Pumped Storage Hydropower

Summary Report on a Summit Meeting Convened by Oak Ridge National Laboratory, the National Hydropower Association, and the Hydropower Research Foundation

Washington, DC
September 20-21, 2010

Introduction

A Pumped Storage Hydropower Technology Summit was convened on September 20-21, 2010 in Washington, D.C. under the auspices of the National Hydropower Association (NHA), Oak Ridge National Laboratory, and the Hydro Research Foundation with the support of the U.S. Department of Energy (DOE). Over the two days of the meeting, approximately 50 participants – experts, and knowledgeable and interested individuals – sought to address issues and barriers related to pumped storage development, and actions that could be taken to facilitate appropriate development.

Background

There is general agreement among persons knowledgeable about the U.S. electricity system that the network could benefit from the provision of meaningful amounts of storage capacity – that is, new storage capacity in orders of magnitude exceeding 10,000 MW [10,000 MW is approximately equal to 1% of U.S. total generating capacity].

New grid-scale storage capacity benefits the stakeholders by (1) enhancing the stability and reliability of electric power systems by providing ample regulating capacity and contingency reserves for deployment by system operators and (2) by providing off-peak storage and regulation to accommodate high penetrations of variable renewable energy sources. The need for and value of these benefits varies according to several factors, including the adequacy of existing generation and transmission capacity in electric power systems, the short-term variability and geographic diversity of wind and solar resources to be accommodated in an electric power system, and the ability of power system schedulers to forecast the availability of variable renewable generation over future hours and days.

Pumped Storage Hydropower (PSH) is the only conventional, mature commercial grid-scale electricity storage option available today. PSH typically provides hundreds to thousands of megawatts of capacity in a single facility, and is highly flexible and responsive – e.g., with ramping rates that can exceed hundreds of megawatts per minute.

In the mid-twentieth century, the U.S. was the world's leader in installing pumped storage hydro. Most U.S. PSH facilities were built during the 1960s-1980s, typically for balancing base-load nuclear generation. The pumped storage plant most recently completed in the U.S. is the 1,046 MW Rocky Mountain plant in Georgia; it went online in 1995. Total installed U.S. PSH capacity exceeds 21,000 MW, constituting about 2.5% of total generating capacity. Other countries and regions have surpassed the U.S. About 5% of European Union's total capacity is pumped storage hydro, and its percentage is growing; Japan – currently the world's leader in pumped storage, has 10% of its capacity as pumped storage. Worldwide, many pumped storage plants are under construction. At the end of 2009, total installed pumped storage capacity exceeded 127,000 MW; this worldwide total is expected to exceed 203,000 MW by 2014 – an annual growth rate of 10% [Ingram, Elizabeth A., "Worldwide Pumped Storage Activity," *HRW*, Vol. 18, No. 4, September 2010, p.13].

PSH is capable of providing services that are of value to non-PSH operations. PSH units can accommodate load requests that would otherwise lead to inefficient dispatch of gas, coal-fired, and conventional hydropower units. Potential benefits of this accommodation include reduced fuel costs and reduced emissions. PSH units can also provide regulation of changing loads that would otherwise require modulation of output from other generating assets, with concomitant wear and tear and expense.

PSH provides services that support efficient transmission of electric power and grid reliability and stability. The electrical services used in this role are typically referred to as "ancillary services" and defined as various types of "reserves," "black start capabilities,", voltage and frequency regulation and other contingency reserves. Owing to rapid response and large energy storage capabilities, PSH can readily provide these services. For example, pumped storage can quickly accommodate disturbances that occur on transmission grids – loss of generators, failure of transmission lines, instant demands (or cessation of demands) from large multi-megawatt loads (e.g., electric furnaces, large industrial motors). Perhaps the best example of the capabilities of pumped storage in this role is Dinorwig Pumped Storage Station in Wales, United Kingdom. This power station, with a nominal peak capacity of 1,700 MW, is used to stabilize the entire U.K. National Grid (which has a peak demand exceeding 60 GW). Owing to fact that the plant can either consume (when pumping) or produce (when generating) electricity, a power "swing" of more than 3,000 MW can be achieved by this single plant. In its role as the grid stabilizer, the Dinorwig plant switches between producing electricity (as a generator) and consuming electricity (when pumping, constituting an electricity "sink") an average of more than 100 times per day. The plant has an extraordinary ability to ramp up and down to accommodate the needs of the grid – the plant can increase and decrease power output at ramping rates exceeding 100 MW-per-second over a range of more than 1,000 MW.

