Francis turbines for power generation

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1. Motivation and ObjectivesAs the world shifts to greater reliance on sustainable energy sources, the design and optimization of relevant turbomachinery devices are imperative. The CFturbo software allows its users to build and optimize all components of Hydro Turbines, as shown in this introductory case study of a Francis turbine.

The Francis turbine is a longstanding monument in the world of turbomachinery, dating back to the mid-19th century. Today, Francis turbines are globally the most widely used turbines for hydroelectric power generation.

3. Baseline DesignA baseline geometry was prepared using the Hydro Turbine module within the CFturbo software. The initial design point was defined by a volumetric flow rate of 3.89 cubic meters per second, a net head of 26 meters, and a rotational speed of 600 revolutions per minute. An inlet temperature of 20 ?C and an inlet pressure of 4 bar were also defined. The meridional view is shown below, Fig.1.

4. Design Exploration using Star-CCM+To optimize the Francis Turbine base geometry, three design parameters were strategically varied with hopes of analyzing variable sensitivity in performance: 1. the blade position (angle) of the wicket gate, 2. the blade angle at the leading edge of the runner, and 3. the blade angle of the trailing edge of the runner.

Using a CFturbo engineered Python script solution in conjunction with the Replace Part Operation within Star-CCM+, 25 unique Francis Turbine CFturbo designs were created and simulated using a mesh of approximately 8.5 million polyhedral cells and a steady-state solver. Figure # shows the Star-CCM+ mesh of the best design out of the 25.

Figure 4 is a parallel plot displaying the design parameter values as well as significant quantities of interest. The baseline design is displayed in pink. Various result variables were analyzed to evaluate the optimum design. Viable designs were chosen by ensuring the outlet mass flow rate approximately matched the original design point. Next, both the total efficiencies and the runner efficiencies were analyzed.

Finally, the products of the outlet peripheral speed and the outlet absolute circumferential velocity were analyzed to minimize downstream swirl. Given these criteria, "design 20" (displayed in blue) was selected as the best design; at approximately the same outlet mass flow rate, the total efficiency increased from 89.9 % to 90.3 %, and the runner efficiency increased from 94.8% to 95.0%.

Although these improvements seem relatively minuscule, it"s important to highlight that these changes have significant consequences due to the immense scale of Francis turbines. Overall, designs with lower wicked gate angles lead to a decrease in downstream swirl and improved efficiencies. In contrast, models with relatively lower runner blade angles resulted in worse efficiencies in this particular case.

5. Baseline & Optimum Design Performance Maps using Simerics MPComparing results of two CFturbo compatible simulation software, performance maps of the baseline design and the selected best design were calculated using Simerics MP.

Both steady-state and transient simulations were performed for the two designs using a Binary Tree mesh of approximately 5 million cells. Figure # shows the Simerics MP mesh of the best design, "design20".

6. Key ResultsData regarding the performance of baseline design and design 20 was extracted from SMP and StarCCM+ and plotted below. The following three charts showing efficiency, net head, and power over volume flow rate, are for one wicket gate angle at one rotational speed.

The initial design point coincided with the best efficiency point. In terms of simulation precision, the transient results from Simerics MP more accurately agreed with the steady-state results from StarCCM+. This outcome is logical given the more refined quality of the