Development of the Very Low Head Turbine for Pico and Micro Hydro Application

Abdul Muis[1 2], Priyono Sutikno[1], Aryadi Suwono[1], Firman Hartono[1]

[1]Institut Teknologi Bandung
Jalan Ganesha 10, Bandung, 40132
[2]Universitas Tadulako
Jalan Soekarno Hatta, Palu, 94224
amuis19@gmail.com

Abstract

The very low head turbine is one of the solutions to maximize the utilization of the available hydro power resourcesbecause its capability to minimize limitation of conventional hydro turbine. This turbine will gain an advantage from the very low head site of the hydro power resources (less than 4 meters head) so it is suitable for Indonesia who has a lot of rivers and existing irrigation canal. The construction of the turbine installation is simple because it does not require a complex canal to regulate the flow at the inlet and outlet of the turbine,this will minimize the investment required. This turbine is can be designed to be a compact turbine to simplify installation and also environmentally friendly on its operation.

To design this VLH turbine will be used commercial softwareAutodesk inventor in developing the three-dimension model of turbine and CFD AnsysFluent for simulation and design validation. Guide vane and rotor blade geometry will be generated from the airfoil design.Computer code XFoil to be used in the selection of the airfoil to reach the maximum advantage from the flow characteristics of selected airfoil. The Quasi three-dimensional (Q3D) analysiswill be applied to generate blade models. Designed turbine efficiency is expected to have a maximum efficiency in the range of 90%.

Keywords: Very low head, Ansys, Airfoil, quasi three-dimensional, blade**.**

Introduction

Indonesia is one of the tropical countries with a lot of water sources and potential of hydro power such as oceans, lakes and rivers. Particularly rivers, the water flows down the height until the sea has an enormous energy potential. The theoretical potential power derived from the difference in the height (head) and the volume of water flow. However, not all of the rivers have flow areas with extreme height difference, and if there were, normally is located in a mountainous area which is sometimes quite distant and difficult, also the construction of dam or reservoir that required for hydropower generation which would require a also result in high investment costs required [1].

The very low had (VLH) turbine is a type of turbine that can be the solution to the above mentioned constraints. This type of turbine can be operated at very low head (less than 4 meters). Construction required for turbine installation is quite simple because it does not require a complex water canal for the flow regulation. This Turbine also can take an advantage from an existing of large investment.

To maximize the utilization of the potential energy of the water flow, application of turbine that can generate energy from low head is required. Due to the low of head, this type of turbine will be dominant utilize the volume of flow to generate power. The types of turbines are widely used for this purpose is the Kaplan and Bulb turbine that can be operated on the head with a range between 2 to 40 meters. However, this type of turbine installation requires a fairly complex canal construction to regulate the flow of water before and out of turbine in order to achieve maximum turbine efficiency. For that, of course, will

irrigation channels and therefore can be made in the form of compact turbine; it has a high flexibility in installation. Application of this type of turbine will maximize the utilization of the potential of the renewable energy.

Turbine Power

Because the utilized head is sufficiently low, then the resulting power turbine of this type will be significantly affected by the flow rate through it. In the following chart is illustrated the utilization of potential energy by VLH turbine when compared to other turbine types.

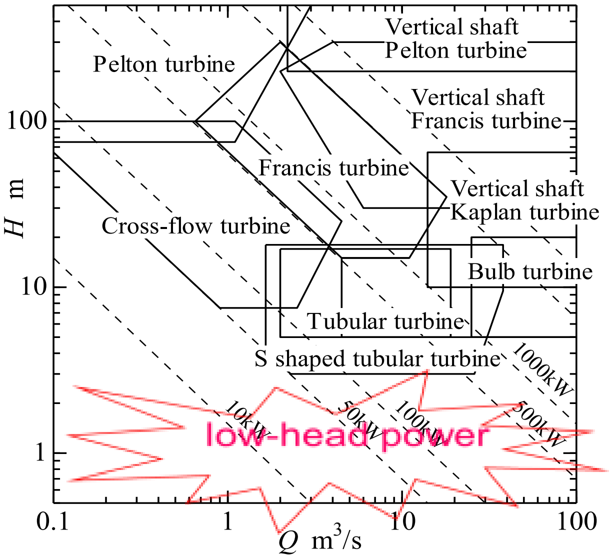

Figure 1. Selection chart of hydro turbine [2]

