Wind and the Electric Grid

TRANSMISSION, STORAGE AND SMART GRID OPTIONS

WEST MICHIGAN WIND ASSESSMENT | ISSUE BRIEF 8

The West Michigan Wind Assessment is a Michigan Sea Grant-funded project analyzing the benefits and challenges of developing utility-scale wind energy in coastal West Michigan.

More information about the project, including a wind energy glossary can be found at the website, www.gvsu.edu/wind.

Introduction

Michigan's Renewable Energy Standard requires renewable sources that generate 10% of its electricity supply by 2015.

Wind energy is developing at a rapid pace. In 2001 the total amount of electricity in the United States generated by wind power was 6.7 million megawatt-hours[1] (MWh). By 2011 that amount skyrocketed to 120.2 million MWh, an eighteen-fold increase in 10 years [1]. Michigan's Renewable Energy Standard requires renewable sources, like wind turbines, to generate 10 percent of its electricity supply by 2015 [2].

Wind is considered to be an intermittent energy source because it is constantly fluctuating throughout all hours of the day depending on wind speeds, air density, and the location of wind turbines. The addition of wind and other intermittent energy sources into the electricity grid at levels at or below 10 percent of total generation is generally not an issue for the transmission system. However, achieving substantial reductions in carbon emissions would require greater than 10 percent deployment of intermittent generation sources. The Electric Power Research Institute (EPRI), for example, estimated that an electricity portfolio designed to reduce carbon emissions by 40 percent by 2030 (compared to 2005 levels) would require renewables to compose 15 percent of the total generation capacity. In order to effectively incorporate intermittent power, we may need to improve how we manage and distribute electricity [3].

To effectively incorporate intermittent power, we may need to improve how we manage and distribute electricity.

This issue brief presents the main challenges that wind energy developers and engineers have to address to make wind energy a more reliable source of electricity. The brief concludes by introducing and summarizing the smart grid and how these new technologies could increase the amount of wind energy we use.

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[1] A megawatt hour is the amount of energy used if work is done at an average rate of 1 million watts for 1 hour. More definitions relevant to wind energy can be found at www.gvsu.edu/wind/project-documents-3.htm.

[2] An electric generating unit is a solid fuel-fired steam-generating unit that serves a generator that produces electricity for sale to the electric grid. More information can be found at: http://www.epa.gov/nsr/ghgdocs/electricgeneration.pdf.

The Transmission Grid

Before investigating how wind energy affects the electrical grid, it is imperative to understand that wind farms do not operate in isolation. Think of the electrical grid as a huge bathtub with thousands of taps (electric generating units[2]) that provide the water (electricity), and millions of drains (customers) that drain the water from the reservoir. Wind farms are currently just a small part of this extensive, complicated network. The task assigned to the grid operators is to ensure that there is enough electricity in the grid system to maintain a secure environment that meets everybody's needs.

The North American electrical grid consists of more than 9,200 electric generating units with more than 1 million megawatts of generating capacity connected to more than 300,000 miles of transmission lines [4]. Our grid system has evolved from many small local grids to a series of larger grids that make it possible to transmit large amounts of power within a region. However, because the ownership and operation of the grid is divided up by regions (Figure 1) this makes it difficult to transport power over long distances such as from the Midwest to the Southeast United States.

Wind farms do not operate in isolation.

The transmission grid is managed by several organizations with responsibilities for regulation and operation. The North American electrical grid is segmented into four networks which, for all practical purposes, are independent from one another; the Eastern Interconnection, the Western Interconnection, ERCOT Interconnection (Texas), and the Québec Interconnection. Michigan is part of the Eastern Interconnection.

The transmission grid is managed by several organizations with responsibilities for regulation and operation.

Electricity generation and reliability is giverned by the North American Electric Reliability Council (NERC), a non-governmental organization with statutory authority in the U.S. (and is seeking similar authority in Canada and Mexico). NERC delegates its enforcement authority to eight regional entities (Figure 1). Most of Michigan, including the west Michigan region, is part of the Reliability*First* Corporation regional entity [5]. While the reliability organizations set and enforce standards, regional transmission organizations (RTO) actually operate the electricalgrid. Michigan's electrical grid is operated by the Midwest Independent System Operator (MISO) [6].

