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An Innovative Vertical Axis Current Turbine Design for Low Current Speed

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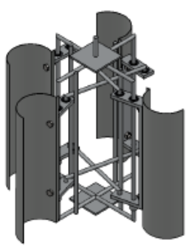
Graphical abstract



Innovative concept of vertical axis current turbine for low current speed

Abstract

This article presents the new innovative concept for optimal design of Vertical Axis Current Turbines (VACT) applicable in low current speed which is being increasingly used to harness kinetic energy of water and convert it into other useful forms of energy as a clean and renewable energy. Widespread commercial acceptability of these turbo machines depends upon their efficiency. This largely depends upon the geometric features of the hydro turbines such as operation of designed system, joints, number and shape of blades and etc. The concept of VACT was proposed to provide a solution for the case of low current force inflow to vertical axis turbines. VACT has four suitable blades with flexible hinge joint to guide the water in come to reduce the drag force, light shaft and arms with stiff metal to make rigid and strong structure. The current study discusses the components of VAC turbine, rigidity of structure, performance, executive concept, efficiency, material, gearbox, environmental impacts and prevention of water corrosion. The new proposed innovative concept of VACT has flexible hinge connection for changing the blades directions automatically to reduce hydrodynamic drag and increase the hydrodynamic pressure to rotate the main shaft and enhance the efficiency as well. Main shaft connected to epicyclical gearbox to provide the higher torque for maximum electric power generation.

Keywords: Innovative concept; vertical axis current turbines; renewable energy; low current speed

1.0 INTRODUCTION

In general, current turbines are categorized into two major types: horizontal axis type (HACT) and vertical axis type (VACT) machines (Duvoy *et al.* 2012, Khan *et al.* 2009 and Hydrovolts 2006). Particularly, the VACT is divided into three basic types: Savonius type, Darrieus eggbeater type, and Darrieus straight type. Figures 1 - 3 show the schematics of the HACT and the VACT. (Sornes 2010 and Sornes *et al.* 2012)

The growth of climate change and electrical demand as well as rising diesel fuel prices are the key subjects encouraging the use of renewable technologies. Utilization of electrical energy plays an important role in economic growth and improvement of people's living standards. An ideal energy source should be renewable and should have minimal effect on environment [Güney and Kaygusuz 2010). It has been proved that one-third of the world's population does not have access to electricity, but does have access to moving water (Bertsch 2009). Majority of rural residents are very poor, with low living standards, limited education and little access to information. Despite the efforts in remote area electrification, progress and success rates remain low. Poor planning, lack of research and negligence are some of the factors contributing to the delay of rural electrification deployment (Anyi *et al.* 2010).

The amount of electricity that can be generated from current water energy source is dependent on the volume and velocity of the water resource. It can be installed in a flow with water velocity ranging from 0.5m/s and above (Tanbhir *et al.* 2011). There are many concepts for harnessing this energy, but turbine has being the most common and proven one. Similar to wind energy converters, the total available power (Watt) captured by hydrokinetic turbine is dependent on the density, cross-sectional area, velocity cubed and turbine coefficient as shown in Equation 1.

The advantage is that the water is approximately 800 times denser than air (Maniaci and YeLi 2011). This simply implies that the amount of energy generated by a hydrokinetic turbine is much greater than that produced by a wind turbine of equal diameter under equal velocity of wind and water.

$$P_a=0.5 \times A\times\rho\times V\text{^}3\times Cp \qquad (1)$$

Where A is the turbine area (m2), ρ the water density (1000kg/m3), V the water current velocity (m/s) and C_p the turbine power coefficient or efficiency which is 16/27=0.592 (theoretical maximum power available)

2.0 HIGHLIGHTS OF VERTICAL AXIS CURRENT TURBINES

There is no consensus yet on whether horizontal-axis or vertical axis will be the best option for using current water energy.

