Dynamic Response Analysis of Darrieus-Type Vertical Axis Water Turbines

Norbert V. Dy¹, Farooq Saeed² and Ion Paraschivoiu¹

¹Département de génie mécanique, Polytechnique Montréal, Montreal, QC, Canada
²Aerospace Engineering Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

ABSTRACT

The paper investigates the dynamic response of single and multiple rotor Darrieus-type vertical axis water turbines in order to determine the best configuration. Three configurations are considered: a single two-bladed rotor, a twin two-bladed rotor with blades aligned, and a twin two-bladed rotor with rotor blades offset by 90 degrees in azimuth. The Double-Multiple Streamtube model is employed to compute hydrodynamic loads and turbine performance. The structural dynamic response of the turbines is determined through the spinning finite element approach in which the turbines are modeled using 3D beam elements. The study reveals that the twin two-bladed rotor with blades aligned is structurally more resilient than the other two configurations.

KEY WORDS: Water turbine; hydrokinetic energy; multiple rotors; Double-Multiple Streamtube model; finite element method; structural dynamics.

INTRODUCTION

Following the fast growing trend of wind energy, hydrokinetic power is now being considered with great interest as a viable solution to the world growing electricity demand due to its high potential for clean and reliable energy. Hydrokinetic water turbines operate using the same principles as lift driven wind turbines, however with seawater being approximately 832 times denser than air, the amount of kinetic energy available in a 4 knots (or 2.06 m/s) water current is equivalent to that of a wind velocity of 19.4 m/s. Among the advantages associated with vertical axis hydrokinetic turbines, one can list the possibility to design a rotor with a diameter-to-height ratio different than unity and the possibility of siting their electrical components above the water level, reducing maintenance cost. Compared to wind turbines, water turbines are subjected to severe hydrodynamic loads, which limit the maximum size of the rotors. To compensate for the limited size of the rotors, the current trend is to use an assembly of multiple rotors. The aim of this paper is to investigate the benefits of using multiple Darrieus-type rotors connected to the same central shaft. For this study, a design and analysis tool that takes into account the hydrodynamics, as well as the structural dynamic response of the turbine is used. To evaluate the hydrodynamic loads and performances of the Darrieus-type vertical axis water turbines, the Double-Multiple Streamtube model (Paraschivoiu, 1981) is employed and the structural dynamic response assessment of the turbines is based on spinning finite element approach (Leung and Fung, 1988).

HYDRODYNAMIC PERFORMANCE ANALYSIS

Analysis Conditions

In this study, the CARDAAV code (Paraschivoiu, 2002) was used to evaluate the hydrodynamic loads and performances of the Darrieus water turbines. The model implemented in CARDAAV is the Double-Multiple Streamtube model, which is based on the conservation of momentum principle in a quasi-steady flow by equating the forces on the rotor blades to the change in streamwise momentum through the turbine. The particularity of the Double-Multiple Streamtube model is that the flow through the rotor is regarded as being subdivided into a number of independent streamtubes. Each streamtube contains a pair of actuator disks in tandem (Fig. 1), the first one representing the upwind half and the second one representing the downwind half of the surface swept by the rotor blades. As a result of the forces created by the actuator disks on the fluid, the stream flow velocity changes along each streamtube and decreases in the flow direction. Along any given streamtube, the fluid velocity variation is reproduced through five different velocities, related by two interference factors. By applying in each streamtube the momentum equation to the control volume containing the actuator disks, the forces on the disks and the induced velocities can be calculated. The forces on the disks are drag-type forces and can be determined using the blade element theory, which involves the static aerodynamic drag and lift coefficients of the blade airfoil/hydrofoil. The CARDAAV code has been validated numerous times in the past with experimental data and showed accurate results in performance predictions of vertical axis wind turbines (Paraschivoiu, 2002).