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Design and Development of Miniaturized Aerofoil Profiled Vertical Axis Blades for Pico-hydro Electricity Application

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Abstract—

The water supply pipes of high-rise buildings are the potential site for pico-hydroelectric generation. 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. To examine the feasibility of using pico-hydroelectric power technology in high-rise buildings, residential power use patterns are analyzed, and individual (or family) water use surveyed. This work is to design and develop an aerofoil blade for pico-hydroelectric power generation. The object is to design a hydraulic turbine rotor blade while enforcing typical wind turbine design constraints such as tip speed ratio, solidity, and blade profile. The innovative pico turbine blades with an aerodynamic design will be develop for smaller cross-sectional area of water flow. These blades are advantageous because they are small, lightweight, and less expensive.

Keywords— Water supply pipeline, Pico-hydroelectricity, renewable energy, high rise buildings, Aerofoil design.

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.

The purpose of this study is to design blades for pico hydro power generation that are suitable for high-rise building water piping systems. The water flow of the pipe drives the rotation of the power generation blades, thus achieving power generation. The pipeline diameters of building water supply systems are typically about 4 to 6 inches, so the blades to be placed inside the pipe require extreme miniaturization; and considering the length of blades, precise calculations are required. This innovative research is an attempt to develop vertical axis type turbine blades suitable for pico-hydroelectric systems.

The urban architecture of cities of India is mainly in the form of apartment complexes and high-rise residential towers due to the demographic expansion of the cities and migration of people from small towns and villages to cities. [1] Most of the buildings possess a "potential energy", which is very suitable for the development of pico-hydroelectricity.

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*

Dilip Singh [2] in his report, resource assessment handbook of micro-hydro power in 2009, stated that the first commercial use of hydroelectric power to produce electricity was a waterwheel on the Fox River in Wisconsin in 1882. In India, the first hydroelectric power plant was set up in Darjeeling during 1897 and marked the development of hydro-power in the country.

H. Zaiduddin et al [3], 2009, designed and developed pico hydro system for energy storage using consuming water supply to residences and describes the parameters important for functioning of the pico hydro system generator. They used pelton turbine.

Vicente Leite et al [4], 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.

Kamaruzzaman Sopian et al [5], compared the two types of turbine cross flow turbine and pelton turbine and found that cross flow turbine is more suitable for low flow and low head conditions. They also did case studies in Malaysia.

Helena M. Ramos et al [6], 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 [7], 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.

Sarala P. Adhau [8], 2009, did the cost analysis of micro/pico hydro power plants with large hydro power plants and found that cost / KW of micro/pico hydro power plant is high as compared to large hydro power plants and the supply is limited to local community and suggested the new technology development for cost reduction.

R. Krishna Kumar et al [9], 2012, used Archimedes screw turbine in domestic water supply lines in Coimbatore, Tamil Nadu, India, for pico hydro power system and found that head of water and water flow rate are the main determining factors this hydro electric system. They also suggested that permanent magnet AC generator and their circuitries could improve the conversion efficiency.

The World Bank Energy Unit [10] (The World Bank Group Energy Unit, Energy, Transport and Water Department, 2006), studied recently, found pico hydro yielded the lowest generating costs amongst off-grid energy options.

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.

Punit and Franz [12], 2009, focused on the production of simply constructed microhydroelectricity equipment by proposing to optimize propeller blade design.

Yen et al. [13], 2010, invented the "Hydroelectric generator for use in a water pipe of a building". This patent sets up a guide blade wheel in a water pipe; the blade wheel direction and the water flow direction are horizontal; the rotation of the blade wheel is driven by the water flow, thereby allowing the generator to spin for power generation.

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 [14].

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% [15].

III. DESIGNING PROCEDURE

A. *Feasibility study of high-rise buildings for pico-hydroelectricity*

The feasibility study of pico hydro system in water supply pipes in high-rise buildings depends on various factors. They are:

i. Power available from the flow of water inside the pipes. This depends on the water pressure, amount of water available and friction losses in the pipelines.

ii. Type of turbine used.

