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Energy Loss Evaluation of a Reversible Mixed-Flow Pump Applied to Low-Head Pumped Storage Based on Entropy Production Theory

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Extended Abstract

Renewable energy, such as wind and photovoltaic power, is expected to account for 60% of the energy supply in China by 2050. However, the existing electrical grid systems can hardly integrate mass-scale intermittent and uncertain weather-driven power sources without destabilization [1]. The instability in the grid can be alleviated by increasing the installed capacity of energy storage devices. Pumped hydro storage (PHS) is generally acknowledged as the most cost-effective and mature energy storage device, comprising 90.3% of the world's energy storage capacity in 2020. Most PHS are confined to the high-head terrain, where hydropower resources have been fully developed [2]. Nevertheless, the potential of the widespread virgin land characterized by the low head is tremendous but still locked [3]. Hence, more attention has been turned to reducing the operating head of PHS by reversible low-head turbomachinery [4].

The mixed-flow pump usually works with a head under 50 m, which is appropriate for plain terrain [5]. Meanwhile, counter-rotating pumps have been confirmed to generate power efficiently and economically [6]. Accordingly, a reversible mixed-flow pump (RMFP) [7], which can also reverse as a turbine for power generation, is a promising solution to low-head PHS. To evaluate hydraulic loss and improve the energy efficiency of the fluid machinery, the entropy production theory is gradually applied to CFD numerical simulation [8], which can reveal a detailed distribution of the energy dissipation at any location [9].

In this research, the energy loss in both pump and turbine modes of the RMFP has been simulated and assessed. To investigate the energy characteristics of the RMFP and verify the accuracy of the numerical simulation, we designed and constructed a bidirectional experimental system at the National Research Centre of Pumps, Jiangsu University. The transient flow in the RMFP was simulated based on CFD with a boundary layer-refined and independent structural mesh. The entropy production theory based on the second law of thermodynamics is applied to the simulations to quantitatively analyse the hydraulic loss and capture the distribution of energy dissipation.

The reliability of the simulation is verified by comparing the numerical energy characteristics to the experimental results. The error of head and efficiency are within 3% and 5%, respectively, in both pump and turbine modes. Meanwhile, the headloss calculated by entropy production is compared to the pressure drop method's results, and the error is within 10% in both pump and turbine modes. Then, the energy loss in different flowing components is evaluated. In pump mode, the most loss is in the volute, accounting for 44%, followed by the runner, 32%. However, in turbine mode, the runner produces the most loss, accounting for 46%, followed by the draft tube, 38%.

It is concluded that the numerical simulation based on the entropy production theory can predict the energy loss and its distribution in two opposing flow modes of the RMFP. In both pump and turbine modes, flow separation on the suction surfaces produces considerable entropy in the runner. To reduce flow loss and improve the efficiency of the RMFP, multi-objective optimization, targeting minimizing entropy production, can be carried out to the runner shape in the future.

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