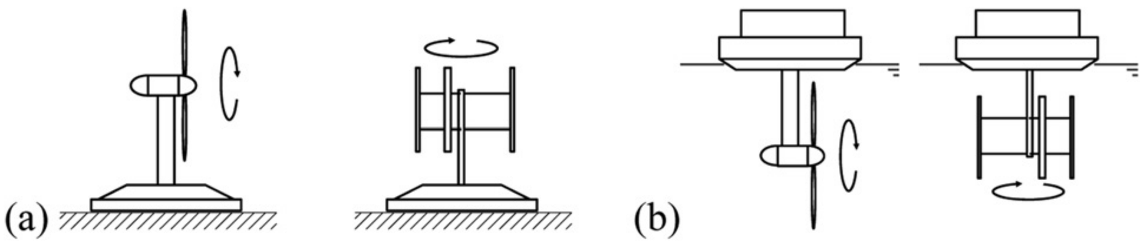


Figure 1 Water stream turbine configurations: (a) horizontal axis and vertical axis turbines placed on sea bed and (b) supported by a float.

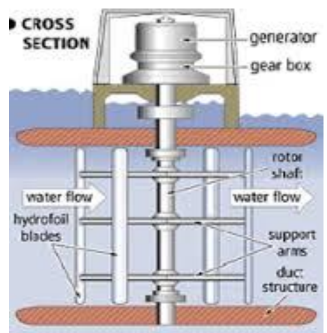


Figure 2 Water stream turbine configurations: H-Darrieus

(i) In-plane axis (ii) Squirrel cage Darrieus (iii) H-Darrieus

(iv) Darrieus (v) Gorlov (vi) Savonius

Figure 3 Vertical axis turbines

friendly purpose (Clarke *et al.* 2009) and gear less turbine for cost minimization purpose (Drouen *et al.* 2007).

While more focus has been given to the operation and maintenance issue of vertical and horizontal axis current

From time to time, researchers also proposed different designs of vertical-axis and horizontal-axis current turbines which address different issues. For examples, the various designs include: introducing duct for flow acceleration purpose (Shives and Crawford 2010), contra rotating turbine for maintenance

turbines, it is important to consider the challenges associated with increasing the efficiency and electric power generation using better design of blade's shape to reduce the negative drag force. Some more, there is restriction on the current speed in rivers and water currents to make more rotational speed in shaft. These works will become more challenging and costly when it comes to get the electric power from current turbines. To date, less focus has been given to these challenges either in industry or academia.

3.0 COMPONENTS OF SELF-MOVEMENT BLADES OF VERTICAL AXIS CURRENT TURBINE (SVACT)

Self-Rotating blades of vertical axis current turbine (SR-VACT) consists of blades with Hinge connections, Auxiliary and main shaft, fixed framing, gearbox and generator.

3.1 Blades

Blades are the most significant part of the rotor. The designing of the blade is crucial as the performance of the turbine depends upon it and among all the parts of the turbine, blades are highly exposed to water. In this section the blade position and configuration for self-movement around its axis is discussed.

The original design of the vertical axis current turbine consists of three fixed blades as commonly practiced for wind turbines. Three-bladed turbine is believed to be an optimum configuration in terms of stability and performance (Danish 2013). However, the blade number can be varied from two to ten, depending on the needs.

The hydrodynamic drag will have negative effect on rotational speed acceleration of main shaft due to reduce the positive force. In this innovative patent, the blades have self-movement around their shaft using Hinge connections, separately. While the current inflow to vertical axis turbine, make the pressure and push the face blade to rotate the main shaft. On the other hand the current make the drag in back side of blade in opposite of arm's end.

Finally, the rotational speed will be decreased due to negative drag and resistance force applied by current on the back surface of blades. For reducing the drag, it should be change the direction of blades and rotational shit the blade using hinge connections as shows in Figure 4. The rotational speed will be increased along of reduction the drag force and hydrodynamic blade's shape faced to current.

This new innovative patent has significant effect in low current force area because the electricity is generated using total pressure force to rotate the shaft in low current speeds.