A. Power available from water flow

Power available, $P_{av} = \rho g H Q$

Where, ρ = Density of water = 1000 Kg / m^3

g = Acceleration due to gravity = 9.81 m / sec2

H = Net head available = $h - h_f$

h = Overall length of pipe, m

h_f = Friction loss in pipe

Q = Water flow rate in the pipe = A x V m^3 / sec

A = Area of cross-section of pipe, m^2

V = Velocity of flow of water in pipe, m / sec

B. Considerations

Pipe Diameter, D

Assumed height of pipe, h meter = height of one floor in the building

Friction loss in pipe, h_f

Net head, $H = h - h_f$

Power available, P_{av} = 694.22 Watt

The blades of this study were miniaturized by combining the design technique with hydromechanics from aerospace research, so that the blades do not affect the flow velocity within the pipes. The rotational force generated by the blade can be transferred through the bearings to the generator rotor to generate electricity. A pico-hydroelectricity blade set is placed in the pipe and it is perpendicular to the flow direction of the pipe; the pipe size can be from 4 to 6 inches; different pipe diameters can be matched with different blade sizes. When water inside the tube flows through the pico hydro blades, the water flow action on the airfoil blades produces a surface force and a body force, which is collectively called the flowing force. Due to different flowing forces through the blade under unit time flow, the blade set produces an unbalanced stress, thereby driving the rotation of the blade set. The shaft of the rotation is connected to a generator, whereby the water energy can be converted into electric energy.

This work adopted CATIA software to build the blade model of the pico-hydroelectricity system. The model of the aforementioned construction will be helpful for the future adjustment of the geometric conditions of the blade via parameter changing methods for the purpose of optimal design; the geometric conditions include the geometry and quantity of blades, and the water flow height, etc. The design concept proposed by this research uses the principles of an airfoil blade set and fluid mechanics to absorb the energy of moving water. This design structure does not affect the velocity of the water flow in the pipes and can be applied to any water supply or drainage system, unlike the design constraints of the Francis type hydroelectric power in the past.

B. Pico hydro blade geometry

An obvious choice is the NACA 4 – series airfoil. The majority of vertical type rotors use NACA airfoil sections because they are easy to manufacture. [16] For better efficiency of turbine an airfoil shape is selected for a fixed tip speed ratio. Figure 1 shows cross-section view of NACA 4 – series airfoil blade.

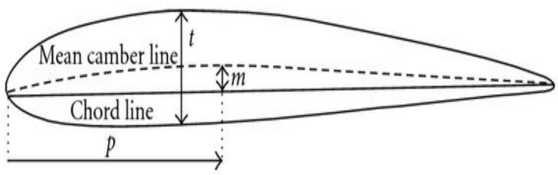

Fig. 1 NACA 4 – series airfoil

The NACA 4 – series airfoil sections have maximum thickness, t, located at 30% of the chord length. The maximum camber, m, is located at a distance p from the leading edge of the airfoil.

The values of m, p, and t are expressed as percentages of the chord length and represented the four digits defining the NACA 4 – series airfoil.

For an x – coordinate, the ordinate of the mean camber line can be expressed as

$$y_c = \begin{cases} \frac{m}{p^2}(2px - x^2) & \text{forward of maximum ordinate} \\ \frac{m}{(1-p^2)}[(1-2p)+2px-x^2] & \text{aft of maximum ordinate} \end{cases}$$

Where, m is maximum camber and p is the chord wise location of the maximum camber.

The thickness distribution can be found by the following equation

$$\pm y_t = \frac{t}{0.20}(0.29690\sqrt{x} - 0.12600x - 0.35160x^2 + 0.28430x^3 - 0.10150x^4)$$

Where, t is the maximum thickness of the airfoil located at 30% of the chord.

B.1 Blade size calculation

The rotor size, such as diameter and length is based on aspect ratio. Aspect ratio is the ratio of length to the overall diameter of the rotor. In general, aspect ratio is 3:1.

The length of rotor, l and diameter of rotor d should be in such a manner so that it can be pleased inside the pipe of nominal diameter D.

