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SCIENCE AND TECHNOLOGY LITERATURE SURVEY OF WIND POWER INTEGRATION WITH HYDROELECTRIC ENERGY (S&T X9608)

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Introduction

As the amount of wind power capacity installed in the United States increases there is a corresponding need for the capability to integrate these resources successfully into the power system as an integrated whole. The intermittency of wind energy output, both in periodicity and magnitude, is an essential challenge to successful integration into existing power resources. Research is required for ideas to integrate the increasing potential of wind to maintain adequate power supply, system stability, and operating reserve during fluctuations in output that may grow to as much as a fifth of the power system supply.

Currently, generator unit, plant, and area control systems are designed to operate with largely fixed schedules over each hour. Variations to match changing load are included, but generation is assumed to be relatively constant. With the advent of wind generation, additional fluctuations in supply will create a need for more variations in traditional generation. Hydropower generation is much more flexible than coal-fired steam or nuclear generation and will be needed (along with natural gas units) to meet the more dynamic needs of the power system. Doing this in a manner that preserves efficiency and minimizes operating costs is the goal of this research – Wind Hydropower Integration (WHI). First, a survey of the existing literature provides a foundation for new studies that build on the research that has already been performed. Then, the next effort will consist of modifications to standard designs and operating procedures. As the scope of this research is not limited to operation that is specific to Reclamation, publication of the results in peer reviewed transaction journals will be essential to inform the entire industry.

Goals of the research are to 1) optimize operation to ensure that the maximum power is produced from water releases, 2) quantify and minimize operating costs associated with more loading cycles inherent in wind and solar integration, and 3) identify options to increase dynamic capacity.

Reclamation's Role in Integrating Wind Energy

Hydropower could have a significant role in the successful integration of wind energy. With more wind resources being introduced, power system reliability, dependability, and stability will be eroded and major blackouts will occur if changes are not made to the way the power system is managed and scheduled. This is an opportunity for the hydroelectric industry to adapt and manage its resources to assist in addressing these national issues.

The Hydropower Technical Services Group has led Reclamation's effort in maintaining the electric power system reliability, dependability, and stability. This group is active in WECC (Western Electricity Coordinating Council) and formulates many of Reclamation's operations and maintenance policies via FIST (Facilities Instruction, Standards, and Techniques) volumes. For the past several years this group has been evaluating the impact that wind will have on Reclamation's power plants.

Reclamation is in a unique position to consider the issues and new opportunities in managing and scheduling its resources to compensate for Wind Energy intermittency. Optimizing the use of hydro assets to assist in the integration of wind energy will maximize the amount of renewable wind and hydro energy produced while also maintaining and enhancing power system reliability, dependability, and stability.

The list below outlines the hydropower industry's and in particular Reclamation's role in integrating wind energy. It describes technical issues that Reclamation should start addressing today. Many of these issues are long term or need to be address by staff at Reclamation's powerplants; however, there are several issues that could be addressed by contracting with U.S. companies and be accomplished within the next two years. These issues are summarized below:

Unit Protection:

- Reclamation's hydro generator must continue to support and contribute to power system stability and reliability (preventing the next regional blackout). The protection relays in many of Reclamation's power plants need to be updated to newer digital relays. Roughly 200 generators and/or associated equipment are in need of the newer relays. Relay packages run about $10,000 per unit. Thus up to $2M could be used for new relays to enhance power system stability and reliability.

Condition Monitoring Systems:

- In a wind integrated power system, condition monitoring systems that monitor the health of hydro units will become necessary to preserve an effective, efficient, low-cost maintenance program. The Hydropower Technical Services Group has research and tested several commercially available systems to identify which of these systems would meet Reclamation's needs. Roughly 250 generating units could be outfitted with a monitoring system. The cost to replace a generator can range from $1M to $6M or more and take over a year to purchase and install. Lost energy revenue from a generator failure can be in the $50M range. An

average cost to purchase and install a monitoring system would be roughly $100,000 per unit. Thus, up to $25M could be used to deploy a Reclamation-wide hydro-based diagnostic system.

- The health of power transformers is another major concern. In recent years new online technology has been developed that can monitor transformer oil for contamination and water accumulation. This relates directly to the health of these units. Many of Reclamation's critical transformers would benefit from real-time, online monitoring. The cost to replace one of these transformers can range from $2M to $5M and take at least a year to purchase and install. Lost energy revenue from a transformer failure can be in the $50M range. An initial estimate is that Reclamation could use roughly 100 units at a cost of $20,000 each for a total of $2M.

Hydro Models

- Models for past industry studies regarding the impact of wind energy on the power system used very simplified models of a hydroelectric plant. Reclamation has been working with NREL and universities to address these shortcomings and to update these models. Improving the hydro models will improve the quality of the wind integration studies and better define the impact and opportunities.

Cycling and Stop/Start Costs

- Little is known about the additional hydroelectric generator stator related costs associated with increased maintenance and the loss of life that occurs because of load cycling and start/stops. These costs need to be researched and identified so that the cost of providing system reserves can be recovered. The Hydropower Technical Services Group along with BPA has initiated a research effort to look into these issues but much more work is required.

Literature Survey

IEA Wind/Hydropower Integration Experts Meeting November 5-6, 2003

One of the earliest appearances of WHI literature papers were presented during a 2003 International Energy Agency (IEA) meeting on the subject. The literature available for this meeting is available in the form of presentations recorded for the meeting. Deborah Linke, Power Resources Office Manager, represented Reclamation with a presentation entitled "Challenges & Opportunities for Hydropower & Wind Integration". The meeting introduction, goals, summary, conclusions and cited references are included below.