The potential energy of water source P_w, may be described by the following equation:

$$P_w = \rho g Q H$$

Where ρ is the water density, g is the acceleration of gravity, Q is the water flow rate and H is the potential head of site. To produce a high power, this type of turbines also requires a high flowrate of water.

To generate the potential energy of hydro power, turbine runner blades are made to be able to absorb and changes the potential energy to the maximum level of power (high efficiency). Designing of guide vane and runner blades on the base of flow conditions is very important. For this purpose, the geometry of the blades will adopt an airfoil shape with certain characteristics to gain the maximum efficiency of designed turbine.

Particularly for runner, there are two main forces of the water acting on the runner blades and greatly affect the efficiency or power result, the lift and drag force. Both can be written mathematically in equation below.

$$L = C_L.\rho.\frac{v_\infty^2}{2}\, l.dr$$

$$D = C_D.\rho.\frac{v_\infty^2}{2}\, l.dr$$

The force acting on blade in the rotational direction F_u,

$$F_u = F.\cos\left(\frac{\pi}{2} - \beta_\infty + \lambda\right) = F.\sin(\beta_\infty - \lambda)$$

$$F = \frac{L}{\cos\lambda} = C_L \frac{\rho.v_\infty^2}{2.cos\lambda}\, l.dr$$

The energy produces by designed turbineP_D,

$$P_D = F.u = C_L \frac{\rho.v_\infty^2}{2.cos\lambda}.sin(\beta_\infty - \lambda).u.dr$$

Where L and D is the lift and drag force, C_L and C_D is the lift and drag coefficient, ρ is the water density,v_∞ is the velocity of water enters the blade, l is the chord length of blade, and r is the blade radius.

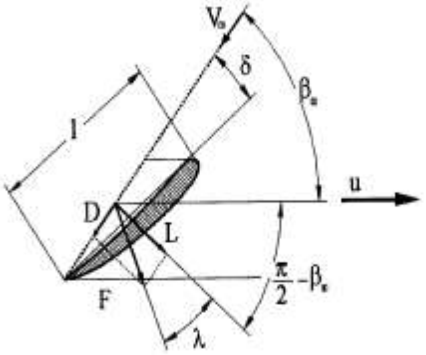

Figure 2. Vector components of forces acting on a runner blade

Power of turbine generated by the CFD simulations can be written

$$P_{turbine} = T_{tot}.\omega$$

And the turbine efficiency, η_T is

$$\eta_T = \frac{P_{turbine}}{P_{water}}$$

Where T_{tot} is the total torsion generated by turbine and ω is the angular velocity of turbine.

Turbine Model

VLH turbine designed for the purpose of this paper is expected to operate at 0.3 meters head with a mass flow rate of 0.55m^3/s or 549kg/s. Base on the calculations, designed turbine will operate at rotation 180rpm, with a blade diameter of 0.6 meter and 0.2 meter diameter hub. Number of rotor blade is 4 and the guide vane is 24 blades.

Turbine modeling starts from modeling of guide and rotor blade. The resulting blade shape was developed from the airfoil profile. Selection of the airfoil profile using of the free computer code XFoil developed by Mark Drela [3]. Information obtained about the airfoil characteristics are used to determine the blade geometry that can provide maximum benefit in generates energy from the water flow inside the turbine. Airfoil profile which is used for guide vane is Naca0012 and Gottingen480 for rotor blade.

