Experimental Study of Hydrokinetic Power Generation System Integration – Straight Blade Cascaded (SBC) Vertical Axis Darrieus Turbine

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Abstract. The utilization of hydrokinetic energy as renewable energy is an effort in meeting the increasing demand for energy. The development of vertical axis hydrokinetic turbine - straight blade cascaded (VAHT-SBC) at previous research has successfully extract energy with high-performance coefficients. However, the developed VAHT-SBC has not yet been integrated with generators as a power system generator. This research was conducted experimentally on an open channel, including an integrated system designed using VAHT-SBC and Permanent Magnet Synchronous Generator (PMSG) with a belt-pulley mechanism. The result shows the proportional relation of generator rotational speed to voltage and frequency. On the contrary, the generated voltage experience drop due to the loading in the integration system. The value of the voltage and frequency of inverter is not affected by rotational speed and load. The resulting inverter voltage has a value of 230 V and a frequency of 56 Hz. The installation of the integration system on hydrokinetic turbines prototype with the current velocity of 0.82 m s^{-1} and 0.92 m s^{-1} could produce 50 W of power.

Keywords: Hydrokinetic energy conversion, integration system, load, rotational speed, voltage.

1 Introduction

Hydrokinetic energy has become one of the renewable energies which extract kinetic energy from the water current. The hydrokinetic turbine is one of the hydrokinetic utilization [1], which is adapted from wind turbines due to its similar mechanism in power generation [2]. This technology could operate at low freestream velocity and is independent of the incoming flow direction. There are two types of hydrokinetic turbine based on its axis, i.e., Horizontal Axis Turbine and Vertical Axis Turbine [3]. The use of Vertical Axis Hydrokinetic Turbine [VAHT] with the Straight Blade Cascaded (SBC) mechanism can produce efficiency of 0.42 [4] due to its unique configuration of blades

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using both fixed and passive pitch mechanism [5]. The self-starting mechanism has the best performance at the angle of attack of -10 <α <10.

In order to further develop the potential of VAHT-SBC then it is important to develop its energy conversion system. One component of the system is a generator that is needed to produce electricity [6]. This study designed an integration system of turbines and generators as a technology for implementing hydrokinetic energy conversion. The integration system studied uses mechanical transmission of belt and pulley types as a connector of VAHT-SBC with Permanent Magnet Synchronous Generator (PMSG). PMSG is chosen because it can be used in renewable energy, such as wind turbines [7–9]. Tests were carried out experimentally by utilizing an open channel as the primary energy source. Aspects that will be examined in this integration system are the influence of voltage and frequency on rotational speed and loading, as well as loading on the performance of VATH-SBC. This research is expected to strengthen the hydrokinetic energy conversion system as a commercial hydrokinetic power generation technology.

2 Design and configuration

This configuration is an effort to support the realization of the integration system in the hydrokinetic turbine as a hydrokinetic energy conversion system. In this study, an open channel in Umbulan PDAM with different speed variations is used.

2.1 Design of hydrokinetic turbine

Based on its rotor axis, hydrokinetic turbines can be divided into the vertical axis, horizontal axis, and crossflow turbine. In the process of optimizing the design of the turbine, several aspects need to be taken into accounts, such as blade design, number of blades, determination of pitch angle, and shaft design. The turbine type used in this system is a vertical axis hydrokinetic turbine with a straight blade cascaded (VAHT-SBC) because this has a fairly good performance coefficient [4]. Blade configuration of this turbine consists of nine blades, which are six fixed-pitch blades and three passive-pitches blades. Figure 1 shows the hydrokinetic turbine used in this research; the yellow blades have a fixed-pitch mechanism while the greens use a passive-pitch mechanism. The passive pitch mechanism on the turbine's outer blade has an attack angle of -10 <α <10; this mechanism has the good self-starting ability [5].

