Environmentally Enhanced Turbines Allowing for Safer Fish Passage

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Introduction

The pressure to ensure safe fish passage and the health of tailrace waters has led federal agencies and turbine manufacturers to collaborate in improving the design of hydroelectric turbines. Early results are encouraging, showing a high potential to improve fish survival rates, turbine efficiency and downstream water quality.

Turbines that are fish-friendly, energy-efficient and able to mitigate water quality issues are now commercially available and ready for full-scale deployment. After more than 15 years of research and development, new types of turbines are available that offer solutions to some of hydropower's most persistent issues: safe downstream passage of fish through turbines, improvements in tailrace water quality and increases in generation through reductions in spill.

Along with the continued development of the two turbine designs resulting from the U.S. Department of Energy's Advanced Hydropower Turbine Systems program (Alden turbine and Voith's minimum gap runner), there has also been considerable progress on the methods and tools required to measure fish passage survival, quantify potential injury mechanisms associated with fish passage through turbines, and verify generation performance.

These advancements feed into an effective and efficient turbine design/modification process in which biological criteria can be taken into account while engineering efficient machines for producing low-carbon electricity. These new methods and tools also provide a means to verify the predicted performance of these technologies in a full-scale field setting.

Beyond the turbines designed to safely pass fish downstream, other significant improvements have been made with technologies designed to address downstream water quality issues, such as low dissolved oxygen in tailraces and the potential release of oil and grease used for lubrication of turbine components.

1.0 Educating the industry

Noting the need to disseminate information on the advancements in the design, evaluation, and testing of environmentally enhanced hydro-turbines, the Electric Power Research Institute and DOE hosted the Conference on Environmentally-Enhanced Hydropower Turbines in Washington, D.C., in May 2011. The conference organizing committee was comprised of members from federal agencies, EPRI and private industry. The diverse committee representation was instrumental in providing the opportunity for collaboration -- a critical component of efficient hydropower development in the U.S.

Of particular importance was the participation of the federal agencies -- DOE, the Department of Interior (Bureau of Reclamation), and U.S. Army Corps of Engineers -- that, on March 24, 2010, entered into a memorandum of understanding for hydropower. The purpose of the MOU is to "help meet the nation's needs for reliable, affordable, and environmentally sustainable hydropower by building a long-term working relationship, prioritizing similar goals, and aligning ongoing and future renewable energy development efforts" among the MOU participants. One specific action item of the MOU was to "convene a workshop to discuss ongoing federally funded efforts, initiatives, and technology R&D." This conference, with substantial participation by the MOU agencies in the organizing committee, was successful in satisfying this goal.

The conference presentations are available for public review and download at www.epriturbineworkshop.com. In addition, an EPRI report has been published which contains all of the technical papers from the conference. The report, titled "EPRI-DOE Conference on Environmentally-Enhanced Hydropower Turbines: Technical Papers" is available publicly at www.epri.com by searching for the product code (1024609).

2.0 Accomplishments in environmentally enhanced turbines

Great strides have been made in recent years in the design and development of new turbines, as well as the tools and methods to address fish passage issues.

Advancements in the design and development of new turbines

An area that has garnered a substantial amount of research and development efforts is the development of fish-friendly turbines that can safely pass fish downstream. By engineering turbines pass fish downstream with minimal injury and mortality, an ancillary benefit emerges -- the ability to generate electricity with water that would otherwise have been dedicated to bypasses or spill. The Alden turbine and the Voith MGR are two such units designed to be fish-friendly; each has been under development since the inception of the DOE's AHTS program in 1995.

The Alden turbine is a completely new hydro turbine runner design. It was conceptualized and tested at a pilot scale in the laboratory for fish survivability in the early 2000s. Intense development over the past decade using state-of-the-art laboratory and computational fluid dynamics techniques have optimized its biological and generating performance.