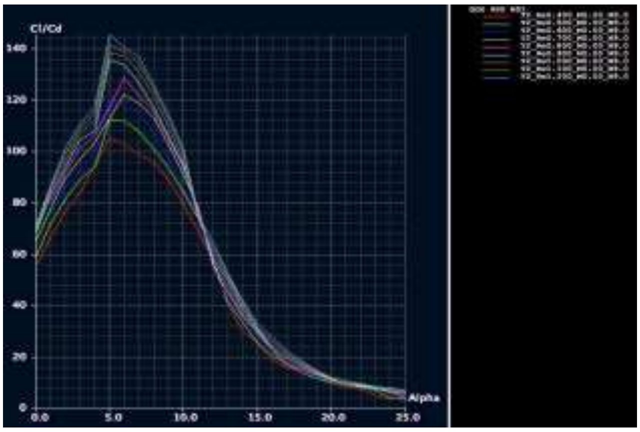

Figure 3. Xfoil results, rasio lift and drag coefficients of Goettingen0480 at various of angle of attack and Reynolds number

Analysis quasi three-dimensional (Q3D)was applied to develop the airfoil profile which is used to form the turbine blade geometry [8]. The forced vortex swirl velocity criterion has been used for this purpose [4][7]. The blade geometry is formed from 11 airfoil profile section, but only 3 sections are shown here, section hub, mid and tip to show the differences between them. Models created with the help of Autodesk Inventor.

Table 1 Parameters of guide vane and rotor blade geometry

Section	Hub	Mean	Tip
Swirl velocity, $c_\theta (m/s)$	0.2342	0.4685	0.7027
Meridional velocity(m/s)	2.2629	2.1888	2.0599
Guide Vane			
Inlet angle, β_1 (°)	0	0	0
Outlet angle, β_2 (°)	84.09	77.92	71.16
Chamber Angle, θ (°)	5.91	12.08	18.84
Tip and chord ratio, t/l	0.333	0.667	1
Chord length, $l(m)$	0.080	0.080	0.080
Number of blade, z	24	24	24
Rotor Blade			
Inlet angle, β_3 (°)	84.09	77.92	71.16
Blade angle, $\beta_\Phi - \delta$ (°)	48.01	27.77	17.23
Tip and chord ratio, t/l	0.961	0.961	0.961
Chord length, $l(m)$	0.167	0.335	0.502
Number of blade, z	4	4	4

