Summary Report

CEATI International Inc.

Hydraulic Plant Life Interest Group

CEATI Project No. T104700-0371

The Hydroelectric Industry's Role in Integrating Wind Energy

Introduction

Renewable energy has been part of the electrical industry for as long as the industry has existed. Some of the first generating stations ever built were hydro powered. Worldwide, hydropower is responsible for 12.3% of electrical energy generation in 2007[1], with over 775,000 MW of installed capacity[2]. However, over the last decade wind power has made some dramatic strides in becoming a relevant part of the electrical generation mix. The global installed capacity of wind power has increased dramatically during the last decade, from 15,400 MW in 2000 to in excess of 145,000 MW at the beginning of 2010. This momentous growth is expected to continue

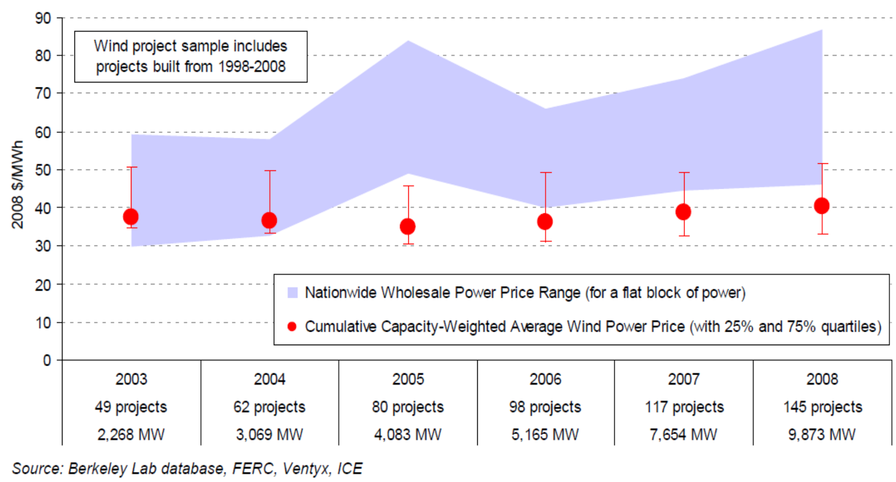


***Figure 1**: Wholesale power prices and wind power prices over the past several years in the United States. (Source: Wiser and Bolinger 2009)*

[1] International Energy Agency, *Renewables Information 2008*, IEA Publications, France, ISBN 978-92-64-02775-6, OECD/IEA, Paris, 2008.

[2] US Energy Information Administration, International Energy Annual: http://www.eia.doe.gov/iea/

over the next several years to several decades. The expansion of wind power is being encouraged by a wide variety of factors: government policies and incentives, societal pressure for additional "green" energy sources, and high and volatile fuel prices for coal, oil and natural gas to name a few. However, perhaps the largest factor supporting this growth is that the price of electricity produced by wind energy has become competitive with conventional thermal power generation plants (e.g., see Figure 1). Integration of wind energy into the electric power system has now become a major issue facing electrical utilities throughout the world

A modern utility-scale wind turbine.
(Source: US National Renewable Energy Laboratory)

Wind Power

Because of its price competitiveness, wind energy will supply a significant fraction of the renewable energy that will come into service over the foreseeable future. The wind resource is also ample; recent wind mapping conducted for the US Department of Energy[3] estimated that there is in excess of 10,400,000 MW of "developable" wind energy resources in the US. Compared to the peak power demand in the US of about 780,000 MW (2008[4]), it is easy to see that wind power can become a significant contribution to the electricity supply system. Wind energy resources are not exclusive to the US; there are similarly impressive wind energy potential numbers across the globe. Perhaps one caveat that should accompany these wind power potential estimates concerns where the wind resources are located. People don't often like to live in very windy places, so the wind resources tend to be remote from the load centers. The implication here is that the transmission grid and its ability to move power over long distances is a key and potentially limiting factor in wind power development.

