HydroCen
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Procedure and tools for design and optimization of variable-speed Francis turbines

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Objective

Nowadays, synchronous-speed hydraulic turbines are required to operate at off-design loads much more frequently than before, resulting in decreased efficiency and higher dynamic loads. Several researchers have previously suggested a speed variation during off-design operation as one possible mitigation measure, with a turbine design that is specifically optimized for variable-speed operation.
Therefore, the main objective of the WP task was to develop new tools and methodologies for designing a turbine that will operate at variable-speed exclusively. Standard methods were combined with new ideas to develop advanced in-house codes for design and optimization of variable-speed turbines.

Background

A through design and optimization was conducted on a replacement runner to explore the full variable-speed potential of the Francis-99 turbine model. The idea was to use numerical simulations and optimization algorithms that will search through the vast possibilities for geometry modifications and identify the best trade-off design. After performing the optimization cycle, the optimized model runner was manufactured and tested in the Waterpower laboratory to compare the performance against the existing Francis-99 runner that was used as the reference.

Results/Findings

The results suggested that it is the main dimensions of the turbine runner that define the variable-speed performance, while the detailed blade design that was attempted turned out to be more restricted in unleashing the full potential. Additionally, the results had verified the expected performance and proved that the proposed methods can be used in real design scenarios of prototype Francis turbines.

Relevance/utilization

The results so far suggest that the variable-speed performance can be greatly improved by modifying the main dimensions of the turbine. The developed methods can be directly used for optimization of either new variable-speed designs, or for exploring the possibility for upgrading to variable-speed in an existing powerplant. The same approach can be used for the entire range of Francis turbines, however, because hydraulic turbines are tailor-made and highly customized, the actual results from the PhD thesis can only be used for similar turbine designs to the Francis-99, and up to some extent only.

Conclusion

In broad terms, the implementation of variable-speed technology can increase the flexibility of existing hydropower plants, mostly in terms of increased hydrodynamic stability and faster response to output variations, as well as increased efficiency at off-design operating conditions, especially for larger head variations. This will promote better utilization of the hydropower resource, without increasing the environmental impact, and provide system stability for more intermittent renewable sources to be included, such as solar and wind. The proposed methods are validated in relevant environment with documented test performance demonstrating agreement with analytical predictions. The technology readiness level is TRL-5.

Refrences and links to publications and thesis

Thesis - **https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2646508**
Paper 1 - **https://www.sciencedirect.com/science/article/pii/S1364032118308281?via%3Dihub**
Paper 2 - **https://iopscience.iop.org/article/10.1088/1755-1315/240/7/072034**
Paper 3 - **https://iopscience.iop.org/article/10.1088/1742-6596/1042/1/012003**
Paper 4
https://asmedigitalcollection.asme.org/fluidsengineering/article/142/10/101214/1084905/Optimization-of-Francis-Turbines-for-Variable