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Modernizing a Century-Old Hydropower Plant: Redesign and Optimization of a Francis Runner

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ABSTRACT

This paper details the redesign of a Francis turbine runner for a historic 1912 hydropower plant in Southern France. The goal of the project is to enhance turbine performance and power output while maintaining the existing distributor and draft tube configurations, which cannot be modified.

To achieve this, the upstream chamber and draft tube geometries were reconstructed using 3D scanning and historical drawings. The new runner was designed from scratch to seamlessly integrate with the existing layout. The design process employed a suite of commercial tools, including turbomachinery design and parametric blade modeling software, computational fluid dynamics (CFD) simulations, and optimization algorithms.

The CFD modeling approach evolved through progressive stages: initial simplified models combining guide vane and runner passage simulations with a virtual outlet diffuser, followed by comprehensive full-domain simulations incorporating the upstream chamber, complete distributor, and draft tube. These models guided the optimization process to develop a runner that maximized efficiency while ensuring a minimum threshold for mass flow rates and at the same time mitigating cavitation risk.

Key steps in the optimization workflow included parametric blade model definition, database generation, and design optimization. Variable and fixed parameters were strategically chosen, with bounds set to ensure a robust design space. Design of Experiments (DOE) techniques generated sample data, while a surrogate model coupled with an evolutionary algorithm optimized performance objectives and constraints.

Advanced data mining and analysis tools—including Leave-One-Out cross-validation, analysis of variance (ANOVA), and self-organizing maps (SOM)—were integrated to enhance both procedure and results. The effectiveness of these methods is illustrated through their application in this design process.

Finally, the paper presents the resulting runner geometry and the corresponding turbine performance improvements, demonstrating the success of the optimized design.