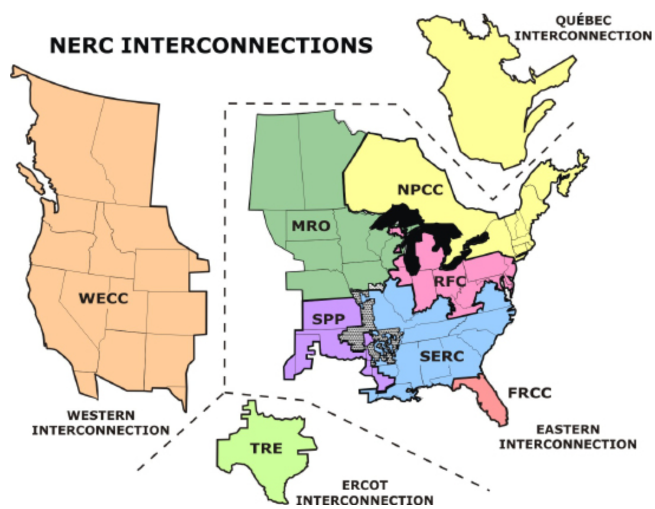

Figure 1: Map showing the eight Regional Reliability Councils and four Interconnections in North America. The ReliablilityFirst Corporation (RFC) covers most of Michigan.

Effects of Wind Energy on the Electrical Grid

Renewable energy has the potential to help reduce Michigan's dependence on fossil- fuel-based electrical generation [7]. Small amounts of variable energy sources like wind easily integrate into the electricity grid. The National Renewable Energy Laboratory (NREL) reports that reaching high proportions of wind energy generation, about 20 to 30 percent of electricity demand in the eastern U.S., is technically feasible if there are significant investments to expand the transmission infrastructure [8]. There are three main challenges that wind energy developers and engineers have to address for wind energy to be a reliable source of energy: variability, energy storage and long distance transmission [9]. All three of these hurdles could be addressed by diversifying the types and locations of energy sources connected to an electrical grid [10].

Variability

Three challenges in making wind a reliable energy source are: variability, energy storage and long-distance transmission.

Maintaining a reliable stream of electricity and avoiding black-outs is incredibly important. All electricity generating technologies require backup capacity, called operational reserve, to accommodate fluctuations in demand, scheduled maintenance and unplanned outages. The amount of electricity produced by wind turbines fluctuates across short time periods (generally across hours within a day), which may require more operational reserve than other electricity generating technologies. How much additional operational reserve is needed to support a wind farm depends on the characteristics of the grid and the composition of the energy portfolio.

While wind power may be variable, a diverse portfolio of energy sources powers the electricity grid. Having a diverse collection of energy sources that are located in areas that can maximize the energy production by each power center will smooth out the fluctuations in the electrical grid [11]. Therefore, having energy sources distributed nationally, and in some cases internationally, through interconnected grids can mitigate the ebb and flow of the supply and demand associated with electricity.

A diverse collection of energy sources in an area will help to smooth out the fluctuations in the electrical grid.

Wind is a spatially diverse resource. That is, wind blows unevenly across the landscape, even on the scale of a single wind farm. While a single turbine may not be producing electricity at a given moment in time, another turbine in the wind farm might be. This phenomenon holds true at larger spatial scales. While one wind farm may not be producing much electricity at a given time, another wind farm nearby might be producing a significant amount. A NREL scientist has shown that as more wind farms are constructed across a region, their combined electricity output becomes less variable, which is a desirable characteristic. As the distance between wind farms increases, the combined variability also decreases. As more wind farms are connected to the electricity grid across wider distances, the reliability of the whole system is enhanced. The spatially diverse nature of wind means that electricity output from a large wind farm will not drop from full-power to zero rapidly, even during rare events when wind speeds drop suddenly or high winds induce an automatic cut-off [12].

The grid operator for Michigan and other Midwestern states, MISO (Midcontinent Independent System Operator), analyzed the impact of wind on the electrical grid. MISO used data from operating turbines in seven states between 2004 and 2009. Michigan was not included because it had no large wind farms at the beginning of the study period. MISO came to the following conclusions about integrating wind into the Midwestern grid:

- The daily average level of wind is constant, but can vary substantially across hours within a day.
- Peak electricity production from wind turbines tends to run opposite the daily patterns of electricity demand (e.g. wind declines during morning when demand is rising).
- The capacity factor for wind farms across the MISO region for the first half of 2009 was 31.6%. Meaning on average, wind farms generated 31.6% of the electricity they could have produced if wind was always at ideal speeds.
- Variability at current (2009) levels of wind generation can be managed with existing reserve capacity. The system can handle a 21% drop (1,400 MW) in electricity coming from wind farms over a four-hour period.
- Increasing wind generation capacity from 6,600 MW (in 2009) to 15,000MW in the MISO region would pose challenges particularly during the morning ramp-up and evening ramp-down times [13].