Fig 1. Design of VAHT-SBC

The dimension of VAHT-SBC is designed with an aspect ratio of 1:8, with chord and span length respectively are 10 cm and 80 cm, using NACA 0018 as hydrofoil profile. The detailed design of the hydrofoil and the whole turbine are presented in Figure 2 and Figure 3.

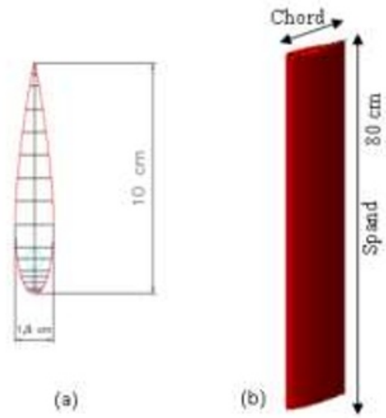

Fig 2. Coordinate profile of NACA 0018 hydrofoil (a) top view; (b) three dimensional view

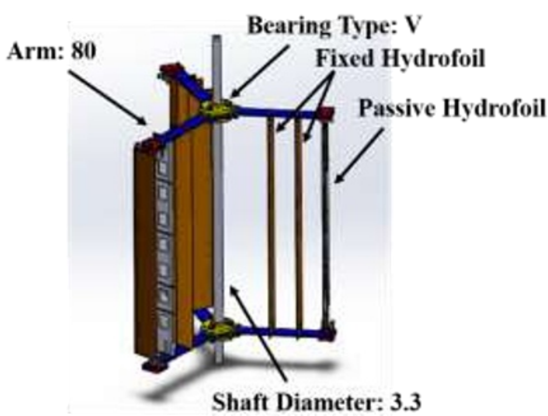

Fig 3. Prototype of VAHT-SBC

2.2 Configuration of the power conversion system

The power conversion system in hydrokinetic energy is an important element because it determines the power which can be produced. As a way to convert the kinetic energy in the turbine into electrical energy, a conversion system will need a generator. Since a high-performance generator is a priority in this system, then a generator type of Permanent Magnet Synchronous Generator (PMSG) is used. This type has an excellent performance on a variable-speed generation, including high efficiency and high controllability for an electricity generation system [10].

A three-phase generator is used in this system, with AC voltage as its output. The capacity of the generator used needs to be above the power generated by the turbine. In this energy conversion process, the voltage of the generator will be converted by the regulator

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before it goes to the inverter fully utilized in a network. As for the power conversion system block, which is used in this integration system is shown in Figure 4.

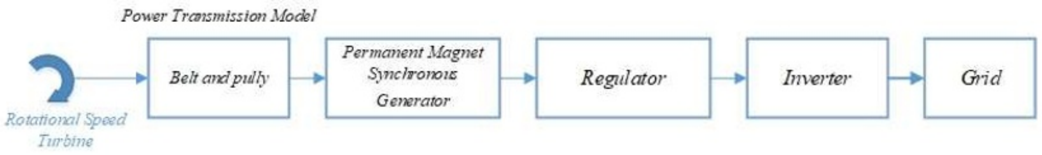


Fig 4. Power conversion block system

2.3 Integration of hydrokinetic power generation system

The hydrokinetic turbine is the main source to propel the generator. The kinetic energy produced by the turbine is then converted into mechanic energy, which is needed by the generator. Therefor a transmission system in between those processes is essential to enhance the number of rotation and maintain the torque. Hence this system uses a belt and pulley type as its transmission system, with three variations of pulley diameter. The variations are 1:3, 1:4, and 1:5, with a bigger diameter installed on the turbine shaft. The reasoning behind this variation selection is the fact that the generator voltage output which is received by inverter has a rotational speed above 150 rpm. The system integration of this mechanism is presented in Figure 5.

Fig 5. Pulley mechanism in system integration

3 Experimental setup and system integration

The turbine performance in this research is tested in an open channel with various numbers of freestream velocity, which are 0.74 m s^{-1}, 0.82 m s^{-1}, and 0.92 m s^{-1}. Variables measured by this experiment are turbine torque and turbine rotational speed at each site. Instruments used in the measurement process are tachometer and torque wrench. Figure 6 shows the hydrokinetic power generation system generation experiment conducted at site B.