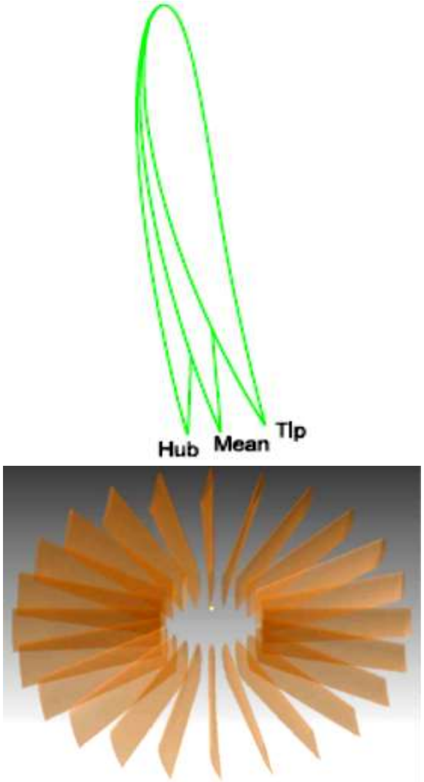

Figure 4. Guide vane development

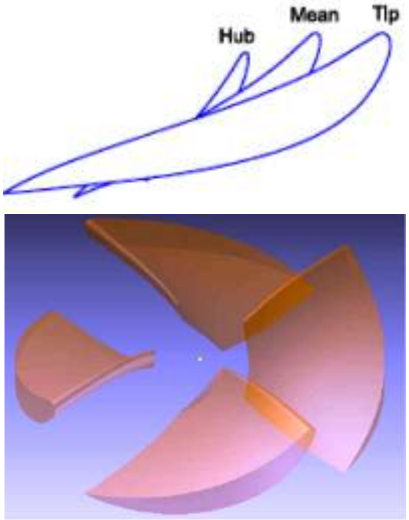

Figure 5. Rotor blade development

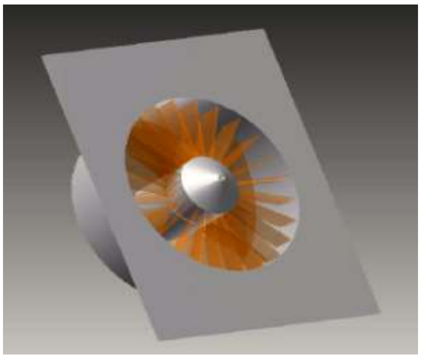

Figure 6. Final design of VLH turbine

Turbine Installation

Turbine model has been designed to be placedin the canal with slopeof 45 degrees position.The author believes this position will provide an advantage in exploiting the potential energy in the flowing water inside the canal [6].

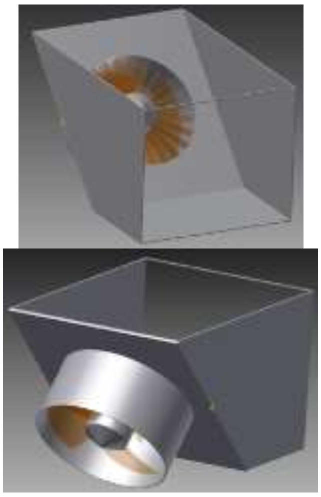

Figure 7. Turbine in position

Meshing and CFD Simulation

For simulation, meshing of model is divided in three sections, and detail as shown in table 1. To validate and study the performance of the turbine, CFD simulations are performed using Ansys Fluent. The analysis type of 3D and viscous model kω-SST models [5][7]. For set of boundary conditions mass flowrate was specified at the inlet and pressure outlet at was specified at the outlet.

Table 2 Mesh of components of turbine models

Component	No. of Node	No. of Elements	Type of Elements
Inlet and guide vane	346,677	1,626,504	Tet/Hybrid
Turbine rotor	251,306	1,174,813	Tet/Hybrid
Outlet	58,438	281,449	Tet/Hybrid