Wind power tends to decline in the morning when demand for electricity is rising. This could pose challenges to grid operators as wind farms expand.

In July 2011, MISO proposed a plan to ensure reliability of the Midwestern electric grid while incorporating additional, variable renewable resources like wind. The proposed plan provides a financial incentive for fuels (such as natural gas) that have high capacity to "ramp up" to balance the load in the morning and "ramp down" in the evening. MISO's plan "lays the ground work to be able to support increased variability and uncertainty in the future"- such as greater use of wind power [14].

Electricity can be transformed to other, storable forms of energy.

The Michigan Public Service Commission's (MPSC) 2013 report on renewable energy noted that wind energy has not affected the reliability of the MISO electricity grid and that "contingency reserves" (a type of back-up power) have never been deployed because of a drop in wind power. The Michigan Thumb Loop transmission line is under construction and will increase the grid's reliability as all kinds of new generation sources, including wind, come online. The MPSC found that "it would be possible to meet increased RPS [renewable portfolio standard] targets of as much as 30% (or perhaps higher) from resources located within the state" [33, p.6]. Advances in technology and increased experience with wind energy have enabled grid operators to reliably manage relatively high levels or intermittent sources like wind energy [33].

Energy Storage

One of the most efficient means for storing excess electricity is with pumped storage.

Electricity cannot be stored efficiently regardless of how it is produced. However electricity can be transformed to other, storable forms of energy. Energy can be stored using chemical energy in batteries, gravity-based pumped hydroelectric facilities, thermal storage, flywheels and compressed air [9, 15]. Each type of energy storage technology has unique implications so developers must choose carefully when considering which technology is appropriate for their project [16].

The following is a summary of the most relevant energy storage techniques available today and how they can be coupled with wind energy.

Pumped Storage

One of the most efficient means for storing excess electricity is with pumped storage. West Michigan already has a large pumped storage facility located south of Ludington. The Ludington Pumped Storage Plant (Figure 2) was constructed in

The Luddington Pumped Storage Plant could be used to store excess energy produced by wind farms.

Figure 2: Ludington Pumped Storage Plant's six turbines [Photo: Consumer's Power].

1973 by Consumers Energy and Detroit Edison, and was built in order to supply an inexpensive, dependable source of energy during times of high demand for Michigan customers. The facility comprises an 842-acre reservoir sitting on top of a ridge overlooking Lake Michigan, and at the time of construction was the largest plant of its kind in the world.

One test battery array has been used to store wind energy and supply about 500 homes for 7 hours.

The facility has six hydroelectric turbines that double as water pumps. The facility works by pumping water up 363 feet into the 27 billion gallon reservoir during the night when demand is low and electricity prices are inexpensive. During the day when electricity demand and prices are high, water is released from the reservoir and allowed to flow down to Lake Michigan through the turbines, producing electricity. Currently the Ludington Pumped Storage Plant has a capacity of 1,872 MW and has the ability to power 1.4 million homes, making this system 70-85% efficient [17]. In 2011, Consumers Energy and Detroit Edison announced that they will invest $800 million over the next six years to upgrade the facility's turbines, which will increase the amount of electricity the facility is able to generate by 16 percent, or by 2,172 MW [18].

The Ludington Pumped Storage Plant has, however, caused serious ecological problems over the years. During its initial years of operation the plan killed millions of fish as it sucked water out of Lake Michigan and pumped it up to the reservoir. The controversy led to a court settlement resulting in the installation of a 2.5-mile-long barrier net in 1989 to protect Lake Michigan fish and other aquatic life from the plant's water intake. Additionally, in 1994 an agreement was signed creating a landmark program to protect fish during operations and created a Great Lakes Fisheries Trust and Scientific Advisory Team.

West Michigan already has three advanced battery manufacturers.

Having a unique facility already connected to West Michigan's energy infrastructure makes this area an attractive destination for wind farm developers. Energy produced by the wind turbines during low demand hours can be used by the facility to pump water up to the reservoir. Water can be released the next day if the wind is not generating enough electricity to meet consumer demand. Furthermore having this facility so close to the shoreline could allow an offshore wind farm to easily access the electrical grid. Pumped storage is used successfully to manage the variability of wind energy production in the Spanish Canary Islands and between the Scandinavian countries of Denmark and Norway [10].

