Analytical modelling of a novel tidal turbine
Shane C. Heavey¹, Patrick J. McGarry¹, Sean B. Leen¹
¹College of Engineering and Informatics, NUI Galway
Galway, Ireland

ABSTRACT

The hydrodynamic analysis of a novel vertical axis tidal turbine concept is presented for identification of optimum operating conditions. The model uses a blade element momentum approach, adapted for the complex spiral geometry of the blades. A range of blade designs is considered, based on different rotor height to diameter ratios, leading to a range of hydrodynamic power curves with different optimal tip speed ratios and peak power levels. The model is validated against experimental data and previous similar work. It is found that decreasing the turbine height to diameter ratio results in increased maximum power coefficient.

KEY WORDS: Tidal energy; Blade element momentum; Vertical-axis turbine;

NOMENCLATURE

\( AR \) aspect ratio
\( A \) area \([m^2]\)
\( a \) interference factor
\( BEM \) blade element momentum
\( c \) chord length \([m]\)
\( C_D \) drag coefficient
\( C_L \) lift coefficient
\( C_N \) normal force coefficient
\( C_T \) tangential force coefficient
\( D \) diameter \([m]\)
\( DMST \) double multiple streamtube
\( F_N \) normal force \([N]\)
\( F_T \) tangential force \([N]\)
\( F_x \) resultant force \([N]\)
\( F_x^* \) force coefficient
\( h \) local blade height \([m]\)
\( H \) overall turbine height \([m]\)
\( l \) length \([m]\)
\( MST \) multiple streamtube model
\( N \) number of blades
\( N_z \) number of heights
\( N_{\phi} \) number of azimuthal positions
\( P \) power \([kW]\)
\( Q \) torque \([N\,m]\)
\( r \) local radius \([m]\)
\( R \) maximum radius \([m]\)
\( Re \) Reynolds number
\( SS \) static stall
\( TSR \) tip speed ratio
\( V \) induced velocity \([m\,s^{-1}]\)
\( V_{\infty} \) freestream velocity \([m\,s^{-1}]\)
\( V_e \) equilibrium velocity \([m\,s^{-1}]\)
\( V_w \) wake velocity \([m\,s^{-1}]\)
\( W \) relative velocity \([m\,s^{-1}]\)
\( x, y, z \) Cartesian coordinates
\( \alpha \) angle of attack \([\text{deg}]\)
\( \phi \) local additional azimuthal angle \([\text{deg}]\)
\( \delta \) blade angle to horizontal \([\text{deg}]\)
\( \theta \) azimuthal angle \([\text{deg}]\)
\( \mu \) dynamic viscosity \([\text{N}\,\text{s/m}^2]\)
\( \rho \) density \([\text{kg}\,\text{m}^{-3}]\)
\( \omega \) turbine rotational speed \([\text{rad}\,\text{s}^{-1}]\)

INTRODUCTION

The development of new technologies for clean, sustainable renewable energy is a key challenge for society. Tidal energy is a leading renewable energy source with significant advantages over competing sources, including predictability and repeatability.

This paper is concerned with establishing the optimum operating performance of a range of novel vertical axis tidal turbines for micro-hydro power through analytical modelling. The development of wind turbine technology is significantly more advanced in this area, leading to potential technology transfer opportunities for tidal turbine developers. Khalid et al. (2013) have assessed a number of tidal turbines and identified key challenges faced by these emerging technologies.

A number of methods have been established for investigating the power performance of turbines including vortex models, by Strickland (1975), and computational fluid dynamics (CFD) models, developed by Le et al. (2014), for example. These methods have proven