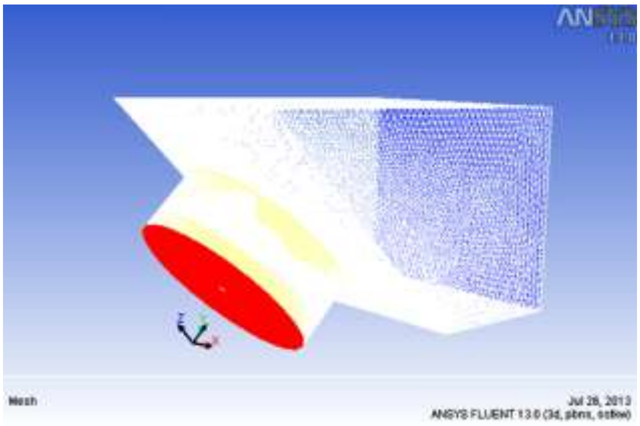

Figure 8. Mesh of turbine installation

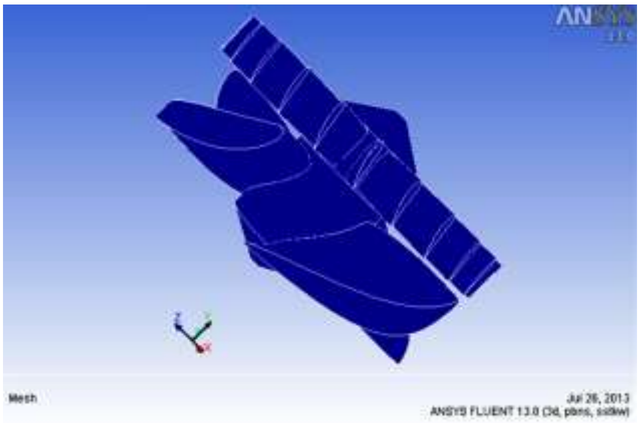

Figure 9. Mesh of guide vane & rotor

Simulation Results

CFD simulation results are shown in figure 10 through to 20. Figure 10 is showing a streamlined fluid passing through the turbine installation. Static pressure distributions are shown in Figure 11, a significant pressure drop occurs in the area of blade runner and its outlet. Minimum and maximum static pressure occurs around blade runner, the maximum pressure is dominant in the area of the leading edge of the blade, and distributed on the pressure side of the blade area through to the runner hub (figure 12). On the suction side of blade runner, the minimum static pressure is shown on the area adjacent to the leading edge (figure 13). Minimum and maximum static pressure (gauge pressure) that occurs in the turbine is -946 Pa and 31278 Pa respectively at the operation pressure 101325 Pa. This indicates that the possibilities of cavitation occurrence inside the turbines are not visible because the minimum absolute static pressure is 100379 Pa, it is still above of the vapor pressure of fluid/water at 30ºC; 4195 Pa.

Figure 14 shows the distribution of the fluid velocities at the turbine installation, where the increasing speed of the fluid will begin at the mouth of the turbine due to changes in geometry. The speed will be growing faster in the runner blade area to the turbine outlet. On the rotor blade, the velocity distribution appears to be increasing linearly from hub to tip (figure 15). This happens on both of the pressure and suction side.

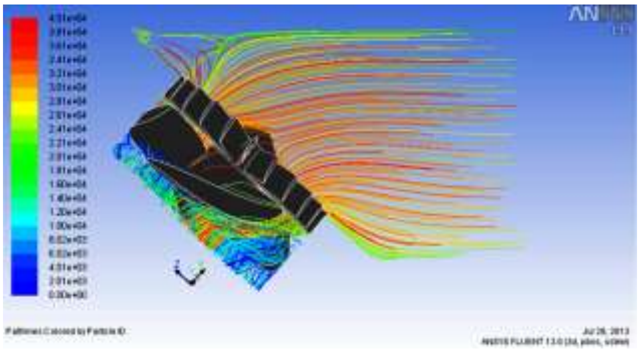

Figure 10. Streamline of fluid flow pass guide vane and

blade runner at 549 kg/s and 180 rpm

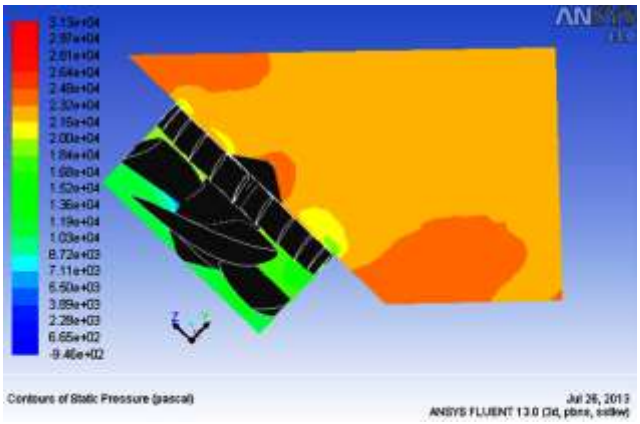

Figure 11. Static pressure distribution along y-axis at 549 kg/s and 180 rpm

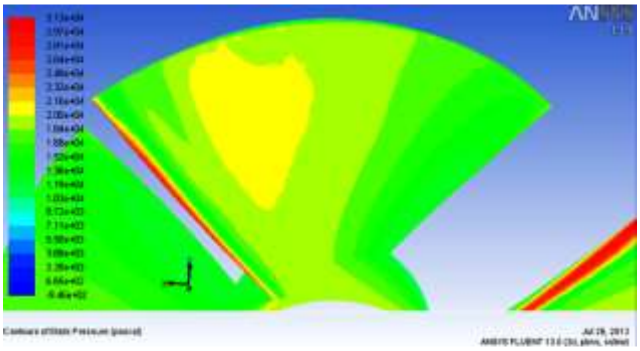

Figure 12. Static pressure distribution on pressure side of rotor blade at 549 kg/s and 180 rpm