PSH is a proven grid-scale and utility-scale option for addressing variability of generation and demand within future robust electric power systems. Complimentary technologies to PSH in this regard include fossil-fueled simple-cycle combustion turbines and diesel engines and expansion of demand-response capabilities for large and small loads. Compressed air energy storage (CAES) is an emerging technology that has been demonstrated at grid scale. To date, two demonstration CAES plants have been built. The first is a 290 MW plant built in Germany in 1978; the second is a 110 MW facility which began operating in 1991 in McIntosh, Alabama. Currently, additional efforts to demonstrate the viability of CAES technology are being pursued, with DOE support. Projects totaling more than 400 MW are proposed for sites in the states of New York, California, and Iowa. From a functional perspective, CAES plants are hybrids between pumped storage hydro plants and combustion turbine generators. While CAES plants store and recover electrical energy (as a pumped storage plant does), they also require fuel in the process of producing electricity (as do a combustion turbines). CAES plants also have a high degree of site specificity (as does pumped storage), owing to the usual requirement for suitable underground geology for air storage caverns.

In a world moving toward a more renewable future, it is clear that existing pumped-storage hydropower assets have value, and that new pumped-storage units should be among the technologies considered in the transition to a secure, reliable, stable, and low-carbon electric power system. Within this framework, the Summit sought to explore the barriers, issues and the challenges that need to be addressed to encourage and enable expansion of the U.S. PSH capacity.

Table 1 - Agenda for the Pumped Storage Hydropower Summit

Day One - September 20, 2010	
Time	*Agenda*
9:00-9:30 a.m.	**OPENING OF THE SUMMIT** • ***Welcome & Introductions, Purpose of Summit, Instructions to Participants*** • ***Role of Federally-funded R&D in Pumped Storage Hydropower***
9:30 a.m.- 12:15 p.m.	**SESSION 1 – CONTEXT FOR CONSIDERING PUMPED STORAGE HYDROPOWER** • ***Pumped Storage Development: Opportunities and Challenges – Perspective of NHA Pumped Storage Council*** • ***Electricity Storage Needs – DOE Office of Electricity Perspective*** • ***How Electricity and Ancillary Services Markets Are Supporting/Can Support Additions to Energy Storage Capacity*** • ***Grid Simulation and its Importance for Pumped Storage Equipment Selection*** • ***Facilitated Discussion of Participants' Views***
12:15-1:15 p.m.	**Lunch**
1:15-4:45 p.m.	**SESSION 2 – BUSINESS CASES FOR PUMPED STORAGE HYDROPOWER** • ***An Owner-Developer Perspective*** • ***A Third-Party Developer Perspective*** • ***A Federal Power Marketing Administration Perspective*** • ***An International Perspective*** • ***Financial Considerations*** • ***Facilitated Discussion of Participants' Views***
4:45 p.m.	**Adjourn – Day 1**

Table 1 (continued)

Day Two - September 21, 2010	
9:00-9:30 a.m.	**OPENING OF THE SUMMIT – DAY 2** • ***Participant Instructions*** • ***Recap of Day 1***
9:30 a.m.-Noon	**SESSION 3 – PROJECT DESIGNS AND COSTS: BOTTLENECKS AND CRITICAL ISSUES** • ***Sketches of Selected Projects*** • ***Construction Issues*** • ***Environmental Issues*** • ***Perceptions of Pumped Storage Hydro – Environmental Perspective*** • *Ov**erview of DOE Loan Guarantee Program*** • ***Facilitated Discussion of Participants' Views***
Noon-1:00 p.m.	**Lunch**
1:00-2:45 p.m.	**SESSION 4 – OPPORTUNITIES FOR ADVANCED TECHNOLOGY AND IMPROVED DESIGNS** • ***Improved Plant Configurations for Current and Future Needs*** • ***Promise of Variable/Adjustable Speed Equipment*** • ***Facilitated Discussion of Participants' Views***
2:45-4:00 p.m.	**REVIEW, SYNTHESIS, AND NEXT STEPS** • ***Roundtable Discussion, Synthesis, and Recap of Key Outcomes***
4:00 p.m.	**Adjourn Summit**

Key Outcomes

The two-day Summit led to the identification of the several key issues, listed below. [The order of presentation of items is happenstance; it does not reflect any judgment as to priority or importance.] Each of these issues is discussed further. Also, following the description of each issue, a prospective action is briefly outlined for addressing the issue.

