ARGUMENTATION OF THE HYDRODYNAMIC PROFILE OF THE MICRO-HYDRO POWERSTATION ROTOR'S BLADES

Assoc.prof.Dr. Viorel Bostan
Technical University of Moldova

1. INTRODUCTION

The inevitable increase of global energy consumption and the risk of a major environmental impact and climate change as a result of burning fossil fuels opens wide prospects for the exploitation of renewable energies. Hydropower, as a renewable energy source, will have an important role in the future. International research confirms that the emission of greenhouse gases is substantially lower in the case of hydropower compared to that generated by burning fossil fuels. From the economical point of view, the utilisation of half of the feasible potential can reduce the emission of greenhouse gases by about 13%; also it can substantially reduce emissions of sulphur dioxide (main cause of acid rains) and nitrogen oxides.

Hydraulic energy is the oldest form of renewable energy used by man and has become one of the most currently used renewable energy sources, being also one of the best, cheap and clean energy sources. Hydraulic energy as a renewable energy source can be captured in two extra power forms:

– potential energy (of the natural water fall);

– kinetic energy (of the water stream running).

Both extra power forms can be captured at different dimensional scales.

Among clean and non-pollutant energy sources, kinetic energy of the flowing rivers is of great importance due to the enormous energy potential. This assertion stands for the vast majority of rivers with large and medium size discharge. Strong public opposition to large scale hydro-electrical power plants caused by large environmental and social costs (from damming of rivers and flooding of large tracts of fertile land to the displacement of people from the affected areas and disrupted fish migration) is making the small scale hydro-electric power plants more appealing, especially for the potential consumers in remote rural areas. Micro-hydro-electric power plants are used on a large scale as decentralized energy sources. Renewed interest for such stations started worldwide in recent decade. Decentralized systems for conversion of the kinetic energy of the free water flow into electric or mechanical energy are using turbines in the absence of dams. The kinetic energy of free water flow is a recommended energy source, available 24 hours per day and it can be efficiently harnessed by micro-hydro power stations.

Systems for conversion of river kinetic energy elaborated by the research team from the Technical University of Moldova (coordinator - Prof. acad. Ion Bostan) have no counterparts among classical systems utilized at international scale. The proposed innovations resulted from a complex theoretical and experimental research in the context of which the rotor's geometrical, functional and constructive parameters have been determined and in a specialized laboratory with modern equipment the blade's fabrication technology using composite materials have been validated [1-5].

The micro hydropower plant is a complex technical system that includes constructive components with distinct functions: rotor-turbine that draws off a part of the water kinetic energy at its interaction with the water flow; mechanical transmissions for the transformation of the converted energy; pumps and generators for useful power generation, etc. The conversion efficiency of the micro hydroelectric power plant depends on the performances of each component.

The functional and constructive parameters of the hydrodynamic rotor adopted within the carried out research separately on each working element demand experimental research of their functioning as an integral system in real conditions. The experimental research on the units of the micro hydroelectric power plant as an integral system aims at the increase of the conversion efficiency of the water flow kinetic energy into useful energy by introducing the relevant constructive modifications in the project documentation of the final industrial product.

Two micro-hydro-power stations prototypes with three and five hydrodynamic blades have been elaborated, designed, tested and manufactured specifically for conversion of the river's kinetic energy into useful energy (electrical or mechanical). The main working parts have non-standard parameters: generators with permanent magnets, low revolution hydraulic and centrifugal pumps, multiplier systems based on planetary transmissions. One of the manufactured prototypes of the micro-hydro power stations with three hydrodynamic blades is shown in figure 1.

Figure 1. Micro-hydro power station with 3 hydrodynamic blades.

2. NUMERICAL SIMULATION OF THE FLOW-BLADE INTERACTION OF THE MICRO-HYDRO POWER STATION

The conversion efficiency of the proposed micro-hydro power stations depends strongly on the selection of the optimal hydrodynamic shape of the blades and hydrofoil positioning, i.e. at each angular position hydrofoil should have an attack angle that will maximize the tangential component of the hydrodynamic force and hence, the resulting torque. Various constructive diagrams can be considered in order to maximize the resulting torque. In the following one blade positioning configuration will be discussed.

In this configuration, the blade in zone I, fig.2, has a constant attack angle of 18^{o} with respect to the water stream velocity vector, in zone II the blade changes the attack angle from 18^{o} to -18^{o}, in zone III the blade has a constant attack angle value of -18^{o}, in the fourth zone IV the blade changes the attack angle up to 90^{o}, keeping this value constant in zone V, and finally the blade changes its attack angle back to 18^{o} in zone VI, thus completing a full revolution.