Relative to the total amount of electrical generation worldwide, which was 4,000,000 MW in 2006[5], the, the amount of installed wind power is modest, at nearly 160,000 MW (end of 2009[6]); an amount that has been rapidly increasing each year. The size of a wind power site can vary considerably depending on the location and wind resource, but typically range from 30 MW to 700 MW and consisting of 10 to 300 wind turbines. The wind turbine technology has also improved greatly over the past two decades as the turbine size has grown to multi-megawatts (1 to 5 MW), to the point where the reliability of the equipment exceeds 98%. Wind energy also offers price stability, as wind power contracts and purchase prices are typically set-up for the life of the project. This information, combined with the facts that wind power does not emit any greenhouse gases or require any water consumption for cooling during generation, provides powerful motivation for increasing the amount of wind power.

Even with all of its positive attributes, wind power is not all roses. As a generation resource driven by natural processes, it behaves differently than traditional, dispatchable resources. As shown in Figure 2, wind power can vary substantially from hour to hour and day to day. These variations create challenges for electrical system planners and operators whose primary job is to ensure the balance between generation and load and to maintain system security. Three questions dominate when addressing the operational challenges accompanying wind power: what is the magnitude and character of the wind's variability, how predictable is the wind power output, and what impact will the variability and uncertainty of the wind have on system operation and costs?

[3] Refer to http://www.windpoweringamerica.gov/wind_maps.asp

[4] See http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

[5] From http://www.eia.doe.gov/iea/elec.html

[6] See http://www.gwec.net/index.php?id=167

Electricity Supply

The development of commercial electricity production and the electrification of cities and towns took place in the early 20th century. Initially, the consumers of the electricity (i.e. the load) and the generation resources that served it were, by necessity, located relatively close to one other geographically. Communities established generation to serve their loads along with the electrical transmission lines necessary to connect them. These communities were essentially "balancing areas" in that the utility in charge would ensure that the generation available was always sufficient to balance the load, and thereby maintain system reliability, "assuring that the lights stayed on." As society expanded and generation technology evolved, larger and larger generation units came on-line and were connected to the balancing areas via high-voltage transmission lines. As more and more of these larger generators were built, the transmission system evolved into an interconnected grid where large power plants could exist far from the load centers. An excellent example of this expansion was the construction of the large hydropower facilities along the Columbia River, located in the north-western part of the United States and British Columbia in Canada, which took place in the mid 20th century, and the high voltage transmission lines that connected them to the load centers mainly in California. In today's electric industry, the generation resources may be many hundreds of miles from the load centers and power can be transmitted across vast distances.

Today, electric power generation is derived primarily from some version of steam generation or hydro generation with new renewable generation, such as wind, starting to make some inroads. In the case of steam generators, the fuel source used to produce the intense heat needed to create the steam may be from coal, oil, natural gas, wood/biomass, or nuclear resources. Note that all of these resources, with the exception of nuclear, produce some type of "harmful" air emission and all are dependent upon access to their respective fuel sources at varying costs. On the other hand, hydro, geothermal, solar, and wind generators, often referred to as "renewable energy generation resources," depend on fuel sources that are natural, utilize a "no-cost" fuel supply, and are non-polluting. The drawback of these resources, however, is that their fuel sources, though freely available in nature, are not always available at the time needed (e.g., drought, night time, cloud cover, no wind, etc.).