After completion of the latest DOE-funded collaboration among EPRI, Voith, and Alden Research Laboratory, the Alden turbine is now market-ready. The scientifically rigorous research and development program has resulted in a unit that is predicted to provide high passage survival (greater than 98% for fish less than 8 inches in length; 99% for eel and sturgeon) and high efficiency (94%). In addition, after accounting for decreased excavation costs associated with the Alden turbine's higher setting and the ability to increase revenues by generating with water that would otherwise be devoted to downstream fish bypasses or spill, the Alden turbine offers competitive economics.

Given the expected high rates of turbine passage survival, the Alden turbine is attractive because it can be used to generate power from flows that would otherwise be spilled over dams or through bypasses to meet fish passage or minimum flow requirements. To deploy and test the Alden turbine in the field, Alden and EPRI are investigating the installation of a full-scale demonstration unit at two sites: one in the U.S. and one in France. In September 2011, DOE announced its intent to co-fund the next phase of deployment and testing of the Alden turbine at a demonstration site in the U.S. -- Brookfield Renewable Energy Group's 38-MW School Street project on the Mohawk River in New York. Brookfield Renewable Power is currently evaluating the economics of an Alden turbine installation at School Street. EPRI and Alden are currently working with EDF on the installation of an Alden turbine at the Pebernat project in France. Efforts are focused on the preliminary engineering at the site and on developing a funding plan. Next steps will include a turbine purchase agreement between Électricité de France and Voith.

The Voith MGR turbine is a Kaplan-type unit that underwent modifications to reduce gaps that can induce injury or mortality. Prototype testing at the 1,076-MW Bonneville project in Washington State indicated that turbine passage survival was equal to or greater than existing units. An MGR was later installed and evaluated at Grant County Public Utility District's 1,038-MW Wanapum project. Survival of salmon smolts was high (about 97%). The MGR was successful in increasing turbine efficiency without affecting the survival of salmon smolts passing through the unit. Plans to replace all of the original 10 turbines at Wanapum with MGR units are under way with a scheduled completion date in 2013.

In addition, the U.S. Army Corps of Engineers has continued development of its interdisciplinary Turbine Survival Program, which seeks to improve knowledge about the turbine passage environment and its effect on juvenile salmon, how to optimize turbine operation for the benefit of fish, and how to support the improvement of turbine designs for increased fish passage survival.

The Corps' Engineering Research and Development Center contributes to the objectives of the program by constructing and evaluating physical models (1:25 scale) that can be used for flow visualization via the injection of neutrally-bouyant beads or dye into the turbine flow. By understanding the flow dynamics, the ERDC can identify potential problem areas for fish passage.

For example, the Corps' Hydroelectric Design Center and ERDC have been working collaboratively with Voith on refining the design of replacement units for the 603-MW Ice Harbor project on the Lower Snake River in Washington State. The comprehensive research approach includes physical model testing and CFD analysis to refine turbine designs. The design process is unique in that the primary objectives of the design are related to improving fish passage rather than power and efficiency.

Similarly, the Corps has developed a CFD model to predict pressures in the turbines at the 2,160-MW John Day powerhouse on the Columbia River. The Corps has demonstrated that this is an effective method for predicting pressures that fish may be exposed to in the turbine runner environment, as well as the probability of exposure to these pressures.

In addition to turbine technologies designed to pass fish downstream, other turbines have been developed and are available to increase dissolved oxygen in project tailraces. Low DO levels are an environmental concern at projects with deep intakes that draw water from a thermally stratified upper reservoir. Providing a means to increase downstream DO protects the quality of the aquatic habitat downstream.

Although aerating turbines are not a new technology, they have been optimized recently through intensive computational analysis by some of the bigger turbine manufacturers, such as Voith and Alstom. Recent efforts have focused on modeling some of the more complex phenomena in aeration, such as bubble plasticity under varying pressure and the simulation two-phase flow (water mixed with air).

For instance, Voith uses its proprietary discrete bubble model to predict DO uptake and bubble distribution for various aeration approaches (central, peripheral and distributed injection points). While it can be difficult to predict the level of aeration achievable, data show that aerating turbines are effective for increasing levels of DO in tailraces with little impact on turbine efficiency.