The computer simulations of the flow-blade interaction of the micro-hydro power station with five hydrofoils have been performed in the academic version of the commercial CFD packages ICEM CFD and ANSYS CFX. The computational domain is a two-dimensional cutting plane orthogonal to the rotor axis and consists of three sub-domains: a

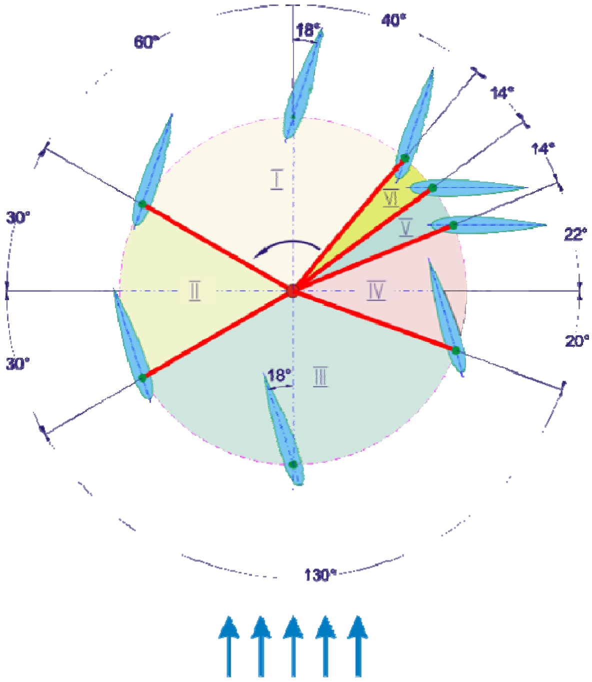

Figure 2.

far-field sub-domain, a rotor sub-domain (a circle of radius 3m with centre at rotor axis) and 5 near-blade sub-domains (circles around each blade), see fig. 3. The rotor itself has a radius of 2m, each blade is a hydrofoil with NACA 0016 profile with chord length 1.3m.

The domain extends 10m upstream and 20m downstream of the rotor axis, while laterally it extends 4m to each side. Since the computations are two-dimensional, the hydrofoils are considered infinitely long and therefore the effects due to the endplates of the hydrofoils are not taken into account.

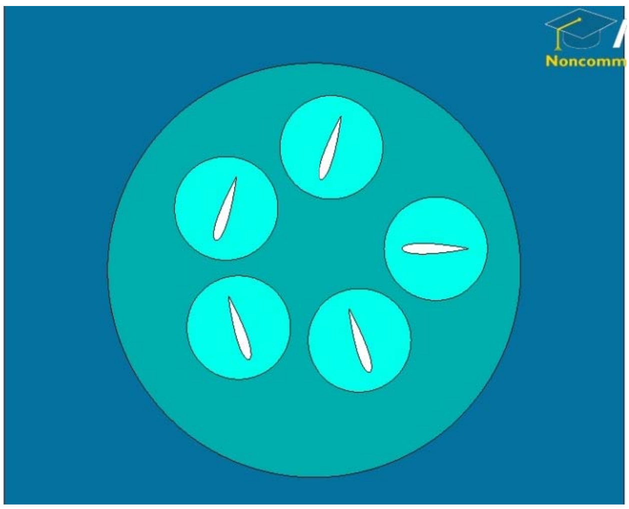

Figure 3.

The no-slip boundary condition is imposed on the surface of each hydrofoil, the streamwise flow boundary conditions with initial velocity of 1m/s and medium turbulence intensity (5%) are imposed on the upstream boundary (inlet), the free-slip boundary conditions are imposed on the lateral sides, while on the downstream boundary (outlet) a constant zero averaged pressure condition is enforced.

The geometry and mesh discretisation of the domains have been conducted in ICEM CFD. The mesh is a hybrid mesh containing tetrahedrons and very fine prism elements for modelling the boundary layer near blade walls as presented in fig. 4 and 5. The blade surface was discretised using a total of 1520 nodes. A total number of 16 prism element layers have been used for modelling the boundary layer. The first boundary layer has a height of 0.00018m. The corresponding y^+ is bounded $2 \le y^+ \le 8$, where

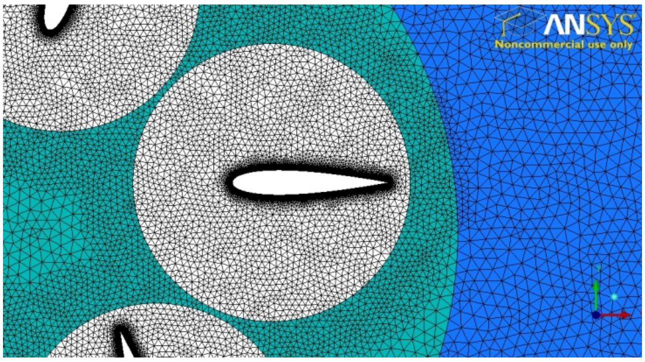

Figure 4. The mesh of the near-blade sub-domain.