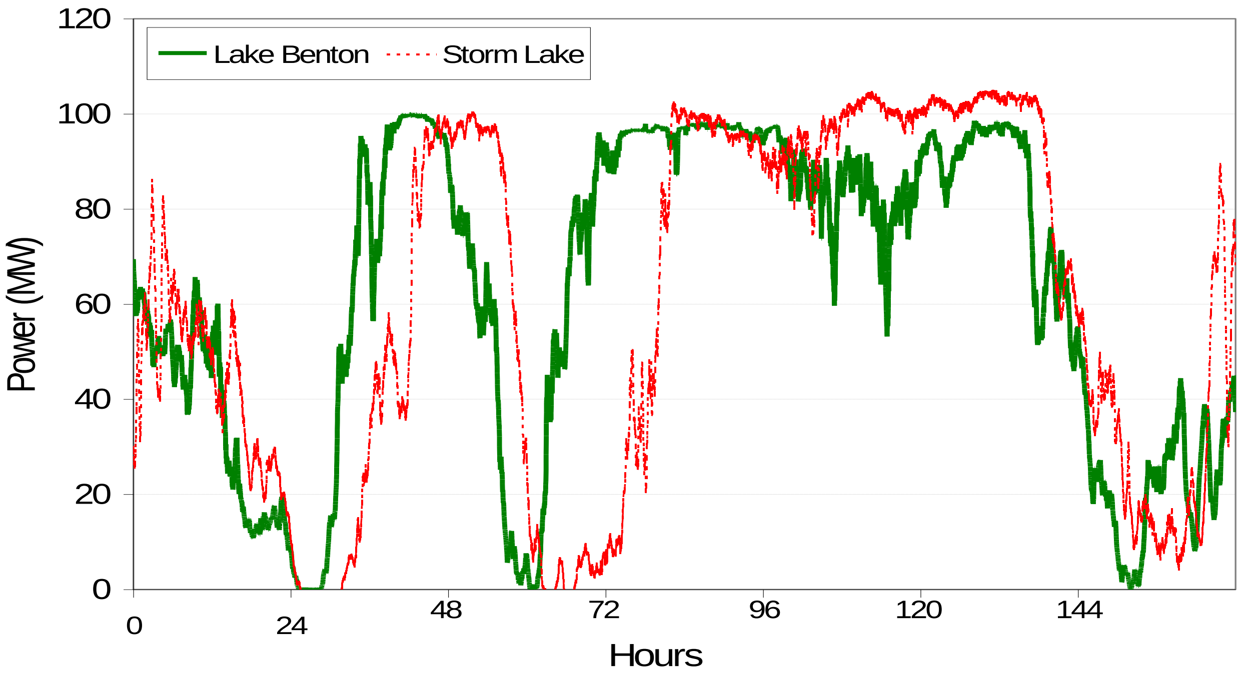


Figure 2: *Wind power output over a week at two ~100 MW wind power plants in the Midwestern US. (Source: US National Renewable Energy Laboratory)*

In the not-so-distant past, it was difficult for many utility owners, managers, and operators to buy into the concept of using a suite of generation resources, including renewable generation from dispersed geographic locations, to provide a blended generation resource pool with blended fuel costs. The basic reason for this is that fossil-fuel based generation is dispatchable at the time needed and their use and cost is well understood. However, with the political-socio infirmities of fossil-based fuel sources, decision makers in the electrical generation and distribution industry are beginning to embrace the importance of including renewable energy generation resources into their respective generation resource pools. Indeed, over the past decade, regulatory bodies and political institutions have begun to require that large percentages of the electrical energy serving the people they represent be derived from renewable energy resources, in excess of 30% in some locales. Other utilities that are self-regulated have adopted renewable energy targets on their own in response to customer demand or to mitigate their risk related to carbon emissions or fuel price volatility.

Wind Integration

Answering these questions is the purview of what is called "wind integration." Figure 2 depicts the time frames of system operation and planning that are impacted by wind integration. Figure 3 shows an archetypal variation of customer load throughout a day: low demand at night and high demand during the day. Though the terminology shown here describing the relevant time frames may differ in electrical systems around the globe, the essential functions of balancing an electrical system are the same, regardless of where it is.

Referring to Figure 3, let's first consider the "regulation" time frame. In this time frame, some generation resources must be on-line and responsive to load via automatic generation controls, such that the short term minute-to-minute fluctuations in load can be met by short-term variations in generation. The "load following" time frame refers to the slower variations in load that occur within an hour and from hour-to-hour, for which the system operator can dispatch generation

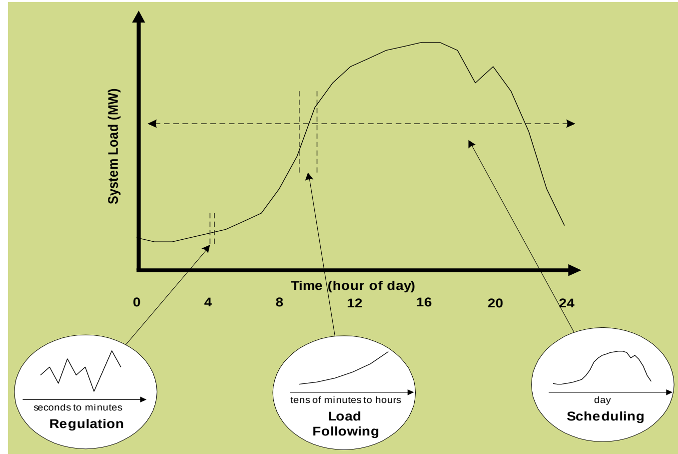


Figure 3: *Time scales of importance in wind integration, when considering the ancillary service impacts due to the variability and uncertainty of wind energy. (Source: US National Renewable Energy Laboratory)*