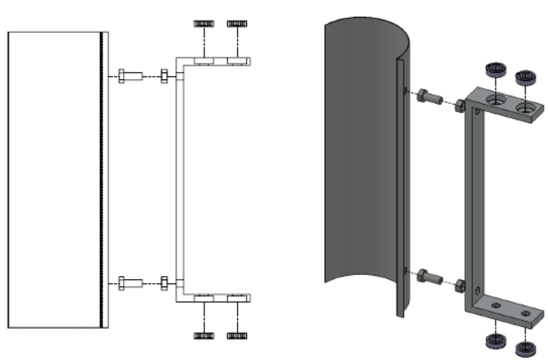


Figure 4 Self-rotating blade with hinge connections

3.2 Shaft and Arms

The main (centre) shaft connects the rotor to the gearbox in order to transfer the rotational force to generator. The shaft of vertical axis current turbine comprises of main rod connected to four arms and two bearings to rotate freely. The shaft and arms are showed in Figure 5.

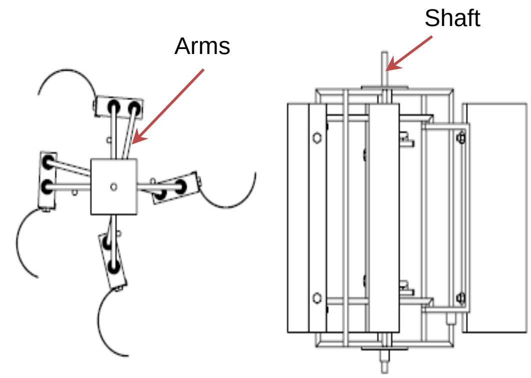


Figure 5 Schematic representations of shaft and arms in SVACT

3.3 Gearbox

The rotor transfers kinetic energy of the incoming flow to produce electric power using a generator. The turbines haft rotates at a lower speed depending upon the available water velocity and a gearbox is normally needed to speed up the rotation to intensify the electricity generation. The speed of induced flow is variable depending on the time period and gearboxes are therefore provided for the both sides of generator (Ainsworth and Thake 2006 and Mbabazi *et al*. 2005).

The gearboxes and generator form one collective unit in SR-VACT. The rotation is speeded up to a desire speed using gearbox which in turn drives the generator. The power train including gearbox and generator is enclosed in a nacelle. The proposed gearbox is a step-up epicyclical gearbox. This gearbox obtains the rotation from rotors through parallel shafts.

The increased speed results in a higher efficiency of electricity generation. Figure 6 and 7 are showed the step-up epicyclical gearbox and electricity generator package with executive dimensions, respectively.

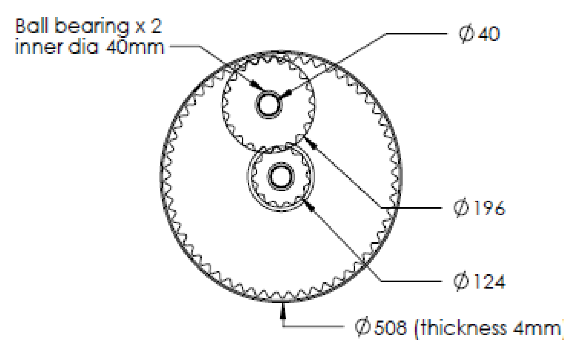


Figure 6 Scheme of epicyclical gearbox

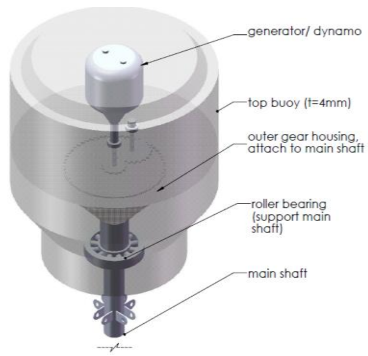


Figure 7 Electricity generator package included gearbox and bearings

3.4 Generator

Generator converts kinetic energy of currents in to electrical energy. The use of both synchronous and induction generator is equally popular. SeaGen, SeaFlow and Kinetic hydropower system current turbines used induction generator while Encurrent turbine and Cycloidal turbine used synchronous generator. Kobold and Gorlov turbines used both induction and synchronous generator. A review on the usage of generators for different turbines is discussed in (Chen *et al.* 2012). The selection of generator from all the kinds depends upon the requirement of the site and the capacity of the power harnessed. Under induction generator the use of doubly fed induction generator (DFIG) is widespread.