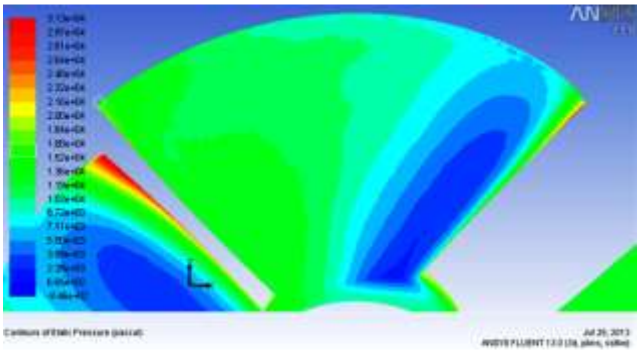

Figure 13. Static pressure distribution on suction side of rotor blade at 549 kg/s and 180 rpm

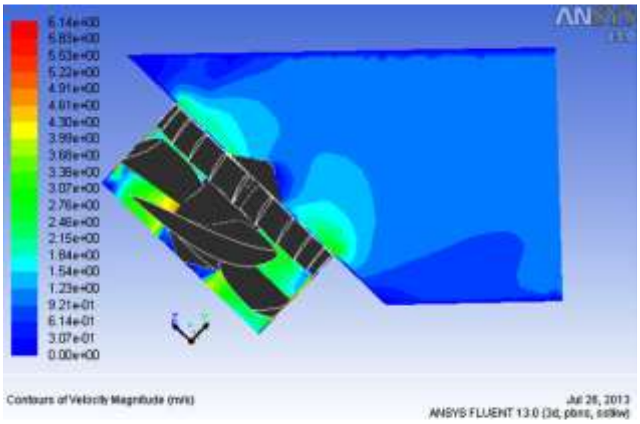

Figure 14. Velocity distribution along y-axis at 549 kg/s and 180 rpm

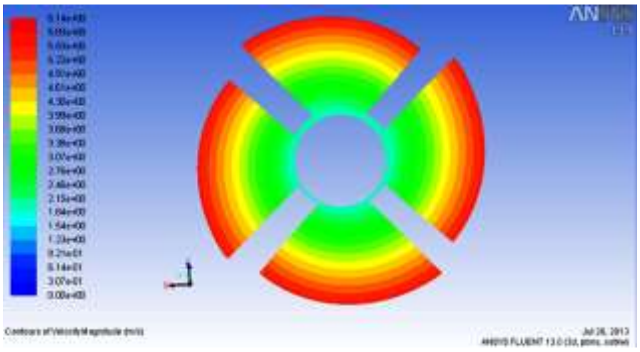

Figure 15. Velocity distribution on pressure side of rotor at 549 kg/s and 180 rpm

Efficiency results are shown on figure 16 and 17. Maximum efficiency obtained on various rotation speeds (30 rpmthrough to 300 rpm)and variation of mass flow rates(415 kg/s, 549 kg/s, 667 kg/s& 711 kg/s) has reached around 90%. For the designed operating conditions with flow rate 549 kg/s at 180 rpm turbine rotation, the efficiency achieved is 90.71% which is the maximum efficiency for this flow rate at 0.53 meters head. Power generated by the turbine reaches 2595.5 W. Power results at various of flowrates and angular velocitiesare shown on figure 18 and 19.Power generated by turbine increases linearly with the increasing of the mass flow rate.The total head produced will vary due to the mass flow rate and turbine rotation is shown in figure 20.