based upon economic justification. "Scheduling" refers to the action of economically scheduling units available on a given day to meet the expected or "forecasted" load, an activity often referred to as unit commitment. "Unit commitment," however, is more broadly defined than this, as it also includes committing units to service the day ahead of operation, and sometimes longer than that, with the understanding that many large thermal power plants require eight hours to over a day to start-up and bring to full capacity, and that start-up costs are expensive.

The commitment process also includes making decisions about the character of the generating units to have on-line during any given day; some units must be very fast responding to in order to handle the regulation requirements in a balancing area, while others must be flexible enough for load following within the hour and hour-to-hour, and others need not vary and can serve the base load. The more flexible generating units are often more expensive to run, and thus an accurate forecast of the amount of flexibility required can save on operating costs. Regulation, load following, and unit commitment are some of the "ancillary services" required to maintain the performance and reliability of the electrical system within the balancing area of an interconnected grid.

Variability & Uncertainty

The methods employed for electrical system operation have been devised to deal with loads that vary moment-to-moment and day-to-day, through the use of sufficiently flexible generation resources. While utilities have a good idea of the upcoming load the next hour or the next day, and the amount of flexibility required of their generation, there is uncertainty and error inherent in any forecast. For this reason, reserves are set aside to ensure adequate generation is available in the event of a missed forecast, or if some unanticipated loss of generation or transmission occurs.

Wind power, due to the natural variability of the resource, is itself variable and predicting its output is fraught with uncertainty. Forecast errors, expressed as a fraction of the wind power plant capacity, usually average about 5% an hour ahead, and between 15% to 25% a day ahead. These are pretty good numbers considering the complexity of the processes that govern wind flow in the atmosphere. However, when the weather is changing from the passage of a weather front, or when the weather is stormy or unsettled, the errors in wind power forecasting tend to be exacerbated. Though large wind forecast errors are infrequent, it is at these times when the system operator will experience challenges in balancing load and generation, and when wind integration costs are usually incurred. This is usually the case because, nominally, about half of the wind forecast errors that exist will be in the opposite direction of a load forecast error and will actually help out the system balancing. Nonetheless, it is in those instances when the wind forecast error and the load forecast error combine that increased system balancing costs are incurred, for example by purchasing expensive power on the spot market.

Wind Integration Costs

In terms of electrical system balancing, wind power will increase the ancillary services required in a balancing area due to its natural variability and the uncertainty in its prediction. Wind power's variability will enhance the short-term minute-to-minute fluctuations (regulation) as well the longer-term system ramping and load following. Its uncertainty will influence scheduling and unit commitment and requires that more reserves be set aside.

The expenses incurred by a system operator in performing these functions are referred to as "wind integration costs." Understanding that these costs will be incurred, it is of interest to know the magnitude of these costs: are they small or large? Much work has been done over the past decade, still on-going today, to answer this question. At wind power penetration rates up to 1% or 2% of the peak system load (e.g., 1% or 2% of the electrical energy served by a utility is provided by wind power), wind power is not very noticeable to the electrical system operator. That is, the wind energy shows up like negative load, so instead of operating the system to meet the load alone, it is operated to meet the load less the wind generation, referred to as "load net wind" or "net load."