- Perceptions/Knowledge
- Operational Modeling
- Advanced Technology Demonstration
- National Policy
- Renewable Energy Industry Alliances
- Financing
- Expedited Development
- Industry Capacity
- Federal Power Role
- Environmental Community Alliances

While the above list of issues is not comprehensive, it represents an effort to capture the most substantive and actionable issues that arose during the Summit's presentations and discussions.

It is believed that giving attention to and appropriately addressing these issues can significantly enhance the prospects for adding meaningful amounts of pumped storage hydropower capacity to the U.S. electrical grid.

Perceptions/Knowledge

While pumped storage is conceptually simple, knowledge and understanding of why pumped storage is beneficial and valuable is often intangible and obscure. Many benefits are un-quantified and difficult to communicate in simple terms. The benefits of PSH (and major conventional hydropower storage capacity) are difficult to model, quantify, and communicate to a diversity of electric power stakeholders. Electric power stakeholders include the affected public, ratepayers, non-governmental organizations, transmission entities, state utility and environmental regulators, utility staff and management, and project development financiers.

Action: Develop strategic efforts to clarify and communicate the benefits and value of pumped storage hydro within appropriate constituencies.

Operational Modeling

Operational modeling generation and transmission systems requires the use of complex modeling software, and software currently in use does not enable realistic and adequate modeling of pumped storage facilities. Pumped storage value is recognized – especially where there are active ancillary service markets – in terms of its ability to provide

reserves and "quick" capacity. To show the real value of PSH plants, business cases need to reflect revenues from spot and reserve market as well as on financial effects within the generation portfolio. European utility experience indicates that, in addition, a nearly equal amount of value can be obtained from "portfolio effects," i.e., the benefits of operating pumped storage in concert with a diverse portfolio of generating assets. Demonstrating the total value of pumped storage requires more realistic simulation of operation than is now possible with existing modeling tools.
The prices for ancillary services are driven by opportunity cost. Though it is the most expensive ancillary service, regulation prices are typically lower than energy prices, but they remain high at night when contingency prices are low. Flexibility in energy and ancillary service provisions adds value and efficiency to power systems. This is highlighted by a California project that saw an 83% increase in profits despite a decrease of 47% in energy profits, which was offset by added profits in regulation (81% increase), spinning reserve (44% increase), and non-spin reserve (5% increase), all while increasing the capacity factor by 6%.

Action: Work with operations modelers (and model builders) to develop and adapt models for enabling accurate simulation and valuation of existing and new pumped storage facilities, including those with variable speed technology.

Advanced Technology Demonstration

Each pumped storage plant is specifically designed and adapted to the characteristics of the site where it is located. A good site with favorable topography and geology is a prerequisite for having a successful project. Constructing civil works – i.e., dams, structures, water conveyances, etc. – typically contribute the largest share of project costs; these can be three-fourths or more of total costs and also contribute to uncertainties – such as geological surprises – and hence increased contingencies. The primary "working parts" are the pump-turbine generators. Within the U.S., the dominant technology used in pumped storage plants is the "reversible pump-turbine generator." Internationally, pump-turbine generator technologies that are more advanced are being and have been applied. For example, in Japan, for more than two decades it has been common practice to incorporate variable speed pump-turbine generators in pumped storage plants. Such units are now in use in other countries especially in Europe. In addition, unidirectional "three-element" (ternary) machines have been installed wherein there is no change in the rotational direction allowing the units to move rapidly from full pumping to full generation unlike a reversible machine where the machines require to stop before restarting in the opposite direction (and vice versa).

While it seems obvious that advanced pumped technologies could be beneficially applied within the U.S., this needs to proven. Moreover, though Japanese and European installations show advanced state-of-the-art equipment applications, there are further opportunities for technology improvements that have yet to be deployed. Currently, individual owners and developers of pumped storage plants do not have the incentive (or confidence based on observing successful operations) to assume the risk of innovative technology application.

Action: Establish a pumped storage "design, siting, and demonstration" project toward the goal of establishing a U.S. demonstration of superior, advanced pumped storage technology and plant configuration. This project would seek to lay a foundation for the enhancement of new pumped storage installations, and for the prospective upgrading of existing installations.