The next step is to select the operating tip speed ratio (TSR). [17]The tip speed ratio, ⍰ can be expressed as:

$$\lambda = \frac{\omega r}{V}$$

where, ω = angular speed of rotor,
r = radius of rotor, and
V = velocity of water at which a hydro-turbine will operate.

For chosen λ, a dimensionless parameter, solidity is selected to define the geometry of vertical type turbine rotor.

Solidity, $\sigma = \frac{Nc}{\pi d}$

Where, N = number of blades,
c = chord length of blade, and
d = diameter of rotor.

The chord length of blade c, will be determine with the help of solidity ratio.

$$c = \frac{\sigma \pi d}{N}$$

A baseline geometry is selected with the idea to select a typical airfoil cross-section. Therefore NACA 0030 is selected as the baseline airfoil cross-section. It is selected simply due to the fact that a number of researchers consider this geometry as good overall aerodynamic performance. Figure 2 shows the aerodynamic blade profile generated on CATIA.

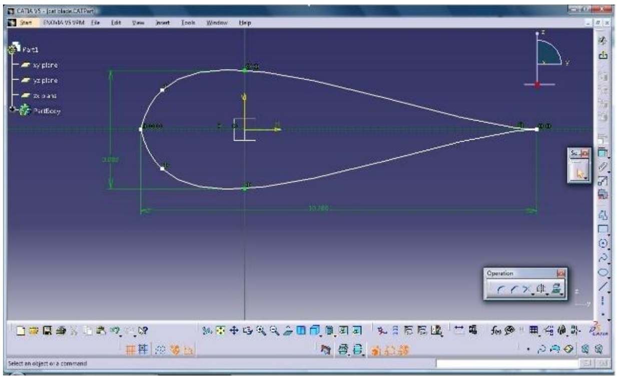

Fig. 2 Aerodynamic blade profile

IV. RESULTS

The blade design and drawings are developed on CATIA by using the values get from the relations for development of aerofoil blade profile. Blades of various sets of dimensions are developed. The biaxial support for rotor blades are developed for better support and smooth rotation inside water supply pipe.

The results showed for a single blade for rotor of pico-hydroelectric turbine. The rotors for different solidity ratio and number of blades are developed.

TABLE 1. Design results

No. of Blades	*Length of Blade, mm*	*Solidity Ratio, %*	*Chord length of blade, mm*
3	*97.15*	*30*	*10.28*
		50	*17.13*
5	*97.15*	*30*	*6.17*
		50	*10.28*

Blades profiles for various solitidy ratio, chord length and blade length are attempted to generate. It is difficult to generate the aerodynamic blade profile for small chord length such as chord length for solidity ratio 30% for 5 blades arrangement. It is difficult to achieve the desired aerodynamic profile for such a small chord length. Blade profiles for solidity ratio 30% and 50% for 3 blades arrangement and solidity ratio 50% for 5 blades arrangement are simplet to generate with desired aerodynamic profile. Solidity ratio 50% for 3 blades arrangement is also not suitable for the intended application.

Fig. 3 shows the 3D geometry of aerofoil blade. The blade profile is smoothened and fine tuned with Design Modeler Software.

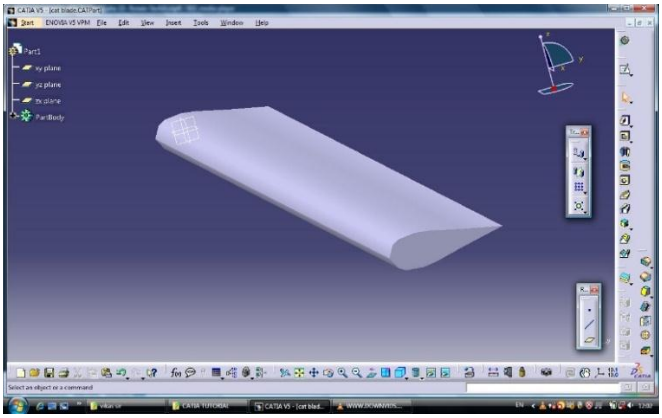

Fig. 3 3D blade profile

Figure 4 shows the two-dimensional drawing of rotor with 5 blades and solidity ratio 50%.