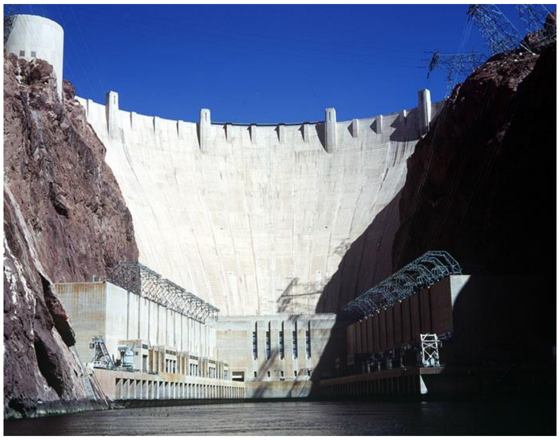
At small penetration levels, the system operator is not concerned with missed wind power forecasts (or having no wind power forecast at all), because the small increment of variability that wind power adds to an already variable load is hardly noticeable. Beyond this threshold, however, wind power can have a noticeable impact causing the net load to differ from the load alone, and the forecasted net load will have a greater error than the forecasted load alone. As many regulatory bodies, political institutions, or customers are requiring large percentages of their electrical energy to be derived from renewable energy resources, and since wind energy will supply a significant fraction of this energy, wind integration has become an important issue for electrical balancing area authorities.

Over the past decade, common methodologies for determining wind integration ancillary service impacts and costs have evolved. Using load and wind power estimates, cost production models are used to simulate the unit commitment and dispatch operations with assumptions about the market, fuel prices, and other operational conditions. Wind forecasts are normally included to capture the uncertainty component of wind forecast errors combined with load forecast errors. This allows for reserve requirements and reliability concerns to be evaluated, in addition to the cost of utilizing more flexible generation resources.

Typically, the impacts of wind integration are assessed in terms of an overall integration cost, generally expressed as a cost per megawatt-hour of wind energy produced (e.g., $/MWh), from added levels of ancillary services for regulation, load following, and unit commitment. The largest components of the integration costs are incurred in the load following and unit commitment time frames, and the total cost can vary from $1/MWh to $8/MWh, depending on a number of factors, most notably the penetration of the wind power, the variability of the load and wind (the net load), the flexibility of the generation resources in the balancing area, and the nature of the market or energy trading system within which the electrical system is operated. These costs are fairly modest, on the order of one-tenth the cost of the wind energy itself. As guideposts for comparison, the average retail price of electricity in the United States in 2008 was about $100/MWh[7], and the average cost of wind energy from new wind power projects built in 2009 in the US was approximately $61/MWh[8].

Hydropower

So how does hydropower fit into this story of wind integration and the enhanced ancillary service requirements? To best answer this question, it is beneficial to first understand hydropower. Hydropower is typically one of the least expensive generation sources, often with generators that are outfitted with automatic generation controls (AGC) that allow very rapid response to changes in electricity demand. Hydropower generators are also capable of rapid ramping and load following, and therefore can supply the valuable "ancillary services" required to maintain the instantaneous balance between generation and load. The ability to provide these services, along with its low cost of energy and, in some cases, energy storage via reservoirs, makes it one of the most flexible and valuable generation assets on the electric grid. Hydro facilities with large storage reservoirs have the greatest potential as system balancing resources.



Hoover Dam and Powerplant. (Source: US Bureau of Reclamation, Photo C45-300-021359)

Generally, hydropower facilities have relatively low average capacity factors,[9] on the order of 20% to 45%. The actual capacity factor at a given plant may vary substantially from year-to-year due to changes in annual precipitation and reservoir levels. These low capacity factors can be attributed to the fact that hydro power plants are typically sized to handle near the maximum river flow, which only occurs for a portion of the year and only in those years of above average stream flow, and therefore have more capacity available than water to run through the system.

For example, consider the 58 hydropower plants operated by the United States Bureau of Reclamation (Reclamation) throughout the western United States. Historical hydro data from Reclamation for ten years (2000 through 2009) shows the average installed capacity at these power plants ranging from 14,745 MW to 14,876 MW, and the electrical energy generation ranging from a low of 34,424 GWh (Gigawatt hours) in 2001 to a high in 2000 of 47,283 GWh. The variation in the average capacity factor across these 58 power plants ranges from 29.1% in year 2004 to 36.8% in year

[7] Source: the US Energy Information Administration: http://www.eia.doe.gov/electricity/epm/table5_6_a.html

[8] Refer to the 2009 Wind Power Technologies Market Report posted on the Wind Powering America web site: http://www.windpoweringamerica.gov/filter_detail.asp?itemid=2788

[9] The capacity factor is a ratio of the amount of electrical energy produced at a power plant divided by the maximum amount it could produce if its generators were running at full capacity for an entire year.