There have also been advancements in environmentally friendly turbine lubrication systems to support efficient operation of ancillary turbine equipment. Recent technological innovations include biodegradable greases, efficient grease management and distribution systems, and the use of greaseless self-lubricating bushings. Each of these innovative lubrication approaches/alternatives represents a low-cost means to decrease an environmental risk associated with hydropower.

Fish passage analysis

The knowledge required for assessing the biological performance of turbines ranges widely from the detailed characteristics of an individual physical phenomenon in the turbine environment to a fully systematic understanding of how all the mechanical, hydraulic and biological components marry to satisfy fisheries goals. Fisheries biologists and engineers at DOE's Pacific Northwest National Laboratory and the Corps have contributed heavily to this ever-growing body of knowledge.

Recent research at PNNL has focused on the characteristics of the turbine environment experienced by fish. Their assessment strategy includes biological experimentation, compliance review, and testing of hypotheses such as identifying the turbine operating conditions under which the highest passage survival can be expected.

PNNL has conducted comprehensive laboratory research to determine the mechanisms of pressure-related injuries to fish passing through turbines (termed "barotrauma"). Using computer-controlled hyper/hypobaric chambers, researchers are able to expose fish to simulated turbine passage pressure changes and determine the impact on fish. Understanding the effects of pressure change on turbine-passed fish provides turbine operators and designers the opportunity to make changes that can improve survival.

Building on the barotrauma research, PNNL has also made advances in determining the effect of implanted acoustic telemetry tags on the rates of barotraumatic injury of salmon smolts. This work indicates that the presence of surgically-implanted acoustic transmitters creates a negative bias in turbine survival estimates, which can lead to an underestimation of turbine passage survival.

Because the Corps uses such surgically-implanted tags in its Juvenile Salmon Acoustic Telemetry System, it is important to understand if turbine passage survival at its projects is actually higher than indicated by the tagging evaluations. To help address this bias, PNNL has been designing and testing a new externally-attached, neutrally-buoyant acoustic transmitter for tracking fish at hydro projects. Recent laboratory evaluations indicate this new tag design does not adversely affect juvenile salmon under laboratory-simulated turbine conditions.

While PNNL's new tags have not yet undergone field evaluation, balloon tags (Hi-Z tags) remain a widely-used and effective technology for estimating turbine passage survival in the field. In this release-recapture method, fish are tagged with a small deflated balloon containing chemicals that inflates shortly after fish are injected into a turbine intake. Test fish then float to the surface where they are collected and assessed for injury and survival.

The sensor fish is a PNNL-developed tool that has shed light on the hydraulic characteristics of flow passing through turbines. It is a cylindrical, polycarbonate device roughly the size of a juvenile salmon and can be used to sense changes in pressure, angular rate of change, and linear acceleration during turbine passage.

As a result of the most recent DOE funding of advanced hydropower development, the sensor fish will undergo a re-design to increase the resolution of its measurements and decrease its cost. PNNL has been working to assimilate hydraulic field data, such as that collected by the sensor fish, with CFD results and injury risk predictions to develop a comprehensive method to predict the biological performance of turbines -- PNNL's Biological Performance Assessment (BioPA).

The CFD simulations function as a framework into which biological data (laboratory and field) and data on the physical and behavioral characteristics of fish can be integrated. Because field-based biological evaluations can be cost-prohibitive, the BioPA method represents a cost-effective means to bridge the gap between fish evaluations in the lab and turbine design.

EPRI also has contributed to the body of knowledge on how to engineer a more fish-friendly turbine through its research on turbine blade leading edge design. EPRI funded multiple years of CFD and laboratory research at Alden that evaluated the effects of various blade geometries and thicknesses on fish injury and survival. Results of the biological evaluations indicate that blunter, more rounded blade edges are less injurious to fish. These findings were incorporated into the latest design iteration for the Alden turbine and also have implications for improving the biological performance of other turbine designs.