Fig 6. Experiment hydrokinetic power generation system integration in site B

The power produced by the hydrokinetic turbine can be determined using equation 1[11].

$$P_w = \frac{1}{2}\rho A v^3 \quad (1)$$

Additionally, the free stream velocity affects the rotational speed and torques of the turbine.

Then those two variables will affect the performance of generators. This research will further analyze the relation between generator rotational speed to voltage and frequency. On the other hand, the loading variation effect to the voltage and frequency of generator and inverter is a vital aspect to be studied. The voltage and frequency output of the generator and inverter are measured using a multimeter. On the generator, the measured voltage is the line to line voltage on each R, S, and T line. Meanwhile, the rotational speed produced by the generator is measured using a tachometer. The loading on this system is in the form of a varies the number of lamps.

4 Result and discussion

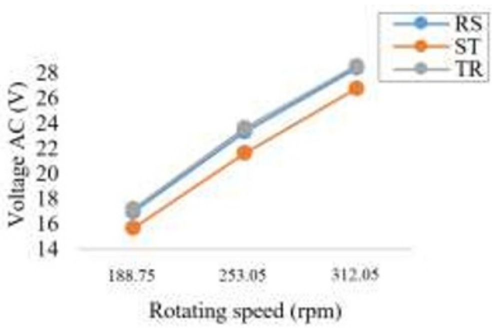
The highest power potential generated by the hydrokinetic turbine is found on-site C with 782.4 W. This power is obtained through equation one where A is the area of the turbine. The results of each site show that the higher the freestream velocity, the greater the power generated. In addition to the geometry of the turbine, this condition shows that hydrokinetic turbine power also depends on natural conditions.

The experiment result shows that the highest power extracted by the hydrokinetic turbine is 174 W. This is obtained by multiplying the torque value with the turbine rotational speed. The increment of freestream velocity is linear with the value of torque. In terms of turbine efficiency, the value is inversely proportional to turbine power. This efficiency value is obtained through a comparison between turbine power and potential water power. Vertical axis hydrokinetic turbine - straight blade cascaded used is capable of producing efficiency of 37.9 % at site C. Table 1 presents the complete result of the experimental tests.

Table 1. Turbine Power

Site	Rotating Speed (rpm)	Torsi (N.m)	Power Turbine (watt)
Site A	61.736	23.923	154.58
Site B	63.156	25.154	166.28
Site C	63.772	26.077	174.06

Furthermore, the experiment on the integration system is a way to ensure that the turbine can be implemented on a real application. The turbine is installed with a generator using a belt and pulley as its transmission mechanism. There are several kinds of pulley ratios such as 1:3; 1:4; and 1:5. The power generated by the pulley mechanism 1:3 on-site A is 40 W, and it is 50 W on site B and C. While the pulley ratio of 1:4 and 1:5 respectively generate 25 W and 35 Won all sites. The sites generate different power due to the inverse correlation between pulley ratio and torque. The power capacity of the integration system is gained by utilizing 1:3 transmission mechanism, which is presented in Figure 7.



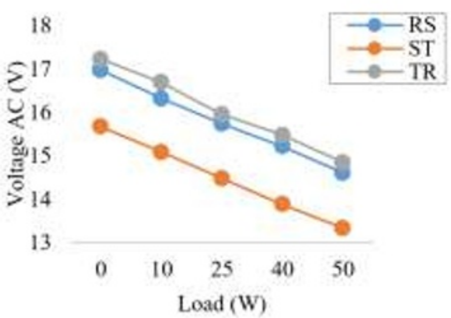


Fig 7. Voltage due to variations of rotational speed and load with pulley ratio of 1:3 in site C

The voltage and frequency of generator is linear with the increment of rotational speed. Figure 7 shows that the highest rotational speed has the highest voltage. On the contrary, voltage and frequency are inversely proportional to the increment of load. As a result of the load of higher power then the lower the voltage of the generator and the higher the current, which needs to be applied to the load.