The reason can be attributed to the capability of DFIG to operate during severe grid faults, maintenance of constant output during fluctuating tidal flow, optimum power factor and extraction of power from both stator and rotor winding (Kyaw *et al*. 2011). However, the use of slip rings and gears are the cons of (DFIG) (Jadhav and Roy 2013).

The use of synchronous generator is more focused towards the sites with low water current velocity. The features like full speed range, possibility to avoid gearbox, brushless, no use of power inverter and complete control on reactive and active power makes PMSG a suitable choice for water current turbine. Besides, PMSG is comparatively expensive requires rare-earth magnets, full scale power converter and multi-pole generators which adds up in the cost. Furthermore, to covert the multi-frequency power generated by PMSG, power electronic units are required. The chances of failure of power electronic unit are 12.96% (failure/turbine/year) while the chances of failure of a gearbox are 5.6% (Lawson 2013). Hence for VACT, DFIG is proposed.

3.5 Material of Blades, Shaft and Rods

The material used for current turbines must be capable of working under the conditions of high pressure, abrasion caused by the sand carried by the flow, PH levels and salinity that can cause corrosion. Hence, appropriate material is required to handle such conditions and micro-biological attachments which cause sheer stress. Cavitation is the formation and immediate implosions of bubbles formed in liquid, i.e. small liquid free zones as consequences of forces acting upon the liquid.

The bubbles formed due to such changes bursts and cause cavities on the surface of turbines. Hence, it is important to prevent the turbine from cavitation (Kumar and Saini 2010). The requirement of various parts and the suitable material for them is discussed in this section.

The material which was earlier used for current turbines was stainless steel as it does not really corrode, rust or stain with water as compared to the ordinary steel. However, stainless steel is not fully stain proof most not ably under low oxygen, high salinity or poor circulation environment. This kind of environment is common under water surface where the turbine is being set up. The main advantage of using stainless steel is it has antibacterial properties.

The introduction of new alloys like high strength low alloy steel (HSLA) (Davis 2010) solved the problem of corrosion to a great extent. A type of HSLA uses Ni, Cu and Si as the alloying elements for making the main frames, main foundation, blades, arms and shaft and parts of turbine as the corrosion resistance it is two to three times greater than that of carbon steel in the splash zone of underwater structures. Hence, SR-VACT is made up of HSLA. If a large SR-VACT is used, the composite material may be useful as proposed for Sea Gen.

In the case of SR-VACT where the number of welds increases, there is a need to protect the parts from being corroded at such places. A metallurgical evaluation shows that a high strain, work hardening austenitic stainless steel produces superior resistance erosion. Cavitation occurs at various degrees in all type of fluid handling equipment. In SR-VACT, the rate of cavitation is higher as it has more space for bubble formation which causes cavitation. Cavitation causes surface penetration of up to 10mm per year to critical components like turbine blades (Liu and Veitch 2012). The severe cavitation can be avoided by the use of high carbon and cobalt base alloys. However, these types of alloys are more cracks sensitive. In case of SR-VACT, It is not recommended to use these alloys.

■4.0 PERFORMANCE AND EFFICIENCY

Design techniques of vertical axis current turbine prediction of hydrodynamic performance of the current turbines are discussed in the academic researcher's meetings is crucial to their design optimization.

Different parameters such as power and torque coefficients and hydrodynamic loads need to be determined and flow field around the rotor has to be visualized in order to carry out the performance analysis. Over the last two decades, there has been significant development of analytical, computational and experimental techniques for fluid flow analysis around a vertical axis current turbine in particular.

Efficiency is one of the most important parameters to analyse the performance of a current turbine design. Efficiency of a current turbine is expressed usually in terms of flow energy utilization factor and coefficient of power (C_p). Recently exergy efficiency (or 2nd law efficiency) has also been employed to analyze the performance of VACT.

