Improving Unsteady Hydroturbine Performance During Off-design Operation by Injecting Water from the Trailing Edge of the Wicket Gates

Bryan Lewis, Ph.D. (May 2014) in Mechanical Engineering
The Pennsylvania State University

Date: April 17th, 2014
Time: 9:30 AM
Venue: 062 Williard Blg.

Abstract
At their best efficiency point (BEP), hydroturbines operate at very high efficiency (up to ~95%). However, with the ever-increasing penetration of alternative electricity generation it has become common practice to operate hydroturbines at off-design conditions in order to maintain stability in the electric power grid. The present work demonstrates a method for improving Francis hydroturbine performance during off-design operation by injecting water through slots at the trailing edge of the wicket gates. By incorporating the concept of circulation control hydrofoils, the injected water causes a change in bulk flow direction at the inlet of the runner. This change in flow angle from the wicket gate trailing-edge jets provides the capability of independently varying the flow rate and swirl angle through the runner, which in current designs are both determined by the wicket gate opening angle. When properly tuned, altering the flow angle results in a significant improvement in turbine efficiency during off-design operation. This revolutionary concept also has the ability to reduce the intensity of the rotor-stator interactions by compensating for the momentum deficit of the wicket gate wakes. A provisional patent application for this technology was filed with the U.S. Patents and Trademarks Office in June 2013 (application number 61836802).

This concept was explored computationally using loosely-coupled steady-state computational fluid dynamics (CFD) simulations of a single periodic distributor vane passage and runner blade passage of the GAMM Francis Turbine, a model-scale Francis hydroturbine. The CFD simulations were performed using a pressure-based finite volume method in OpenFOAM, an open-source CFD software package. In order to add water jets capable of turning the flow, a modified wicket gate design is presented with a beveled trailing edge. Computational experiments show that a +/-5 change in swirl angle is achievable with the new design. This change in swirl angle produces
up to 4% improvement in turbine efficiency at 77% of the BEP flow rate and up to 2% improvement in turbine efficiency at 115% of the BEP flow rate. Unsteady CFD analyses of the complete hydroturbine were also conducted to further validate the wicket gate trailing-edge jet technology, and study the dynamic effect of the rotor-stator interaction. At the low flow rate with a jet speed of 15 m/s, or 2.98% of the inlet volume flow rate, the full-wheel simulations show a 22% increase in head across the runner wheel, a 26% increase in torque, and a 2.7% increase in runner efficiency. The additional power necessary to supply the jets via a pump was estimated by modeling the flow through a representative plenum and jet channel. The pumping power was subtracted from the increase in power obtained from the turbine when operating with the jets. When including the additional pumping power necessary to supply the jet, the overall turbine efficiency increased by only 0.9%, which is still a significant improvement in potential revenue for a Francis turbine.