Flywheels have are not designed for long-term energy storage, but they can smooth out the minute-to-minute fluctuations in wind power production.

Batteries, pumped storage, and flywheels can manage the fluctuations in wind energy.

Battery Storage

Batteries can also be used to store electricity generated by wind. Though an emerging technology, battery storage has been tested at utility scales in several cases. For example Xcel Energy, Inc. partnered with the University of Minnesota, NREL, the Great Plains Institute and Minwind Energy, LLC to test a 1 MW wind energy sodium-sulfur (NaS) battery storage system in Minnesota [19]. The battery array can provide enough electricity to supply about 500 homes for seven hours. Since this technology is relatively new it is also relatively expensive. This wind-to-battery storage project cost approximately $3 million per megawatt in addition to millions in start-up costs [20]. Electric Transmission Texas, LLC in Presidio, Texas has also successfully used the NaS battery system to store energy [21, 22]; however, electricity produced by wind is not being used to charge the batteries. As the research and development of this technology continues to evolve, the cost of battery storage is expected to decrease.

Three advanced battery firms are building manufacturing facilities in West Michigan. The Swiss-German company fortu PowerCell is developing a $100 million facility in Muskegon County. The plant will produce batteries for use in both electric power grid storage and transportation [23]. The two other firms, LG Chem and Johnson Controls-Saft, both have manufacturing facilities in Holland, Michigan. The two firms will primarily focus on batteries for the electric vehicle market, but Johnson Controls-Saft is also looking at a broader range of applications [24, 25]. The presence of three advanced battery manufacturers puts the West Michigan region in a unique position to integrate battery storage and wind energy facilities.

Flywheel

Much like wind turbines, the concept of a flywheel has been around for centuries. However, in the last decade there have been rapid advancements in the technology associated with the flywheel energy storage. The current flywheel technology has a rotor made out of carbon filaments and can turn at speeds up to 50,000 rotations per minute (rpm) (Figure 3). The average flywheel used for grid energy storage only spins at a top speed of around 16,000 rpm. To reduce friction, the rotor is contained within a vacuum container and suspended between two electromagnetic bearings [26]. Flywheels work by accelerating the rotor inside the vacuum to an extremely high speed (approximately 1,500 miles per hour) and maintaining the energy invested into the system as rotational energy. Slowing down the flywheel releases the energy stored in the device and powers a generator [27].

Figure 3: The Smart Energy flywheel constructed by Beacon Power [Photo: Beacon Power].

Experts predict that a 15% increase in wind power must be managed using new methods to mediate the variability.

Winds are strongest in the Midwest; however, the energy demand centers are the East and West coasts.

Flywheels have the ability to store 25 kWh of electricity [28]. Multiple flywheels can be networked together to create an array of devices capable of stabilizing the electrical grid for a short time. Flywheels are not designed for long-term energy storage like the pumped storage and battery technology mentioned above. Instead, they are mainly used to smooth out the minute-to-minute fluctuations that occur due to unsteady wind gust or the short-term breaks between wind gusts [29].

An example of interconnected flywheels is the Smart Energy Matrix™ plant in Stephentown, New York where 200 flywheels have been networked together to store approximately 4 kW of electricity. These flywheels are constantly charging and releasing electricity throughout the day using the electrical grid as a source and recipient of the electricity. This same rationale can be applied using the electricity produced by wind turbines as the source of the flywheel's charge and the grid as the receiver. In 2007, the California Energy Commission partnered with Beacon Power Corporation to install flywheel energy storage technology at a wind farm in Tehachapi, California. The goal of the project was to demonstrate how flywheels coupled with advance control technology can assist in expanding the amount of wind energy delivered to the local electrical grid. This is done by networking 10 Smart Energy flywheels to create a grid-scaled Smart Energy Matrix™. This matrix has the capability of absorbing and delivering several megawatts of electricity for up to 15 minutes, which in turn increases the electrical grid's reliability [26].

Summary of Energy Storage

Advancements in energy storage technologies can increase the resilience and reliability of the electrical grid in both the short-term and long-term [9]. As the production of electricity generated by renewable energy sources continues to increase, how this electricity is stored could be a challenge for engineers. Experts predict that a 15 percent increase in electricity sourced by wind and/or solar must be managed because of the variability associated with these energy sources. A number of existing, new and emerging technologies exist for storing energy to modulate the fluctuations from variable generation sources like wind. These include batteries, pumped storage, flywheels and others.