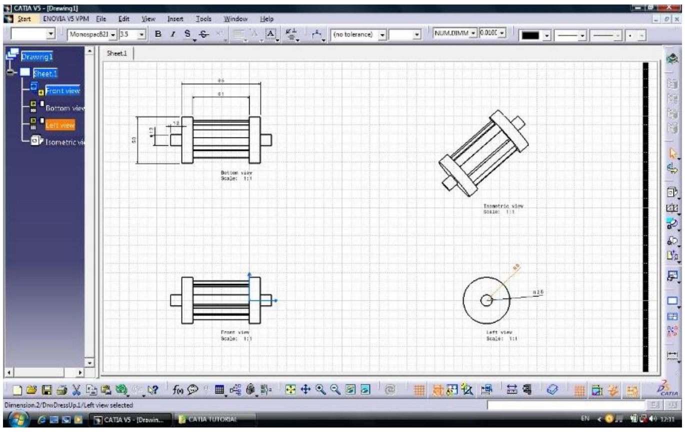

Fig. 4 2D rotor drawing

Figure 5 shows the three-dimensional generation of 5 bladed rotor with biaxial support for rotor blades.

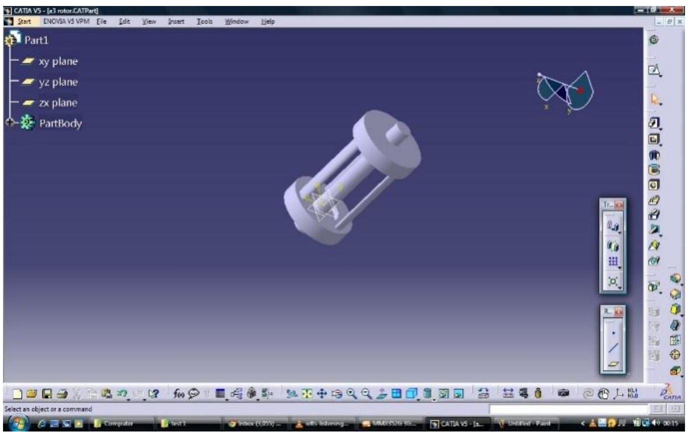

Fig. 5 3D 5 bladed rotor

Figure 6 shows the three-dimensional generation of 3 bladed rotor with biaxial support for rotor blades.

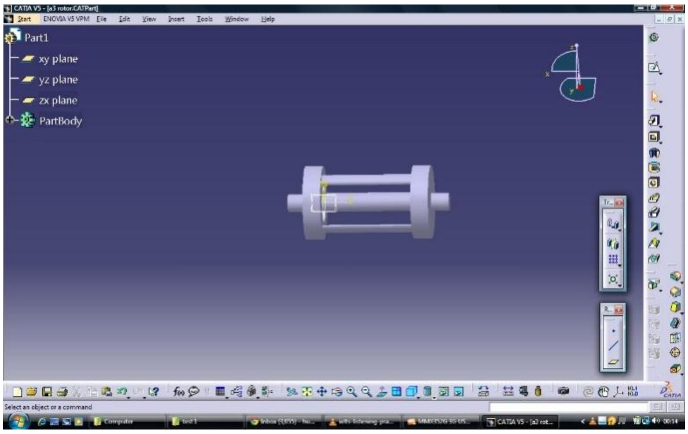

Fig. 6 3D 3 bladed rotor

V. CONCLUSION AND FUTURE SCOPE OF WORK

This work has successfully designed and developed a miniaturized form of vertical axis blades rotors suitable for pico-hydroelectricity application. The blades in this study were developed using CATIA. In future studies, we will focus on the computational fluid dynamics (CFD) analysis, comparison of different bladed rotors and the power developed from the rotors when used in connection with generators. Pico-hydroelectricity is an innovative technology that helps to promote the development and use of renewable energy and new energy, which is in line with the new concept of green energy and carbon reduction. This work hopes that future research and development can produce a pico-hydroelectricity blade set that can be applied in water supply pipes in an actual apartment complex.

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