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Experimental investigation and performance prediction modeling of a single stage centrifugal pump operating as turbine

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Abstract

In small hydropower systems, Pumps as Turbines (PaTs) represent a cost-effective alternative to conventional turbines as long as the turbine mode performance can be predicted before their installation. A closed-loop test rig for experimental studies on hydraulic pumps and turbines has been built at the Department of Mechanics, Mathematics and Management of the Polytechnic University of Bari, in order to experimentally support the theoretical studies on PaTs. A single stage centrifugal pump has been tested in both direct and reverse mode. Furthermore, a literature survey of PaT models has been conducted and a new model, with a more general applicability, has been proposed.

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Keywords: Pump as Turbine; PaT; Hydropower; Centrifugal Pump; Experimental Study; Performance Prediction Model.

1. Introduction

Among renewable energy sources, Small Hydropower Plants (SHPs) represent a promising solution in electricity production, having no significant environmental impact. Approximately 36% of the current global SHP potential has been developed in 2016. SHPs represent 7% of the total renewable energy capacity and 6.5% of the total hydropower capacity (including pumped storage). Europe has the highest SHP development rate, with nearly 48% of the overall potential already installed [1]. Due to the technological complexity of small size turbines, in SHPs the use of pumps

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operating under reverse mode (the so-called PaTs, i.e., Pumps as Turbines) represents a practical solution, considering their wide range of specific speed numbers and available standard sizes. For this reason, PaTs are often used in water distribution networks and oil pipelines, where they can replace pressure reducing valves [2]; in hydraulic pumped-storage plants, these machines can satisfy the demand when energy peaks occur. Furthermore, also in rural electrification, PaTs can represent an economical solution because can be installed and maintained by local technicians [3].

PaTs can become a cost-effective alternative to traditional turbines as long as their turbine mode performance can be accurately predicted. However, pump manufacturers do not usually offer performance curves of their pumps operating under turbine mode. A large number of theoretical and experimental studies can be found in the literature for the prediction of PaT performance. However, these prediction models show low reliability, accuracy and robustness since they usually have been developed based on a limited number of samples. As result, each model is usually accurate only with respect to the set of considered pumps.

In this framework, a closed-loop test rig for experimental studies on hydraulic pumps and turbines has been built with the aim to experimentally support the theoretical studies in the development of accurate and robust models for prediction of PaT performance. At the same time, the test rig could be an important facility for those pump manufacturers that would like to investigate more deeply their machine operations.

Nomenclature

Acronyms

AC	Alternating Current
BEP	Best Efficiency Point
DC	Direct Current
PaT	Pump as Turbine
SHP	Small Hydropower Plant

Symbols

C_V	flow coefficient of valves [m^3/h]
e_H	relative error in turbine head prediction at BEP [%]
e_Q	relative error in turbine discharge prediction at BEP [%]
h	head conversion factor
H	head [m]
$H_{BEP,P}$	head of the PaT at its BEP under pump mode operation [m]
$H_{BEP,T}$	head of the PaT at its BEP under turbine mode operation [m]
N	rotational speed [rpm]
N_S	specific speed number (Q in [m^3/s], H in [m] and N in [rpm])
$N_{s,P}$	specific speed of the PaT under pump mode operation
$N_{s,T}$	specific speed of the PaT under turbine mode operation
P	power [kW]
q	flow rate conversion factor
Q	flow rate [m^3/h]
$Q_{BEP,P}$	flow rate of the PaT at BEP under pump mode operation [m^3/h]
$Q_{BEP,T}$	flow rate of the PaT at BEP under turbine mode operation [m^3/h]

Greek letters

$\eta_{BEP,P}$	efficiency of the PaT at BEP under pump mode operation [-]
$\eta_{BEP,T}$	efficiency of the PaT at BEP under turbine mode operation [-]