Introduction

IEA Wind Hydro Integration Meeting in Portland Oregon, USA, November 5-6, 2003. Four countries were represented including Canada, Norway, Sweden and the USA. Bonneville Power Administration (BPA) and the US Department of Energy (DOE) sponsored the meeting along with the IEA. The IEA policy for long term

Research and Development is stated as to increase value and reduce uncertainties, continue cost reductions, enable large scale use and minimize environmental impacts.

Goals

- The goal of the meeting was to identify technical, institutional, economic and political issues associated with integrating wind and hydro
- Inventory lessons learned from prior work around the world.
- Give consideration to establishing a formal technical IEA Wind-Hydro integration activity.

Summary

- Pricing has come down for wind. Coupled with incentive tax credits pricing coming in under 30 cents per kwh for good sites with large wind farms.
- Transmission continues to be a problem since there is no new transmission being built. Low capacity factor of wind is not conducive to building new lines. Markets in West are not like PJM market rules (PJM's vision is to be the electric industry leader in reliable operations and efficient wholesale markets), which do not penalize intermittent generators. Wind hydro integration depends on operational flexibility. Integration goal: maximize system dependability by shifting hydro generation to periods of low wind availability.
- Large projects being certified in as environmentally preferable. Recognizing that big or small is not the only delineation. Skagit River Project just got certified as a Low Impact Hydro Facility.
- Good combinations for wind hydro integration: Reservoirs with large storage, large active power pools, multiple dams with re-regulation capability, flexible water/power contracts. Small run of river plants can help with instantaneous, hour to hour fluctuate.
- Bad combinations: Over-allocated projects, run of river projects, projects subject to ESA or other institutional problems.
- National Renewable Energy Laboratory is targeting large federal projects. There is a new study about to start called Western Area Power Administration Cooperative Analysis.
- Main thing is that each power system is different and one size does not fit all. The capability to integrate wind power differs among regions. Since capability differs equity in allocating integration ability is important. The capability to integrate is not unlimited. There is also some concern about the impact to system reliability, the long-term product reliability and availability. Reliability councils are grappling with reserve calculations, regulation requirements, load following impacts, and technical interconnection requirements.
- Bonneville Power Administration is offering new service called Storage and Shaping Service. There is more information in the attachments on this. BPA has decided to try a new service to support renewables instead of buying large quantities of renewables.
- Impact of Wind on BPA Operations:

    - Better use of Water (Basin Optimization)-Will de-optimize the scheduling of water in the river because the forecast will be less accurate.
    - Better Use of Machines (Plant Optimization)-1. Big changes will cause units to cycles on and off. Will cause BPA to put more units on. 2. Small changes will not exactly net out a loss of operating efficiency, As you increase wind, the efficiency curve is flatter, as you decrease wind, the efficiency curve is exponential and drops off more quickly, so it won't net out.
    - Better Machines (Unit Optimization) Same as above.
    - Better Inventory Management-Will affect spinning reserve calculations.
- There appears to be a very different attitude in Scandinavian countries where wind is seen as a benefit. In Europe and Netherlands there are green credit certificate markets. This is helping wind development.

Conclusions

- This meeting was unusual because people doing active research and PhDs are the usual participants. There was much more company participation in this meeting. Broader participation is very useful.
- Design of markets and services across US and other countries would be useful to compare in how they accommodate renewable, intermittent resources. There is not general agreement on value of wind to system during dry and wet years. Solutions are specific to the projects.
- Operating experience has been the biggest impediment to utilities. Bureau's idea of pilots in US is a good concept. Case studies of existing integrated projects are very useful.
- Analysis and research of projects where pricing and risk have been assessed are very useful. Coordination between Western and Bonneville needs to occur. There may be an opportunity in the Pacific Northwest to have a group focus on this for the region.
- How wind can contribute or detract from ancillary services is an important piece.
- There is a need to educate regulatory community about what impacts market designs and rates can have on integration of wind.
- There is a need to educate operations and reliability community about the accompanying services needed to support and integrate wind. May want to work with reliability councils in doing this.
- The benefits to hydro from integration of wind need to be defined such as retaining water for fish or recreation.
- Benefits to hydro from integration of wind may also need to be shared for information on interconnection requirements and how those interconnections are working/lessons learned.
- Infrastructure concerns, particularly transmission, needs to be addressed.
- Next step is to approach the Executive Committee of the IEA Windpower Agreement to see if there is possible interest in forming an Annex on the Wind Energy System Integration. It appears that the US Department of Energy and Sweden are interested in this.

- A discussion on the minimization of cost (or optimization of value?) of wind integration for grid operators, A. Forcione, B. Saulnier, S. KrauResearch Scientists, Hydro-Québec Research Institute (IREQ), Canada, G. Lafrance, Professor, INRS, University Of Québec, Canada. Current research in Canada.
- Operational Flexibility at Hydropower Projects in the U.S., Michael J. Sale, ORNL Environmental Sciences Division, ORNLIEA. Conclusion: situation complex but not hopeless. Bottom line: where are the values: "…water flows to money". Other storage options may benefit both. Technology solutions: reregulating weirs; better science for instream flow requirements. Wind will have to join the crowd of demands on hydro.

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EPRI Journal – Putting Wind on the Grid (Spring 2006)

For WHI, the journal cites the difficulties in developing new pumped-storage facilities (terrain, water supplies, large land costs, environmental and building issues). Existing facilities provide some potential for compensating for wind intermittency. It concludes that scarcity of suitable surface topography that is environmentally acceptable is likely to inhibit significant domestic development of utility pumped-hydro storage.