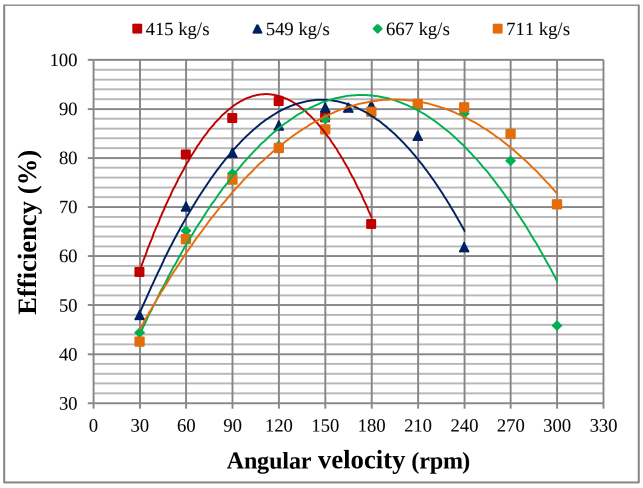

Figure 16. Efficiency results at various of mass flow rate

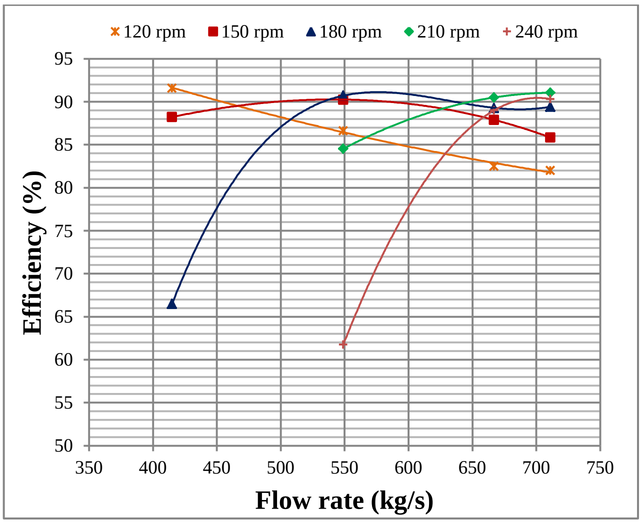

Figure 17. Efficiency results at various of angular velocity

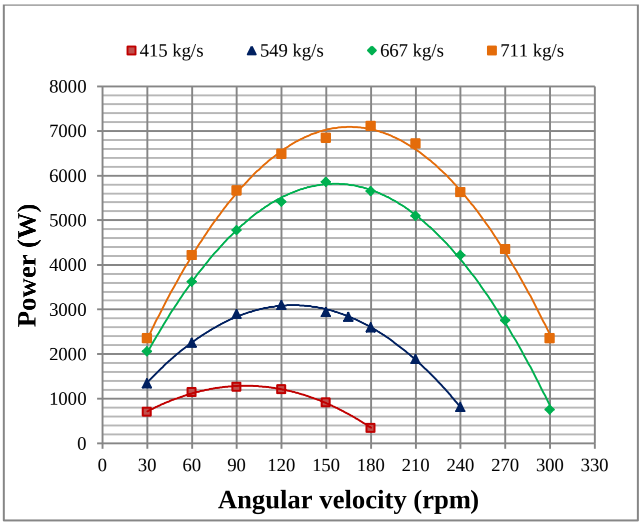

Figure 18. Power results at various of mass flow rate

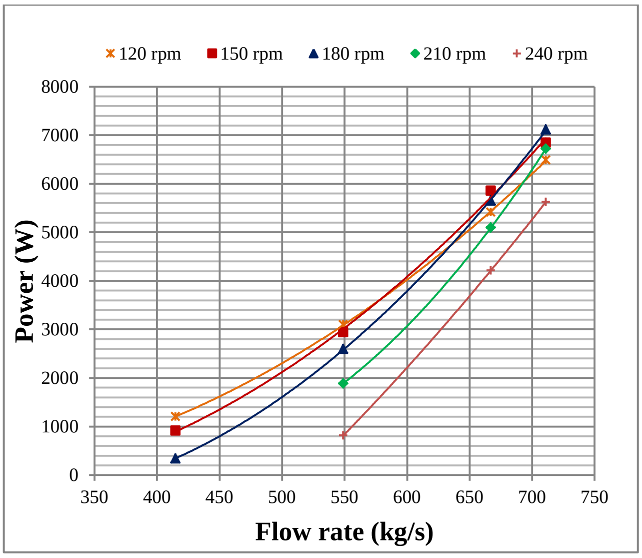

Figure 19. Power results at various of angular velocity

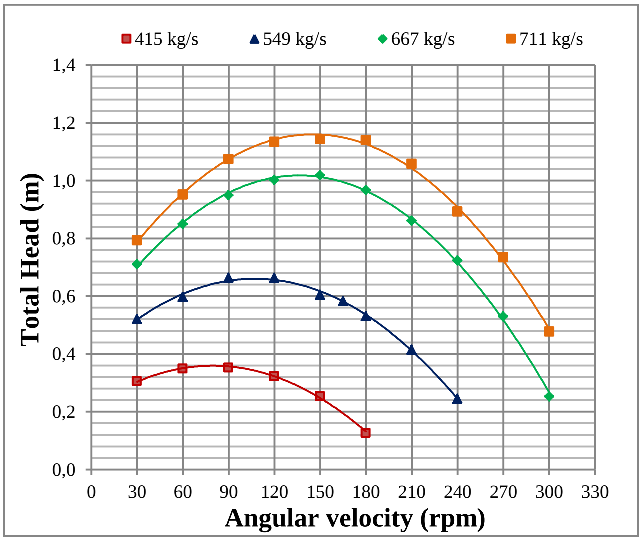

Figure 20. Total head results at various of mass flow rate

Conclusion and Future Works

The simulation results show that the designed turbine has satisfied the expected efficiency 90% and applies to various levels of flow rate at various turbine rotations. The turbine will be well suited to exploit the potential of hydro power from the very low head sources. By developing this type of turbine, Indonesia will be able to take advantages from the enormous flowing water sources and could be one of the solutions in providing the electricity, especially in remote urban areas.

Airfoil shape study including optimization to designing foil for this turbine is a very important step towards the development of an efficient and reliable turbine.The experimental study will be conducted to determine the performance of the turbine under real conditions.

Acknowledgements

The author would like to express special thanks to BPPS Dikti for financial support and ITB for a chance to study and research.

Nomenclature

ρ	Fluid density [kg/m^3]
g	Gravity acceleration [kg/s^2]
Q	Water flow rate [m^3/s]
H	Head[m]