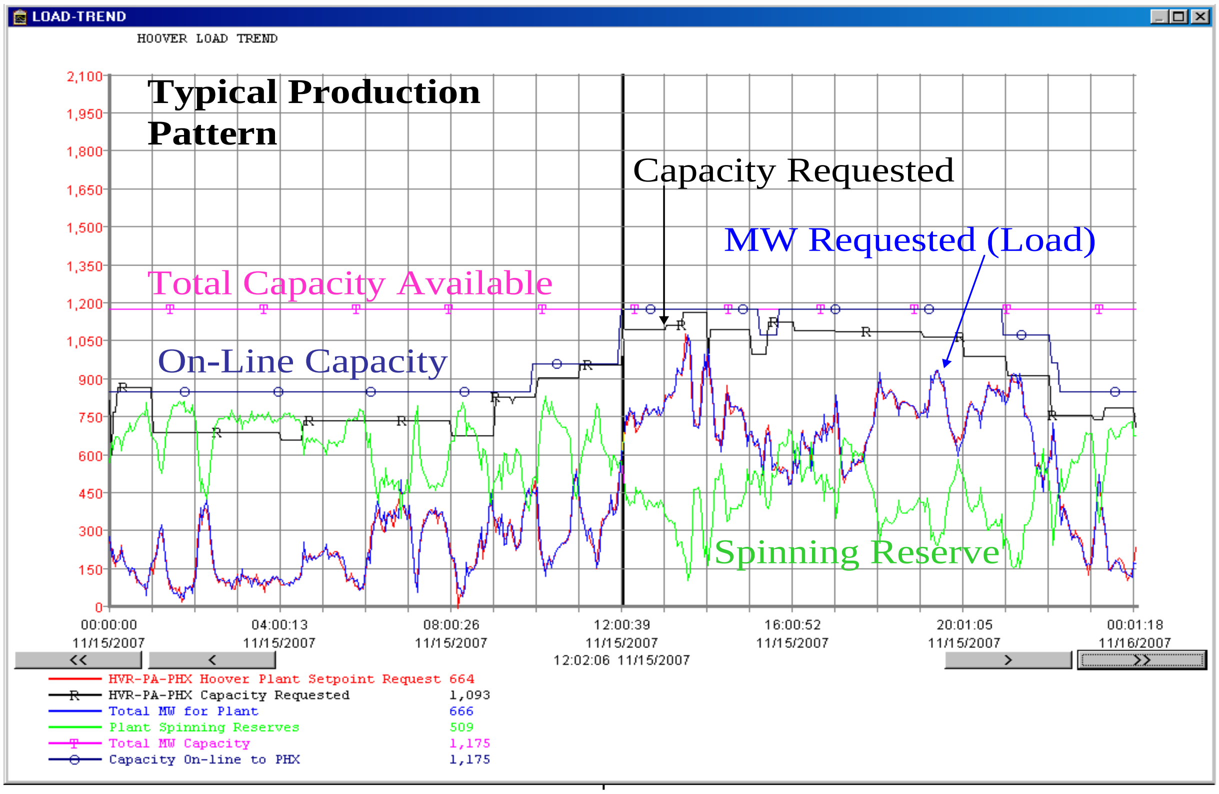


Figure 4: *A typical daily production pattern from the power plant located at the Hoover Dam in the southwestern US. Flow and power constraints due to priority functions of a dam define the generation flexibility of a hydro power plant.* *(Source: US Bureau of Reclamation.)*

2000. With respect to system balancing and the reserves required to cover missed forecasts of the net load, a hydro power plant with a relatively low capacity factor often has the ability to provide large amounts of electrical reserves.

