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Development and Analysis of Pico-hydro Electrical Turbine with Aerofoil Profiled Vertical Axis Blades in Water Supply Pipes for High Rise Buildings

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Abstract— ***In this work, the pico-hydroelectric power turbines developed for applications in rivers and canal are modified and minimized for applications in water supply pipes in high-rise buildings. This work is to design, develop drawings and study the functionality of a vertical axis turbine with Aerofoil profiled blades for pico-hydroelectric power generation in high-rise buildings. The object is to design a pico-hydroelectric turbine which will be placed in water supply pipes risers. Computational Fluid Dynamics (CFD) analysis on single blade is done on ANSYS by varying the striking angle of water on blade. The results are used for 3 and 5 blades arrangement turbine. The output of turbines in terms of power is calculated. Although the power output of single turbine is small but the same can be modified by arranging number of turbines in series in pipes.***

Keywords— High Rise buildings; CFD; Pico-hydroelectricity; renewable energy; Aerofoil profiled bladed turbine.

I. INTRODUCTION

Globally, the awareness for utilization of renewable energy is growing. Renewable energy is found to be a good resource alternate for addressing few globally important issues, such as, climate change, providing energy supply to the billions of people still living without energy availability and creating new economic opportunities in power sector. Hydropower is a renewable, eco-friendly, non-polluting and abundantly available source of energy. Hydropower is based on the concept of conversion of kinetic energy of moving water into mechanical energy in the form of rotation of turbine rotor and electrical energy with the help of electrical generator.

In our previous work we successfully designed and developed a miniaturized form of vertical axis blades rotors suitable for pico-hydroelectricity application [1]. The blades were developed using ANSYS. This work is in continuation with the previous work.

The purpose of this study is to do CFD analysis of designed rotor of different set of number of blades for pico hydro power generation that are suitable for high-rise building water piping systems. The blade for turbine rotor, which is developed on CATIA, is put on ANSYS workbench for Computational Fluid Dynamics (CFD) analysis using FLUENT. Acrylic Plastic is selected as blade and rotor material. Since the size of the rotor is quite small and the rotor has to be placed inside water supply pipes, the rotor has to be light weight as well as strong enough to withstand the water pressure inside water supply pipes. Also, aerodynamic profile and such small dimensional blade is easy to construct on acrylic plastic. Water is selected for the environment. The pipeline diameters of building water supply systems are typically about 4 to 6 inches. This innovative research is an attempt to calculate the power output of a vertical axis type turbine rotor suitable for pico-hydroelectric systems.

II. BACKGROUND RESEARCH

This research uses the successfully developed pico-hydroelectricity technology that has been applied in waterways to carry out a smaller hydroelectricity study. A brief literature review along with comments is presented in the following sections in order to provide definitions of pico-hydroelectricity, the current states of technology development and application.

A. Definition of Pico-hydroelectricity

Pico hydro power is defined as the hydropower plant generating electricity up to 5 KW. It is perhaps the only form of small renewable energy utilization which runs continuously without battery storage. Pico hydro power plants emerged as the most effective method of electricity generation for the utilization of individual houses, housing societies, villages or an individual workshops or facilities. Pico hydro power very rarely used as grid connected power source. Pico hydro technology has emerged as an economic solution of electricity crisis for the world's poorest and inaccessible areas. Pico hydro turbines come under the category of low head and high flow rate of water.

B. Technology development and current situation of applications at home and abroad

G. S. Ananthapadmanabhan et al [2], 2017, conducted the feasibility study of micro/pico hydro system in grey water by developing and testing the scaled prototype. The cost benefit analysis was also carried out. Pelton turbine is selected and a scaled prototype with a tank capacity of 20 liters, 0.00028 m3/s. 3.24 m effective head is designed and the 7.5 watts power output was tested. Further, the test is being carried out in 15 floor building with a collection tank of 6.78m3/s volume, effective head of 23.01 m and 0.0084m3/s discharge, 1.42 kW power output is recorded. They also have calculated the payback period of 8 years for the installation of such system which costs around Rs.150000.

Sujith Kumar Patro et al [3], 2016, did a technical and economic feasibility study of pico hydropower plants. They focused their study on pico hydropower generation using the consumed water in the green building. They concluded that pico hydropower plants are feasible to power upto 100 to 500watts and can be integrated with any buildings and it can illuminate 5 to 6 LED bulbs. They further concluded that the cost of such pico systems are quite less also.

