Available online at www.sciencedirect.com
SCIENCE DIRECT
Renewable Energy 31 (2006) 209–223
RENEWABLE ENERGY
www.elsevier.com/locate/renene

On applicability of reciprocating flow turbines developed for wave power to tidal power conversion

K. Takenouchi [a,*], K. Okuma [b], A. Furukawa [b], T. Setoguchi [c]

[a] *Department of Human Living System Design, Kyushu University, 4-9-1 Shiobaru, Minami-ku, Fukuoka 815-8540, Japan*
[b] *Department of Mechanical Science and Engineering, Kyushu University, 744 Maotooka, Nishi-ku, Fukuoka 819-0395, Japan*
[c] *Department of Mechanical Engineering, Saga University, 1 Honjo-machi, Saga 840-8502, Japan*

Available online 30 September 2005

Abstract

Tidal power generation with reciprocating turbines in a simple system is investigated on a performance simulation in order to enlarge the capability of practical use of tidal power with extra-low head and time-varying energy density characteristics. Four reciprocating turbines, which are two types of impulse and a Wells developed for wave power conversion systems, and a cross-flow type of Darrieus for extra-low head hydropower are focused for utilizing extra-low head tidal power. Their turbine characteristics in a unidirectional steady flow obtained by physical test models are compared in non dimensional forms and power plant performance with the turbines are numerically simulated on equivalently scaled turbines based on the low of similitude on turbine performance with the non dimensional characteristics under one of the simplest controls in combination with suitable reservoir ponds area. The output of the power plant depends on tidal difference and a pond inundation area. The results are summarized and discussed on the averaged electric output of the power plant and the optimum scale of pond inundation area.

Keywords: Tidal power; Extra-low head; Turbomachinery; Wave power turbine; Darrieus turbine; Economical scale

1. Introduction

Tidal energy has a suitable feature of predictability in supply to be positively utilized as local energy resources and compensation for insecurity of other natural energy resources due to fluctuation in time. There are several types of scheme to extract energy from tide, and a typical

* Corresponding author. Tel.: +81 92 553 4532; fax: +81 92 553 4569.
E-mail address: ktake@design.kyushu-u.ac.jp (K. Takenouchi).

0960-1481/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2005.08.018

Nomenclature

A_c, A_t	casing cross sectional area and flow passage area at runner section, respectively (m^2)
A_p	inundation area of pond (m^2)
g	acceleration of gravity (m/s^2)
H_t	total head (m)
H_o, H_p	water level in ocean and pond, respectively (m)
H_m, H_s	mean tide level and tidal difference, respectively (Eq. (2)) (m)
L	generated power (W)
L_{11}	normalized generated power (Eq. (1))
N	rotational speed (rpm)
N_{11}	normalized rotational speed (Eq. (1))
N_{cr}	critical rotational speed (Eq. (5)) (rpm)
P, P_o	average and instantaneous electric output of power plant, respectively (kW)
Q	flow rate (m^3/s)
Q_{11}	normalized flow rate (Eq. (1))
T	tidal period (745 min) (s)
t	time (s)
U	peripheral speed of runner blades at the blade tip of the wave power turbines and on the pitch circle of Darrieus turbines (m/s)

Greek symbols

Δp	power loss due to mechanical friction (W)
Δt	time step (Eq. (3))
η_g	generator efficiency
η_t	turbine efficiency (Eq. (1))
ρ	density of working fluid (kg/m^3)

one is the extraction of potential energy from the difference in head between high and low tides, involving building a tidal barrage on estuary or inlet. As the barrage traps a water level inside a pond, head is created as the water level outside of the pond changes relative to the one inside. The head is used to drive turbines for power generation.

La Rance in France, which is one of the most famous commercial power plants in the world, has been generating 544 GWh a year with 24 tubular turbines under the tidal difference of 13.5 m at maximum and the pond inundation area of 184 km^2. The power generation cost of this kind of power plant is estimated as twice of ordinary water power plants due to its extra-low head and besides, the generation cost exponentially increases with the decrease of total head as shown by an example of cost evaluation of power plant in Fig. 1 [1]. Then sites of tide range below 5 m in general would not satisfy a criterion for economical availability.

The authors have introduced a simple power plant by use of a Darrieus-type water turbine with a vertical axis to utilize extra-low head water power up to 2 m [2]. The simple structure of its runner and casing with two-dimensional shape is expected to reduce the capital and maintenance costs. Since the Darrieus runner operates independent of flow direction across its