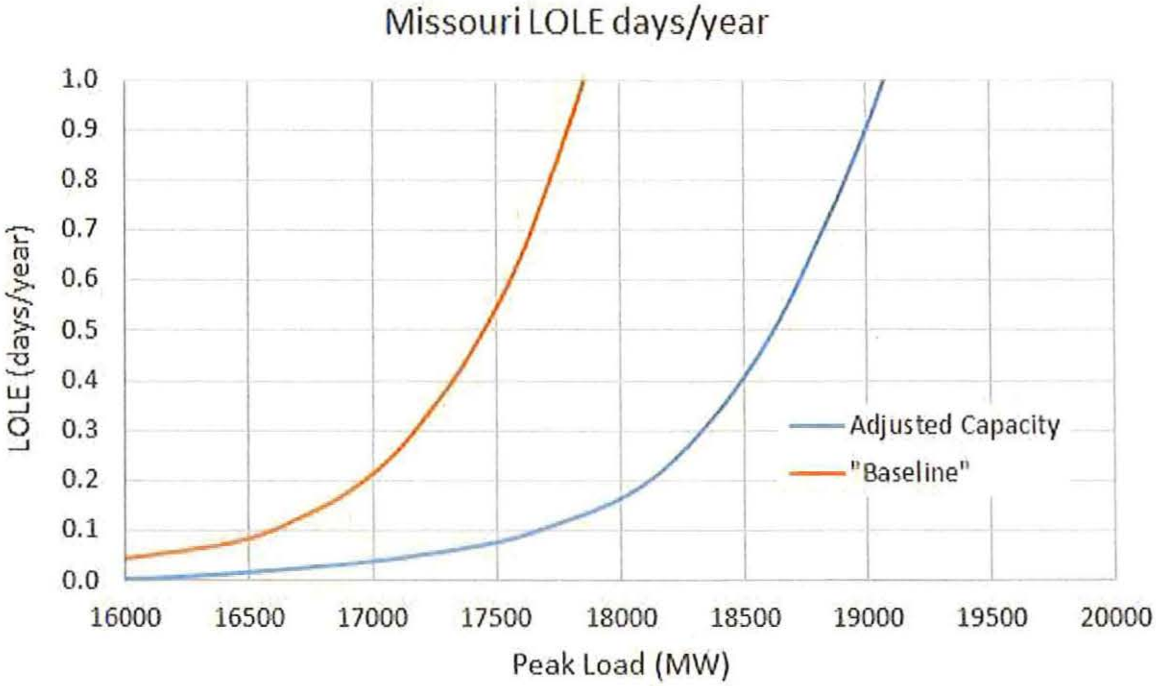

Figure 1: LOLE as a function of peak load level for "baseline" case (Missouri generating unit data extracted from Ventyx Powerbase) and modified case (to establish no-wind LOLE at 0.1 days/year).

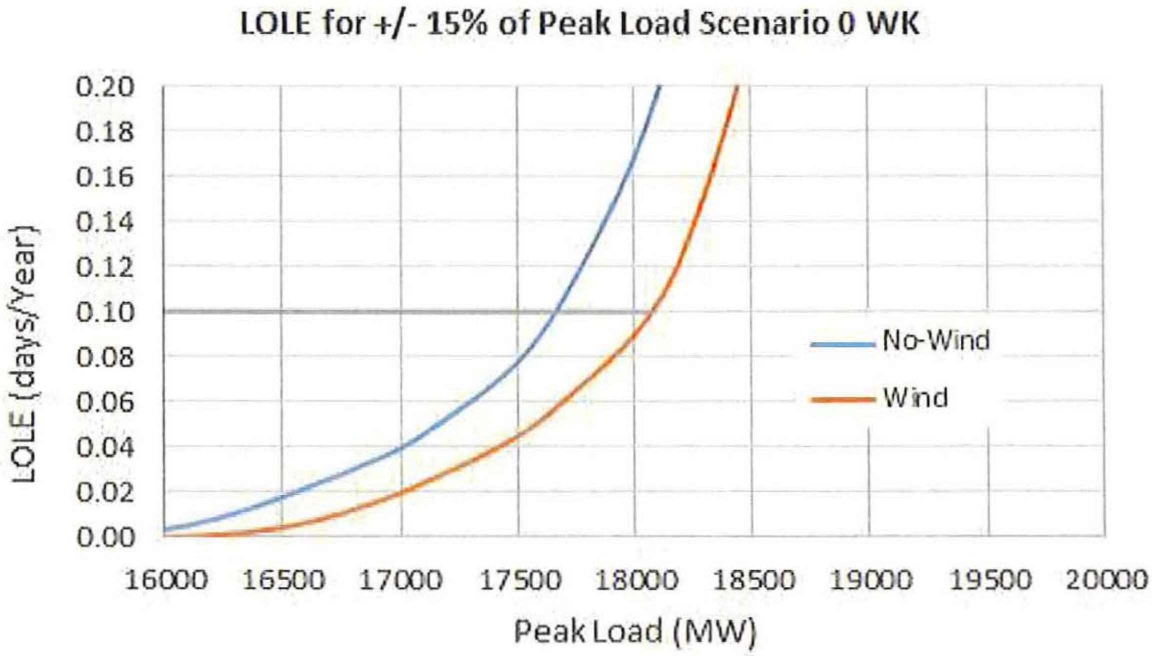

Figure 2: Illustration of ELCC calculation for one of nine wind cases analyzed with GE MARS

Table 1: Annual and Average ELCC values (in MW) and Reduction in LOLE for GBX Wind Energy Delivery to Missouri

Profile Time Shift	-4 Wk	-3 Wk	-2 Wk	-1 Wk	0 Wk	+1 Wk	"+2 Wk	+ 3 Wk	+4 Wk	Average
ELCC	210	79	28	450	419	260	109	75	60	**165**
LOLE Reduction	0.027	0.012	0.005	0.050	0.045	0.033	0.015	0.012	0.010	**0.023**

Analysis/Conclusions

The quantitative results from the study show that the Grain Belt Express Project wind energy injection in Missouri would have the capacity benefit of a single-medium sized natural gas power plant. For the nine (9) scenarios of wind constructed for the study, the annual ELCC averaged 165 MW, with a low annual value of 28 MW and a high value of 450 MW. The 33% average capacity benefit (capacity value divided by the nameplate rating of the Grain Belt Express Project tap) is consistent with what has been calculated for high-quality wind resources in previous studies. Similarly, the reduction in LOLE from the assumed baseline is 0.023 days/year, or a 23% reduction from the assumed baseline of 0.1 days/year.

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