Toms Komass [4], 2015, has designed and developed Darrieus type VAWT pitch system simulation model using MATLAB SIMULINK tool. He has concluded that pitch control simulation compared to simulation without pitch control gave 10% better result. Pitching control system shows highest efficiency at the azimuthal angle between 60° - 120° and 240° - 290°. He successfully suggested that the simulation system algorithms can be adjusted to any turbine dimensions and turbine blade profile.

Punati Sridhar et al [5], 2015, addressed one innovation developed by Mr. G. K. Ratnakar of modified hydro turbine to generate electricity in Jayapura village of Karnataka. The novelty of this project is the suitability for run-of-river schemes. The developed hydro turbine has salient features such as, minimal maintenance, non-polluting and AC current generation.

Sy-Ruen Huang et al [6], 2014, proposed a financial feasibility evaluation method for canal-based micro-hydroelectric energy projects. They suggested that financial feasibility evaluations are required to support investment decisions when selecting a suitable power station site and conducting the technological development of a vertical-axis micro-hydro energy converter (MHEC). They used power generation evaluation techniques to simulate and assess various maintenance activities. Additional, five financial indicators, namely, SLR, NPV, IRR, LCOE, and DPP, were used to conduct financial feasibility evaluations of the energy project. They proposed a micro-hydro energy generation system that exploits the structure of wind turbine systems to absorb the energy of water. They found that the implementation of a vertical micro-hydro turbine structure is very much feasible in existing canals or irrigation channels.

Gunjan Yadav et al [7], 2014, developed a pelton turbine for pico hydro-electric system using house hold water supply. They have established experimentally that the current, voltage and RPM are inversely proportion to the dia. of tap and directly proportional to the head. They have concluded that the head of the supply pipe lines and water flow rate are the very important parameters to developed pico hydro system for residential use.

Vicente Leite et al [8], 2012, did a demonstration project on pico hydro system on run of river in VER campus using two propeller type pico hydro turbines, first stand alone and another grid connected and found that despite of low power generations, they run around 230 days of the year and producing an equal amount of energy of a 3KW photovoltaic system.

Helena M. Ramos et al [9], 2009, did CFD analysis of four type of turbine rotors, a rotary PD turbine, an open mixed-flow PAT, an open-flume propeller and a pipe propeller and found that these new energy converters can possibly be worked quite satisfactorily with the elimination of expensive control systems. It also provided a possible orientation of likely settings for new low-power turbines.

Masjuri Musa et al [10], 2011, did CFD analysis on ANSYS of cross flow turbine and axial flow turbine and found that cross flow turbine is more suitable. However they did not did the field experiment to compare the power output results.

.P. Maher et al [11], 2003, compared pico hydro systems to solar photovoltaic systems in Kenya and determined that the former was more cost effective on a per-household basis with a 15% lower cost per kWh. With lower material costs and careful consideration of distribution and power management, pico hydro was found to be affordable for most low-income households.

The patented invention of Chang (2009) is a "plumbing generator". Its equipment also places a rotary blade into the water pipelines of a building; the blade ends feature permanent magnets; by rotating the spin of permanent magnets at the ends of blades, the generated magnetic field lines interact with the multi-turn coil on the external part of the pipe to produce electricity [12].

C. Type of hydropower use in apartment complex

The major items that consume electricity in high-rise buildings are the following: elevators, power equipment, and lighting equipment. Elevators account for 27.3%; power equipment accounts for 28.8%; lighting equipment accounts for 33%; this accounts for 89.1% of total public consumption. The high conversion efficiency of hydraulic energy is also one of its advantages. Hydraulic energy conversion efficiency is about 90%, while the highest conversion efficiency of wind energy is only up to 60% [13].

III. Analysis Procedure

The analysis of selected acrylic plastic material for a single blade of respective rotors are carried out on ANSYS selecting water as medium and striking at various angles on blade.

Water Striking at 18.44°

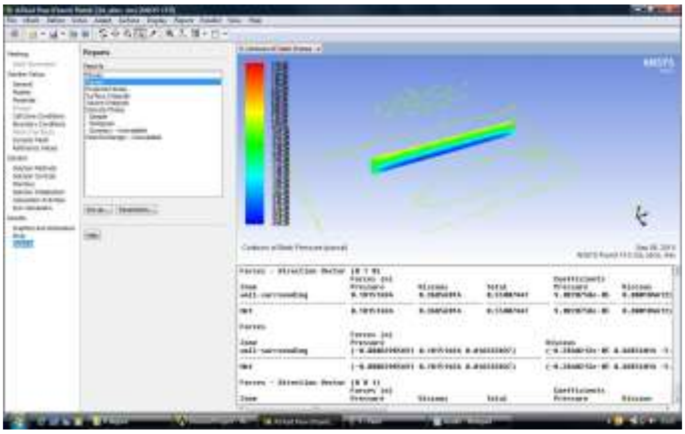

Fig. 1 Forces at (010)