Hydropower's fundamental advantage in integrating renewable energy generation resources, especially wind power, lies in the agility of its generators in meeting rapid changes in the net load by providing system ramping and regulation, by its ability to shift periods of energy production (storage), and by its supply of fast-responding reserves (spinning and non-spinning) to balance system generation and load. Furthermore, hydropower, by virtue of its water impoundment, also has the opportunity to develop unique market products for wind integration customers. "Storage and shaping" products or "dynamic capacity" that supplies within the day balancing for wind integration to compensate for missed forecasts and unexpected ramps in net load is of great value to electricity customers/utilities. An example of a flexible hydropower resource that is very valuable in system balancing is the Hoover Dam and Powerplant. Figure 4 demonstrates a typical 24-hour period showing the variability and variety of power generator usage and response to load fluctuations. Traditional steam generation cannot economically or efficiently provide these rapid and dramatic variations. In terms of its flexibility and reliability, the only comparable generation resource is a simple-cycle combustion turbine, but these are significantly more expensive to operate than hydro turbines.

Issues and Constraints

Nothing is ever as good as it seems, so what's the catch with using hydropower for wind integration or simply as a system balancing resource? Though some hydropower facilities are used primarily for power generation, for example, those found in the Nordic countries, many are not. Indeed, many hydro facilities have numerous priority functions that supersede power generation. Hoover Dam, for example, though an excellent provider of ancillary services, is highly regulated and power production is only one of many priority functions. Understanding what flexibility is available and how it can be equitably employed is a major question for this facility as well as many other hydropower facilities. In North America, there can be a number of complicating issues and constraints concerning hydropower's role in providing ancillary services for system balancing or integrating wind energy. The list below identifies the main issues related to hydropower flexibility, which are of greatest value in wind integration:

• *Priorities.* Hydro facilities have multiple priority functions that often supersede power generation and tend to limit the flexibility of a hydro power plant. These priorities include: flood control, environmental / wildlife / fishery considerations, agriculture / urban water demands, navigation purposes, recreational purposes, and power generation.

• *Environmental Issues.* Flow restrictions to comply with environmental or other regulations may exist, and thus inhibit flexible operation of the power plant.

• *Availability and interconnected river systems.* Factors limiting the availability of hydro generation will also limit their ability to integrate wind. Hydropower must be utilized within a certain time frame related to flow in the river, and in a manner that does not disrupt the hydro operations at other dams along the river. The amount of hydropower available also depends on the precipitation, which can vary significantly from year to year.

• *Complex organizations.* Understanding the authority and priority structure as well as existing contracts for a hydropower plant is the key in defining the flexibility available for purposes such as wind integration. Proper methods to allocate the costs and benefits of wind integration need to be devised, especially in systems with many stakeholders.

• *Determining the impacts.* Understanding the impacts of wind generation on net load, system balancing requirements, and impacts (both physical/O&M and economic) on hydro power is requisite prior to integration.

• *Scheduling intervals and markets.* Infrequent scheduling intervals combined with inaccurate forecasts leads to a significant amount of reserves being allocated. Reduced scheduling intervals can help relieve reserve requirements. Liquid markets or balancing area cooperation are two additional ways of to infuse flexibility into the electrical system.

In addition to the above, one may also postulate impacts on hydropower operations and maintenance: 1) potentially altered schedules for unit maintenance, 2) increased number of unit stop / starts, 3) altered / increased ramping of generating units, 4) requiring more hydro units for providing regulation, and 5) the lost opportunity cost in using hydro to provide regulation rather than providing more profitable peaking power. At present, however, there is little evidence indicating the magnitude of these impacts, either positive or negative, and additional investigations into these questions are in order.

Only a few detailed studies have been conducted to investigate the impacts and address these questions related to hydropower's support of wind integration, and thus this constitutes an area for future research. Past experience has shown that the anticipated effects of wind integration are filled with misconceptions, and that a thorough investigation is required to accurately assess the impacts. A review of the literature suggests that the following topics warrant investigation:

• The development of better wind integration planning tools, and in particular cost production models, that do a good job of resolving the hydro system and its constraints, and are capable of incorporating wind power and wind power forecasts.

• With improved modeling tools in hand, the next step would be to apply the planning tools to conduct thorough cost production studies of electrical systems to investigate wind integration in systems with hydropower.

• Capitalize on hydropower's long legacy of cooperation and create study groups to investigate and address wind integration. These groups necessarily should include all of the relevant stakeholders.

• Investigate the effect of unit cycling and stop/starts on hydropower O&M. Foster an understanding of the mechanisms driving unit O&M costs such that reliable estimates of altered O&M costs could be determined as system balancing requirements increase.