3.0 Where do we go from here?

Tremendous strides have been made in the development of turbine technologies designed to address the environmental concerns associated with hydropower. However, the true value of these technologies can only be determined in the field under real-world conditions. First, the hydropower industry needs support in developing guidelines, standards and best practices relative to the environmental performance of turbines. While there is sufficient governance relative to the standards for performance (power, flow and efficiency) of turbines, those for environmental performance (such as aeration for low DO mitigation) are relatively few. Second, the industry needs financial support to minimize the economic risk associated with installing new technologies in the field.

EPRI and Alden have been working at securing a demonstration site for the Alden turbine. Pending the formalization of agreements with the proposed companies in the U.S. and France, EPRI and Alden will move to modify the turbine design to fit the site, develop a demonstration program plan (including turbine purchase, site preparation and construction, turbine installation and performance testing), develop a funding plan, and begin preliminary site designs.

Once installed, field testing will be an important next step in verifying the predicted performance and in garnering industry and resource agency acceptance of the turbine as a viable method of passing fish downstream at hydroelectric projects. DOE has demonstrated its support of this demonstration effort, committing to co-fund the next phase of deployment and testing of the Alden turbine at the School

Street projects. EPRI and U.S. DOE remain committed to getting the turbine installed and testing its fish passage and economic performance. If, for whatever reason, the current planned demonstration projects do not move forward, the EPRI-DOE team will look for additional project opportunities to demonstrate the Alden turbine.

With an aging hydropower infrastructure in the U.S. and the potential to add hydropower at existing non-powered dams, there is clear potential to deploy advanced turbine technologies. Deployment of these new turbines in the near-term will likely be regulatory driven through the federal licensing process; in the long-term it is likely to be driven by the move toward a greater reliance on renewable energy technologies in the U.S. energy portfolio. However, without baseline data generated from increased demonstrations of these technologies in full-scale field applications, gaining the acceptance of stakeholders may be difficult. The advanced state of environmentally enhanced turbine technology results from the impressive investment of time and research and development dollars. It is time to put this investment to work.

FHO_S1_AldenturbineVoithmodel_Dixon2_FULL.psd: The Alden turbine hydro turbine runner design was designed and tested at a pilot scale in the laboratory for fish survivability in the early 2000s.

FHO_S1_MGRSale_1col.psd: The Voith minimum gap runner turbine is a Kaplan-type unit that underwent modifications to reduce gaps that can induce fish injury or mortality. Prototype testing at Bonneville Dam indicated that turbine passage survival was equal to or greater than the existing units.

FHO_S2_BladestrikeAmaral_1col.psd: Images from recent biological evaluations indicate that blunter, more rounded blade edges are less injurious to fish. These findings were incorporated into the latest design iteration for the Alden turbine and also have implications for improving the biological performance of other turbine designs.

FHO_S2_CFDstreamtracesthroughturbine_Richmond2_2col_FIG.psd: Computational fluid dynamics tests can function as a framework into which biological data (laboratory and field) and data on the physical and behavioral characteristics of fish can be integrated. This method is seen as a cost-effective means to bridge the gap between fish evaluations in the lab and turbine design.

FHO_S4_DistributedaerationFoust_1col_FIG.psd: Voith's discrete bubble model, which can predict dissipated oxygen uptake and bubble distribution for various aeration approaches.

FHO_S5_ExtermaltagDeng_2col.psd: Externally-attached, neutrally-buoyant acoustic transmitters are used for tracking fish and helping determine survivability rates during fish passage. Recent laboratory evaluations indicate these tags do not adversely affect juvenile.

FHO_S5_PhyscialobservationalmodelIceHarborDavidsonRenholds_2col.psd: The U.S. Army Corps of Engineers' Engineering Research and Development Center contributes to the objectives of the Turbine Survival Program by constructing and evaluating physical models that can be used for flow visualization via the injection of neutrally-buoyant beads or dye into the turbine flow.