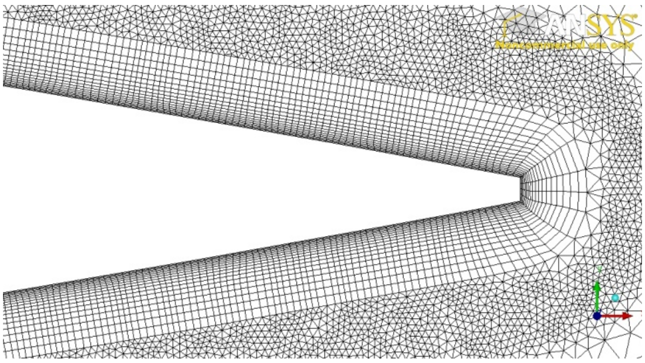

Figure 5. Mesh in vicinity of the trailing edge.

$$y^+ = \frac{\sqrt{\frac{\tau_w}{\rho}}y}{\nu}, \tag{1}$$

with τ_w being the wall shear stress, ρ the fluid density, y the wall normal distance and ν the fluid viscosity. A sufficient boundary layer resolution should satisfy the condition $y^+ = O(1)$ in order to describe correctly the boundary layer behaviour. For each circular near-blade sub-domains 100,150 elements have been used, which resulted in 780,245 elements for the rotor sub-domain and a total of approx 1,000,000 elements for the entire computational domain. Spatial convergence tests identified this discretisation as sufficient for convergence and optimal for computational costs.

The steady CFD simulations have been performed in CFX. The fluid was chosen as water at 25^o. For the turbulence model the SST $k-\omega$ model was chosen. This model was chosen since SST $k-\omega$ simulates quite well separation of boundary layers, a phenomena happening at high angles of attack, angles characteristic to the discussed setting.

3. NUMERICAL RESULTS

In figure 6 the flow velocity distribution and the turbulence kinetic energy distribution in the rotor configuration are presented. It can be noticed that due to the blades located in the upstream direction with respect to rotor axis, the velocity distribution for the blades located downstream significantly differs even if both upstream and downstream pairs of blades are making the same angle of attack of 18^o. This is due to the fact that the turbulence intensity increases in the downstream of the first pair of blades, which in turn affects the blades located further downstream. Also, it can be observed that the high turbulence areas provoked by the blades located upstream extends up to the blades located further downstream.

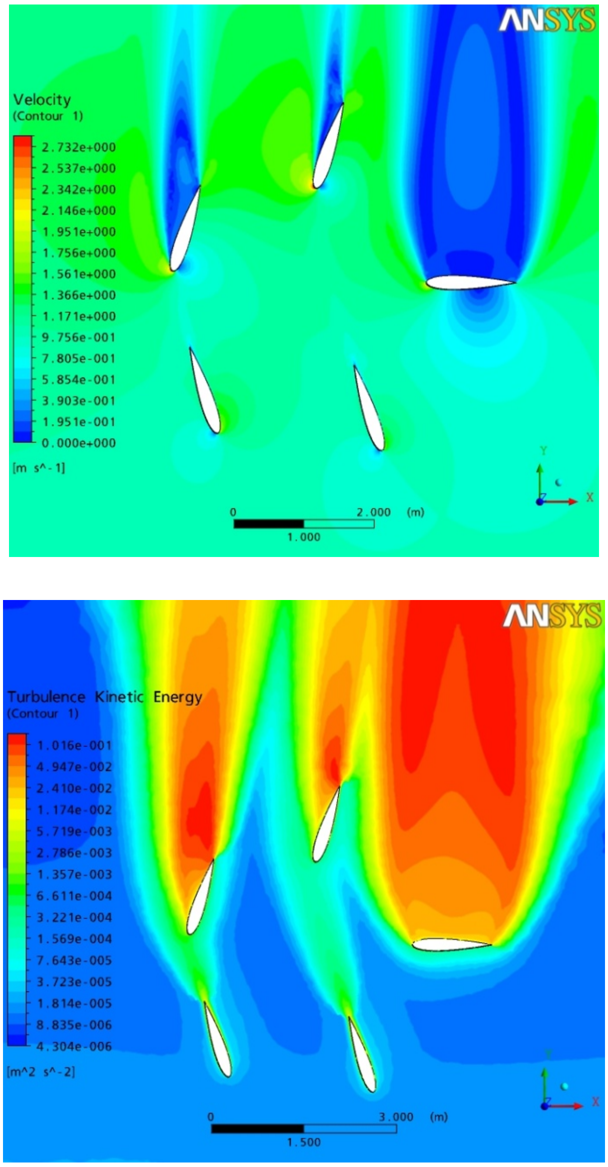

Figure 6. Flow velocity distribution and the turbulence kinetic energy distribution.

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