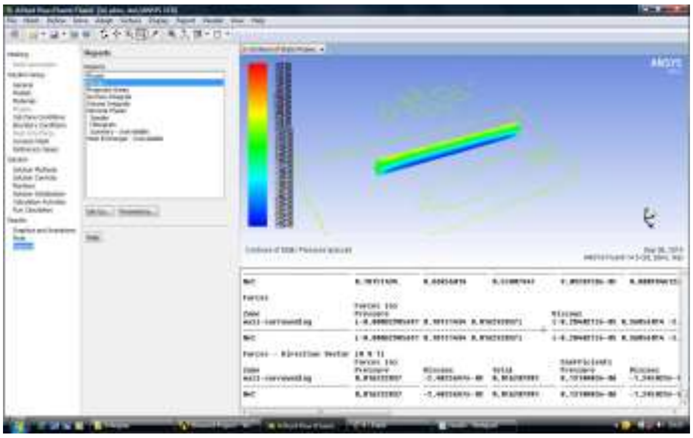

Fig. 2 Forces at (001)

Water Striking at 17.94°

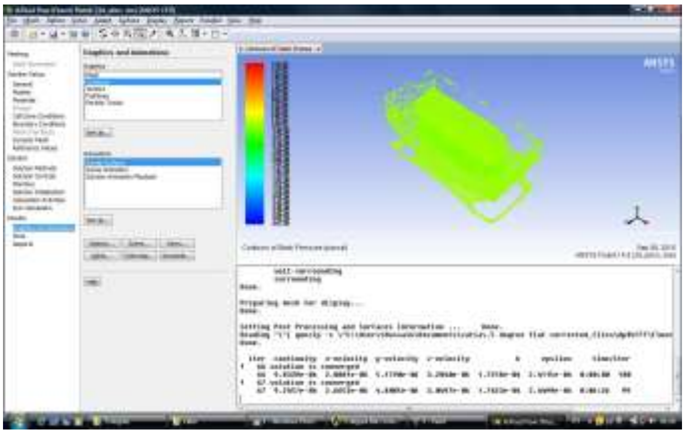

Fig. 3 Contours of static pressure

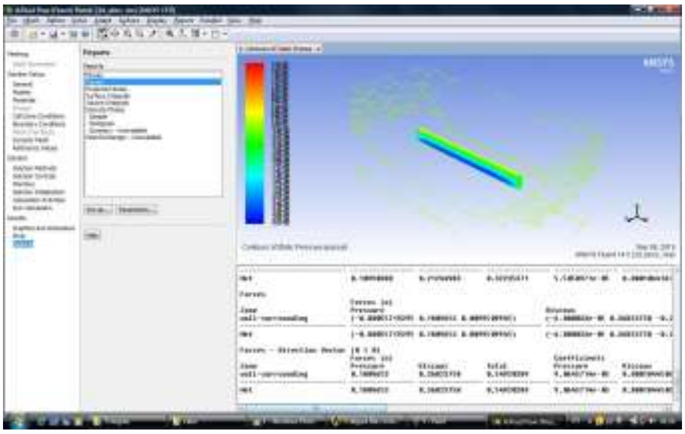

Fig. 4 Forces at (010)

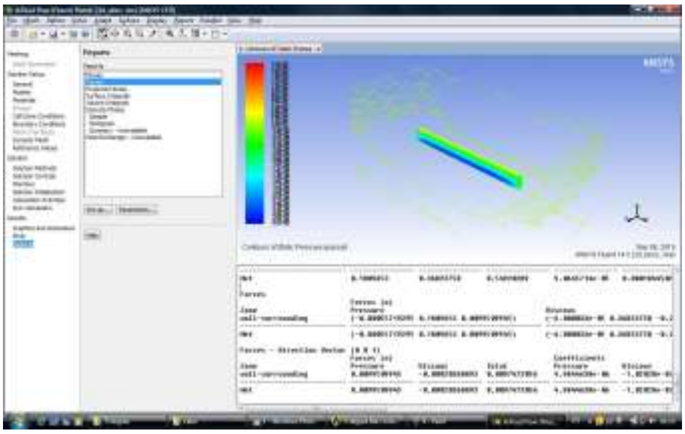

Fig. 5 Forces at (001)