Figure 8 shows the computational domain in Ansys-ICEM-CFD to simulate the four fixed blade vertical axis current turbine which will be improved for low current speed to increase the performance of turbine.

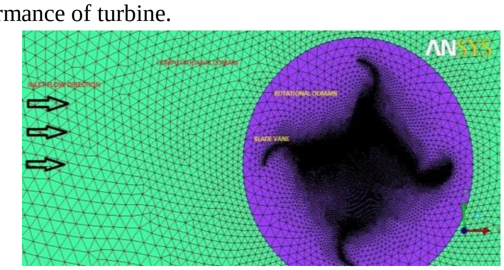


Figure 8 Computational model of fixed blade VACT

Table 1 shows the momentum coefficient (C_m), pressure coefficient (C_p) and estimation power respect to Tip Speed Ratio (TSR) of CFD simulation results for four fixed blades VACT of small model in 0.56 m/s current speed. The simulation results show that the power generated by fixed blades of VACT is 188.88 watt when the design is operating at 0.56m/s current speed.

Table 1 Estimation Power Result

TSR	C_m	C_p	P_t (watt)
0.3	0.923016	0.276905	164.4872
0.35	0.825549	0.288942	171.6377
0.45	0.679476	0.305764	181.6303
0.55	0.578124	0.317968	188.8797
0.65	0.462873	0.300867	178.7216
0.85	0.258281	0.2557	151.9134

Theoretical efficiency of SR-VACT depends upon the reduction resistance and drag force value due to self-rotating blades, gearbox types, generator, frequency convertor and transformer. Efficiency given by the aforementioned elements is mostly same for all type of turbines. For vertical axis current turbine, these can be taken as the efficiency of gearbox, generator, transformer and frequency convertor with performances of 90%, 95%, 98% and 96% respectively.

Hence, the theoretical efficiency of self-rotating vertical axis current turbine will be expected and increased due to blade's movement and arms and gearbox type as abt. 89% with multiplication of all the aforementioned values of efficiencies (Winter 2011). The experimental examination of the self-rotating blade of vertical axis current turbine was done in water canal test of civil Lab. in Universiti Teknologi Malaysia (UTM-K.L.) which is shown in Figure 9.

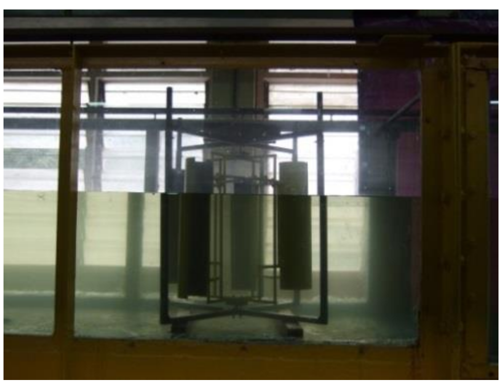


Figure 9 Self-Rotating vertical axis current turbine test in water canal of civil Lab. in UTM

■5.0 CONCLUSION

The authors proposed a new concept of vertical axis water stream turbine. In the novel concept, the turbine is applied with self-movement blades, increasing the hydrodynamic pressure loads, more efficient gearbox with suitable generator and weight. Self-Rotating Vertical Axis Current Turbine (SR-VACT) is a novel concept to decrease hydrodynamic resistance and drag force with increasing performance and efficiency and does not possess many studies in this area.

Thus, with the fabrication of SR-VACT, the other aspects including actual efficiency and rotation per minute (rpm) will become calculative. Hence, with the exact figures of these fields, SR-VACT will help to judge about the idea of energy produced by it. From the above concept and study, it is obvious that the advantages of SR-VACT are leading its loopholes.

Defects such as high cost in remote control and corrosive bearing and movement parts may be decreased through a number of trials and errors to apply the corrosion inhibiters such as grease, epoxy resin, polyurethane and acrylic resin. These may be are searchable topic of future studies since the self-movement vertical axis turbines has a bright prospect in harnessing more power as long as the defects are resolved.

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