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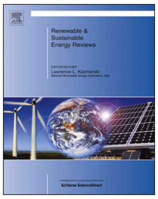

Investigations on pump running in turbine mode: A review of the state-of-the-art

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ABSTRACT

In remote communities where it is not economical and practically possible to take the grid connection, stand-alone small hydro systems can be used to fulfill the energy requirement. Small-scale hydroelectric power systems are emerging as a promising source of renewable energy generation, but they require low cost hydraulic and electric equipments to make them economically feasible. In such plants, pumps can be used in turbine mode considering various advantages associated with pump e.g. ease of availability, proven technology, low initial and maintenance cost, availability for a wide range of heads and flows, etc. The efficiency of pump as turbine (PAT) is usually lower than that of conventional hydro turbines. However, efficiency is not the primary selection criterion for such machines and it is recommended to operate such machines around maximum efficiency point.

In the present study, different turbines suitable for micro-hydropower plants are discussed. The historical development of PAT is described. The review of the state-of-the-art of pump running in turbine mode is presented. Different pumps suitable to run in turbine mode for low capacity power generation in micro-hydropower plants as well as in water supply piping systems are discussed. Theoretical, experimental and numerical investigations carried out by different researchers on PAT are reviewed. The research work on PAT including criteria for selection of pump running as turbine, cavitation analysis, force analysis, loss distribution, various methods of performance enhancement, cost analysis of hydropower plant with conventional hydro turbine and PAT, applications of PAT in water supply pipelines, etc. is discussed. The worldwide implementation of PAT and different manufacturers of PAT are described. The limitations in implementation of PAT as well as the recommendations to improve the performance of PAT are described. The current trends and future scope for the further improvement and implementation of PAT are also discussed.

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Nomenclature

H	head (m)
Q	discharge (m^3/s)
N, n	rotational speed (rpm)
N_s	specific speed
C	prediction coefficient
V	absolute velocity (m/s)
W	relative velocity (m/s)
D	impeller diameter (m)
P	power (W)
Qu	unit discharge
Nu	unit speed
h	head correction factor
q	discharge correction factor
f	frequency (Hz)
p	number of poles
g	gravitational constant (m/s^2)
t	time (s)
d	annual discount rate (%)
PAT	pump as turbine
MW	megawatt
kW	kilowatt
SHP	small hydropower
MNRE	ministry of new renewable energy
BEP	best efficiency point
ISO	international organization for standardization
ANN	artificial neural network
MATLAB	matrix laboratory
CFD	computational fluid dynamics
CSHN	combined suction head number
FEM	finite element method
RANS	Reynolds-averaged Navier–Stokes
FVM	finite volume method
MRF	moving reference frame
RNG	renormalization group
SST	shear stress transport
RAM	random-access memory
SIMPLE	semi-implicit method for pressure-linked equations
SIMPLEC	semi-implicit method for pressure-linked equations-consistent
PISO	pressure-implicit with splitting of operators
PRV	pressure reducing valve
UNIDO	United Nations industrial development organization
ETC	environmental tectonics corporation
TaTEDO	Tanzania traditional energy development organization
ESP	engineering studies program
BGET	border green energy team
PVC	polyvinyl chloride
IG	induction generator
NPV	net present value
BCR	benefit/cost ratio
IRR	internal rate of return
ALCC	annual life cycle cost
US$	United States dollar
Wp	watts peak
Ah	ampere hour
Co	initial cost
CRF	capital recovery factor
Ac	annual expenses
L	equipment life
PV	photovoltaic
EGE	energy generation equipment
CW	civil works
IGC	induction generator controller
KBL	Kirloskar brothers limited
rpm	revolution per minute
bhp	brake horse power
ft	foot
usgpm	United States gallons per minute
lps	liter per second
kWh	kilowatt hour

Greek symbols

η	efficiency
γ	specific weight (N/m^3)
ψ	head coefficient
ϕ	discharge coefficient
π	power coefficient
χ	relation between best efficiency and specific speed of pump
ρ	density of water (kg/m^3)
μ	blade torque coefficient
σ	Thoma's cavitation coefficient/slip factor/axial force coefficient
k	turbulence kinetic energy (J/kg)
ε	turbulence dissipation rate (J/kg-s)

Subscripts

t, T	turbine
p	pump/peak
h	hydraulic
g	generator
m	motor/mechanical
2u	tangential component at pump outlet/turbine inlet
2m	meridian component at pump outlet/turbine inlet
n	net
v	volute
l	leakage
e	kinetic energy
i	hydraulic
crit	critical
opt	optimum