Water Striking at 18.19°

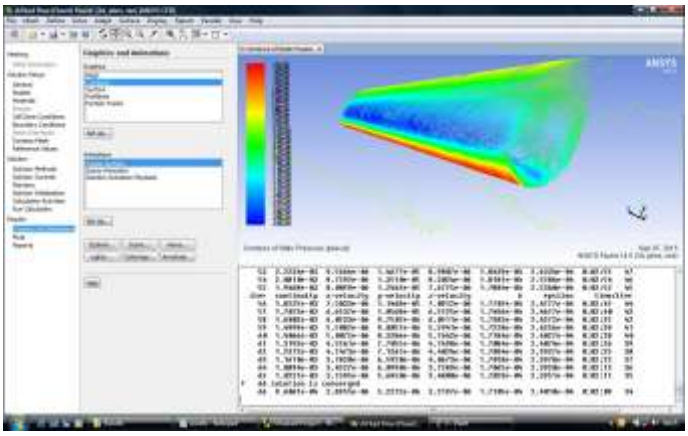

Fig. 6 Contours of static pressure

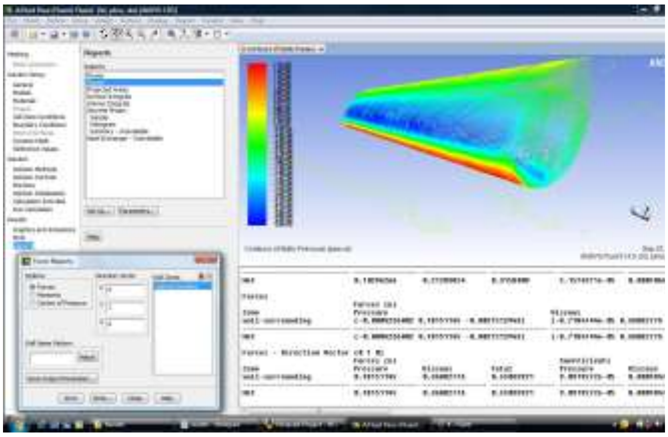

Fig. 7 Forces at (010)

IV. RESULTS

The Drag and Lift forces at various angle of attack are tabulated hereunder:

TABLE 1. Drag and lift forces at various angle of attack

Forces	Angle of Attack		
	α = 18.44°	α = 18.19°	α = 17.94°
Drag, D	0.5501	0.55034	0.5492
Lift, L	0.01621	0.016225	0.00975

The Actual tangential force is tabulated hereunder:

TABLE 2. Actual tangential force

Angle of Attack	Actual Tangential Force, F_T
α = 18.44°	-0.51673
α = 18.19°	-0.51777
α = 17.94°	-0.51949

The values of average actual tangential force at various angle of attack are tabulated hereunder:

TABLE 3. Average actual tangential force

Angle of Attack	Average Actual Tangential Force, F_{Tavg}
α = 18.44°	-0.3399
α = 18.19°	-0.34003
α = 17.94°	-0.3434

The values of average torque, τ for different number of blades are tabulated hereunder:

TABLE 4. Average Torque

Angle of Attack	Average Torque, τ (N-mm)	
	N = 3, d = 32.72 mm	N = 5, d = 32.72 mm
α = 18.44°	-16.6823	-27.8038
α = 18.19°	-16.6887	-27.8144
α = 17.94°	-16.8541	-28.0901

The power output of the pico hydro turbine is tabulated hereunder:

TABLE 5. Power Output

Angle of Attack	Power Output, P_T	
	N = 3	N = 5
α = 18.44°	9.1753	15.2921
α = 18.19°	9.1788	15.2979
α = 17.94°	9.2698	15.4496

V. CONCLUSION AND FUTURE SCOPE OF WORK

The single blade is put on ANSYS workbench for Computational Fluid Dynamics (CFD) analysis using FLUENT. Lifts and drag forces are found to be maximum at 18.19° angle of attack. The maximum power obtained for 3 bladed turbine rotor is 9.2698 Watts at 17.94° angle of attack. The maximum power obtained for 5 bladed turbine rotor is 15.4496 Watts at 17.94° angle of attack. Power generation and efficiency is calculated mathematically and found in accordance with the theoretical approximations. Future work includes the manufacturing and practical verification of the present work carries out in virtual software environments. This work hopes that future research can be carried out with turbulent flow.

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