• Provide education amongst system operators, planners, and other stakeholders concerning wind integration. There are many questions and misconceptions concerning wind integration among stakeholders in the hydro community, as well as misconceptions in the wind industry concerning hydropower.

• Reconsider market and transaction scheduling intervals and investigate ways to develop flexible markets that will benefit both wind and hydropower. Alter system scheduling practices to permit more frequent power system transactions.

• Investigate the effect of larger balancing areas or promote balancing area cooperation in handling system imbalances. Just as reserve sharing pools lessen the burden on any single utility to carry reserves, spreading system balancing requirements over larger pools of balancing resources will ease the burden placed on any single utility.

• Revise market and/or system operational rules that were practical for our historical power system operation, but are no longer well-suited to power systems with high levels of variable wind or solar power resources.

Further research, development, education, application, and implementation will further the understanding, acceptance, and installation of wind generation into the overall generation resources pool, most importantly the integration with hydro-generation facilities of all capacity and production capabilities.

A New Paradigm

The suggestions above reach beyond that needed for successful integration of wind energy. They delve into the basic purpose of the hydro system, the organizational structures within which it operates, and the authority to make changes. In a sense, they encourage taking a holistic view of the hydro system, its uses and beneficiaries. If we are to evolve to an electrical system that contains much greater contributions from clean, renewable resources such as wind, we must expect that changes in operational and planning practices will occur.

Most, if not all, of hydro's functions (it benefits, priorities, and constraints) were defined or set forth prior to wind integration. Hydropower can and will play a significant role in wind integration and it is inevitable that this role will impact the operation of hydro plants. Re-evaluation of hydro's multifaceted functions, and in particular raising the priority of hydro power production to support wind integration, may be necessary. Current license or legislative authority, water agreements, and environmental constraints may need to be revisited to achieve the correct balance between the historic hydro functions and hydro's support of wind integration.

A similarly broad view point should be embraced when considering wind integration itself. Discussions in this article have implied that wind power will cause changes in system operation away from the status quo and that these changes will cause impacts and incur costs. This perspective is correct, but only to a certain degree. If you take a broader view of the electrical system, its role in our society and influences on our environment, and not just consider operational changes but expansion of the system itself and its interaction with communities and the environment, the overall effect of increased renewables on society may be a more secure, economic, and clean energy system with lower costs and higher benefits.

In the mid-20th century, the construction of large hydropower plants accompanied by high-voltage transmission lines dramatically impacted our economies and how we perceived electricity production and system balancing. It caused a paradigm shift at the time, and was critical to the development of western society. A similar, though possibly more subtle paradigm shift awaits us now: evolve the electrical system to incorporate higher levels of clean, renewable, but variable and uncertain energy resources. Hydropower is poised to once again play a key role in transforming our energy system. However, the institutions that govern and control hydropower are large and possess much organizational inertia and have many vested stakeholders. It will take dedicated work, clear vision, and focused resolve to make this happen.

Useful Resources

Additional information can be obtained from the following organizations, with perhaps the best resources highlighted in bold font.

- **Utility Wind Integration Group (UWIG)** http://www.uwig.org/
- **International Energy Agency (IEA)** http://ieawind.org/
- **Integration of Variable Generation Task Force (IVGTF)** http://www.nerc.com/filez/ivgtf.html
- **International Council on Large Electric Systems (CIGRE)** http://www.cigre.org/
- **National Renewable Energy Laboratory National Wind Technology Center (NREL-NWTC)** http://www.nrel.gov/wind/nwtc.html
- Asociación Empresarial Eólica (aee) – Spanish Wind Energy Association http://www.aeeolica.es/
- American Wind Energy Association (AWEA) http://www.awea.org/
- Canadian Wind Energy Association (CanWEA) http://www.canwea.ca/
- European Wind Energy Association (EWEA) http://www.ewea.org/
- Global Wind Energy Council (GWEC) http://www.gwec.net/
- Irish Wind Energy Association (IWEA) http://www.iwea.com/
- National Wind Coordinating Collaborative (NWCC) http://www.nationalwind.org/
- U.S. Department of Energy's Wind Powering America program http://www.windpoweringamerica.gov/

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Report published in February 2011