In the topic of inverter and regulator, its voltage and frequency are independent of the rotational speed and load. The inverter receives the 14.5 Vdc voltage input from the regulator, which the voltage can be stably maintained on 230 Vac and 56 Hz. In this integration system, the highest power is generated in the freestream velocity of 0.82 m s^{-1} and 0.92 m s^{-1} with pulley ratio of 1:3, which can generate power of 50 W.

5 Conclusion

The installation of an integrated system of the hydrokinetic turbine is one of the technologies which must be considered in hydrokinetic power generation. The experiment result shows that the turbine with a transmission system using a pulley with a ratio of 1:3 can produce the most significant power because the torque value is inversely proportional to the resulting rotational speed. The increment of rotational speed leads to the increment of the generator voltage. Conversely, the load decrease the voltage of the generator. Hydrokinetic power generation can be an option in meeting the energy demand. Evidently, at speeds of 0.82 and 0.92 m s^{-1} vertical axis hydrokinetic turbine - straight blade cascaded is capable of producing 50 W of power.

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References

1. M.S. Güney, K. Kaygusuz, Renewable and Sustainable Energy Reviews, **14**,9:2996–3004(2010). https://www.sciencedirect.com/science/article/abs/pii/S1364032110001632
2. Z. Hu, X. Du, Renewable Energy, **48**:251–262(2012). https://www.sciencedirect.com/science/article/abs/pii/S0960148112003151
3. M.J. Khan, G. Bhuyan, M.T. Iqbal, J.E. Quaicoe, Applied Energy, **86**,10:1823–1835(2009). https://www.sciencedirect.com/science/article/abs/pii/S0306261909000713
4. R. Hantoro, E. Septyaningrum, Journal of Engineering and Technological Sciences, **50**,1:73–86(2018). http://journals.itb.ac.id/index.php/jets/article/view/5519
5. R. Hantoro, I.K.A.P. Utama, A. Sulisetyono, J. Eng. Technol. Sciences. **43**,1:27–40(2011). http://journals.itb.ac.id/index.php/jets/article/view/141
6. A.R. Tiwari, A.J. Shewale, A.R. Gagangras, N.M. Lokhande, MJRET, **1**,2:129–135(2014). http://www.mjret.in/V1I2/M5-1-2-7-2014.pdf
7. M. Yin, G. Li, M. Zhou, C. Zhao, Modeling of the Wind Turbine with a Permanent Magnet Synchronous Generator for Integration, 2007 IEEE Power Engineering Society General Meeting, (Tampa, FL, 2007), pp. 1–6. https://ieeexplore.ieee.org/document/4275748
8. M.S. Camara, M.B. Camara, B. Dakyo, H. Gualous, Permanent Magnet Synchronous Generators for offshore wind energy system linked to grid-modeling and control strategies, *2014 16th International Power Electronics and Motion Control Conference and Exposition*, (Antalya, Tukey, 2014), pp. 114–118. https://ieeexplore.ieee.org/document/6980620
9. S.M. Tripathi, A.N. Tiwari, D. Singh, Renewable and Sustainable Energy Reviews, **51**:1288–1305(2015). https://www.sciencedirect.com/science/article/abs/pii/S1364032115006322
10. J.J.A. Lopes, J.R.P. Vaz, A.L.A. Mesquita, A.L.A. Mesquita, C.J.C. Blanco, Energy Procedia, **75**:271–276(2015). https://www.sciencedirect.com/science/article/pii/S1876610215011029
11. R.A. Kishore, T. Coudron, S. Priya, Journal of Wind Engineering and Industrial Aerodynamics, **116**:21–31(2013). https://www.sciencedirect.com/science/article/pii/S0167610513000366