c_x	Meridional velocity [m/s]
c_θ	Swirl velocity [m/s]
C_L	Lift coefficient
C_D	Drag coefficient
L	Lift force [N]
D	Drag force [N]
P_W	Power of water [W]
P_T	Power of turbine [W]

References

[1]Leclerc, M., The very low head turbo generator; A new Turbine for profitable harnessing of very low head applications, www.vlh-turbine.com.

[2] Furukawa, A., Research & Development of Darrieus type Hydro Turbine for Extra-Low-Head Hydro Power Utilization, Kyushu University.

[3] Drela, M., XFOIL; An Analysis and Design System for Low Reynolds Number Airfoils, MIT Dept. of Aeronautics and Astronautics. 1989.

[4] Lewis, R. I., Turbomachinery Performance Analysis, Elsevier Science and Tecnology Books, 1996.

[5] Mamun, M., The Study on the Hysteretic Characteristics of the Wells Turbine in a Deep Stall Condition, Ph. D. Thesis, Department of Energy and Material Science Graduate School of Science and Engineering, Saga University, Japan, 2006.

[6] Priyono S. Ibrahim K.A., Design, Simulation and Experimental with Free Vortex and Minimum Pressure Criterions of the Turbine for Low Head, The 12th Asian International Conference on Fluid Machinery (AICFM12), 2013.

[7] Abdul Muis, Piyono S., Ariyadi S., Firman H., Design and Simulation of Very Low Head Axial Hydraulic Turbine with Variation of Swirl Velocity Criterion, The 12th Asian International Conference on Fluid Machinery (AICFM12), 2013.

[8] Wu C., A General Theory of Three-Dimensional Flow in Subsonic and Supersonic Turbomachines of Axial, Radial and Mixed Flow Types, NACA Technical Note 2604, 1952.