Long Distance Transmission

One-hundred and twenty years after Thomas Edison and Nikola Tesla first introduced different methods for electricity distribution, engineers are still challenged to find the most efficient methods for transmitting electricity from its generation sources to its end users. This challenge is especially difficult when it comes to wind

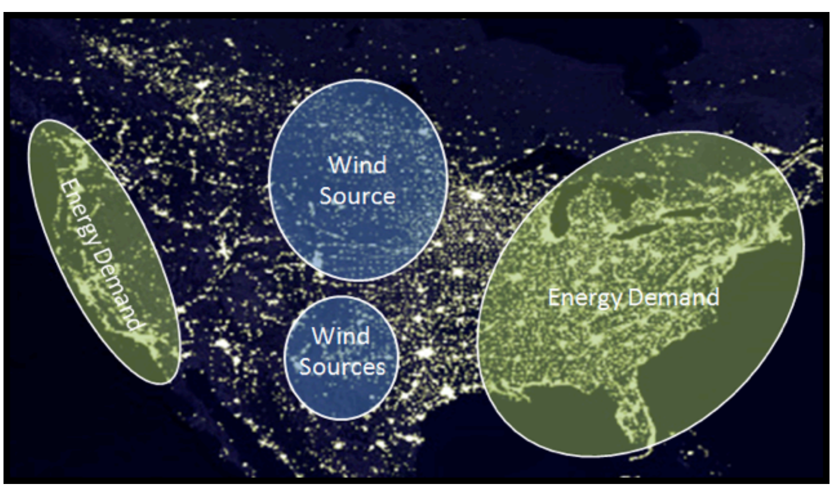

Figure 4: Location of the major energy demand centers and wind energy sources in the United States [APS 2009].

power since many of the windiest places in the United States are located in the upper Midwest, far away from the demand centers of the West and East coasts (Figure 4) [9, 30]. The looming investment that needs to be made in long-distance transmission warrants a more meticulous look at the options available to meeting this challenge.

High-voltage direct current (HVDC) cables are capable of transporting electricity long distances with a minimal loss.

One option for long-distance transmission is using high-voltage direct current (HVDC) cable, which are specifically designed to transport electricity over thousands of miles. As wind farms become larger or as wind farms go farther offshore the practice of using HVDC cables becomes easier to justify economically, especially when the capacity of a wind farm approaches 500 MW. The advantage of using HVDC cables over the standard AC (alternating current) connection is that HVDC cables are capable of transporting electricity long distances with a minimal loss. HVDC cables also have a higher capacity to transport large amounts of electricity compared to its AC counterpart, therefore fewer HVDC cables would be required, lowering costs. The disadvantage of HVDC cables are that they require aboveground towers, which can be unsightly and the process of securing permits for the many electrical towers can take years [9].

In the United States, the Atlantic Wind Connection has proposed building an HVDC cable that will serve as a transmission backbone to facilitate offshore wind energy development along the Atlantic coast. When complete, the $5 billion project will stretch from Virginia to New Jersey and could support 6,000 MW of wind energy capacity. The project is planned in phases, and the first section could be operational in 2016 [31].

The rapid expansion of wind energy in the United States has led to a growing concern about the transmission network. Experts agree that maintaining or increasing the nation's wind energy capacity will require significant additions to the electrical grid [29], but at what cost?

In 2009 the Ernest Orlando Lawrence Berkeley National Laboratory at the University of California investigated 40 transmission studies that have included wind energy. These studies focused on a variety of geographic areas and tried to predict transmission costs necessary to capture the growing quantities of wind energy. The researchers found that the average cost of transmission needs for a wind farm represents approximately 15 percent of the project's cost. The report's authors acknowledge there are limitations to this type of analysis, namely that transmission expansion is not unique to wind energy.

Maintaining or increasing the nation's wind energy capacity will require significant additions to the electrical grid.

In many cases transmission expansion offers multiple benefits and serves multiple purposes. The methods used in this analysis ignore those other benefits and assigns the full cost of transmission expansion to the wind power projects [29]. Regardless of the limitations, this study demonstrates that our transmission network will need to be modified or expanded to integrate renewable energy sources and this will cost money, but the additional transmission costs are relatively small compared to the cost of building a new wind farm.