National Policy

Large amounts of additional bulk electricity storage are needed within the U.S. electricity supply system. This need has been and is being amplified by additions of ever-larger amounts of wind and solar power – additions that have been especially encouraged by favorable federal policies, state renewable energy portfolio standards (RPSs), and, in some cases, local mandates.

Corollary policies are needed to encourage and incentivize the development of efficient, economical, and effective storage. Appropriate policies could be open to new, not yet commercial technologies; however, it is essential that such policies embrace (and not handicap) pumped storage hydro – the only extant commercial bulk electricity storage technology.

Consequently, the policies and practices of the Federal Energy Regulatory Commission (FERC), the primary federal licensing authority for non-federal pumped storage plants, need to be congruent with renewed broad national aims for increasing amounts of pumped storage installed capacity.

Action: Work with legislators to establish policies that encourage and incentivize the development of pumped storage hydro facilities, and work with the FERC to ensure congruent policies and practices.

Financing

Financing is crucial to the development of pumped storage hydro projects – a single project can cost several billion dollars. Adequate mechanisms do not exist for delivering the revenue streams that are essential for the development of such projects. Various mechanisms need to be explored to ascertain what new methods could possibly be employed to ensure the revenue streams. Possibilities include:

- rate base financing (e.g., with the project treated as a transmission asset, both by state regulators and FERC), wherein cost recovery would be authorized by state utility board/commission;
- grid stabilization payments (e.g., received from a Regional Transmission Organization (RTO));
- financing of projects or specific critical elements or development phases under federal loan guarantee program (similar to or adapted from current DOE Loan Guarantee Program).

Action: Create a working group to develop and explore approaches for establishing viable revenue streams that would be suitable for financing projects. Also, explore how the DOE Loan Guarantee Program could be utilized or adapted to provide better assistance.

Expedited Development

Development timelines for pumped storage hydro projects typically exceed ten years (whereas, for example, a combustion turbine generator can be developed from decision to commissioning in three years or less). Anything that can be done to ease the burden of licensing application, license approval, and project development timelines would reduce upfront developer financial risk and benefit pumped storage development. However, such process improvements must preserve opportunities for stakeholder input and ensure appropriate environmental assessment of PSH projects.

Action: Create a working group to explore means of reducing overall time required for the development of pumped storage hydro plants, and for reducing upfront developer risk.

Industry Capacity

Pumped storage hydro currently lacks “industry” status. There are several independent developers and a few utilities having interests in project development, yet stronger interest is needed to create constructive movement. Conditions will need to exist indicating greater confidence in the future of pumped storage hydro to attract more – and bigger – players. From the equipment supply perspective, all of the major manufacturers of conventional hydroelectric equipment – which has a robust international market – also provide pumped storage equipment. These manufacturers certainly have strong interests in helping to facilitate the development of additional U.S. pumped storage.

Action: Work to create advocacy for pumped storage among prospective development interests (including work with the NHA Pumped Storage Council).

Federal Power Role

The recent Memorandum of Understanding (MOU) established in early 2010 among the DOE, the Department of the Interior, and the U.S. Army Corps of Engineers commits these agencies to work toward common goals to “help meet the Nation’s needs for reliable, affordable, and environmentally sustainable hydropower …” through a variety of actions. While several initiatives prescribed by the MOU are related to the focus of the Pumped Storage Hydropower Summit, two initiatives are directly relevant. These initiatives (under the heading within the MOU of “Renewable Energy Integration and Energy Storage”) call for conducting a “technical, economic and environmental feasibility analysis of environmental sustainable potential pumped storage sites ...” and for the collaboration “with other Federal agencies and various industry stakeholders to assess the amounts and distribution of energy storage needed ….”

Action: By mutually supporting the aims of the MOU, parties to the MOU and industry stakeholders can cooperatively bring focus to meaningful opportunities for the expansion of pumped storage capacity and to pathways for getting new capacity installed.

Environmental Community Alliances

The environmental community is a supporter and enabler of renewable energy, especially wind and solar power. In concert with renewable energy sources, pumped storage is also a "green" source and appears to be compatible with the aims of environmental organizations.

Action: Work with environmental organizations/NGOs (nongovernmental organizations) to gain support for pumped storage as a "renewable" enabler of desirable renewable energy supplies.