The Smart Grid

The system for distributing electricity in the U.S. has changed very little since power lines were first widely deployed in the early 1900s. Despite huge technological breakthroughs in other parts of the economy, the U.S. is reliant on a centrally planned and controlled electrical grid that was mostly created before the advent of computers. This lack of technological change limits the current electrical grid; it is not as efficient or secure as it could be and it lacks the flexibility to maximize renewable energy [4]. Smart grid technologies could address these limitations. A smart grid integrates traditional power hardware with sensing and monitoring technology, data technology and communications to improve grid performance and support additional services to the end consumers [32]. A smart grid will enable utilities to improve their response to power demand, manage power outages more efficiently, store electricity, and improve the integration of renewable energy into the grid [30].

The current electricity grid mainly consists of a one-way flow of electricity and information from centralized locations to consumers. The smart grid combines Internet communication with energy delivery so that electricity and information can flow in two directions from decentralized generation sources. Smart grid technologies will transform the conventional electrical grid to be more secure, resilient and efficient- not just for wind energy but for all types of energy. The smart grid concept involves a number of new innovations, as stated by U.S. Department of Energy:

The smart grid combines Internet communication with energy delivery.

"As one industry expert explains it, there is no silver bullet when it comes to enabling technologies for a smarter grid; there is instead a 'silver buckshot,' an array of technological approaches that will make it work.

Further clarification: devices such as wind turbines, plug-in hybrid electric vehicles, and solar arrays are not part of the Smart Grid. Rather, the Smart Grid encompasses the technology that enables us to integrate, interface with and intelligently control these innovations and others." [4, p. 15]

According to researchers at The Brattle Group, incorporating smart grid technologies will require an investment of approximately $1.5 trillion between 2010 and 2030. The cost of implementing these infrastructure upgrades is significant; however, improving our grid system will allow us to conserve electricity in the long run. For example it is anticipated that smart grid improvements will alleviate congestion and increase utilization, sending 50 to 300 percent more electricity through existing energy passages [4].

West Michigan utilities are experimenting with smart grid applications. Consumers Energy, one of the two large electric utilities in the state, has deployed 60 smart meters in the East Hills neighborhood of Grand Rapids [32]. These smart meters are a good example of the two-way flow of information that characterizes the smart grid. Smart meters will enable utility customers to more precisely track energy usage by hour, day, week or month. When customers know how and when energy is being

Smart meters will enable utility customers to more precisely track energy.

> *An improved energy infrastructure, complete with advanced metering technology and an enhanced electric grid will increase grid reliability and security. It will improve the ability for consumers, businesses, and utilities to manage demand and control costs.*
>
> *A well designed smart grid would make energy optimization and efficiency efforts more fruitful.*
>
> ~ Nicholas Occhipinti
> Policy and Community Activism Director
> West Michigan Environmental Action Council

used, they can then take measures in reducing their unnecessary or unintended energy usage. Preliminary data show that using smart meters have already reduced the amount of electricity used by a business or homeowner, which in turn is saving energy, money and emissions [32].

As the electrical grid in the United States gets smarter the integration of renewable energies will increase. Smart grid will be able to smooth out the variability associated with renewable power sources by drawing surplus power from other parts of the country and from other renewable sources. The smart grid will be able to transfer surplus electricity from wind turbines to hydroelectric facilities, pumped storage, batteries, and other types of technology for storage. Lastly when wind is generating at a surplus for an area, that electricity can be used in other places that need electricity, regardless of distances. Basically, a smart grid could address the three main hurdles to integrating renewable energy sources into today's electrical system: variability, storage and long-distance transmission.

Conclusion

Wind energy production is developing at a rapid pace. In 2011 wind energy accounted for 2.9 percent of all electricity generated in the United States [1]. Most experts agree that our current electrical system can handle receiving 10 percent of our electricity from wind energy with only minimal or no additional costs or changes to the transmission infrastructure. Despite wind's intermittent nature, diversifying the electricity generation portfolio and enhancing electricity transmission benefits all generators and makes the entire electricity grid more reliable.

The smart grid will be able to transfer surplus electricity from wind turbines to other types of technology for storage.

However, if wind energy were to contribute more than 20 percent of the total electricity load for the eastern U.S., significant infrastructure investments would be required. Infrastructure upgrades would be needed to manage the variable nature of wind energy and move energy long distances, from regions with great wind resources to places with high energy needs, such as the coasts. These challenges can be addressed by diversifying the types and locations of power plants on the grid, incorporating facilities to store energy, developing more robust transmission infrastructure, and building a smart grid. When integrated into a robust electricity grid, wind energy can reliably contribute to electricity generating capacity.

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Principal Investigator: Erik Nordman, Ph.D.
Assistant Professor of Natural Resources Management
Grand Valley State University
nordmane@gvsu.edu

www.gvsu.edu/wind

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