Turbine Slope Testing in Microhydro Plants as a Regional Electricity Source near River Flows that are not Reachable by PLN

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Abstract: Electrical energy has become the main need of society. PLN manages the supply of electrical energy in Indonesia as the State Electricity Company. The problem is that not all areas of Indonesia are covered by the PLN electricity network. Various energy sources can be converted into electrical energy in remote areas not yet reached by the PLN network. One example of this energy source is micro hydro energy, energy from river flows that are not too strong. The equipment for converting micro hydro energy into electrical energy is called *Microhydro Power Plant* (MHPP). This research is part of the application of MHPP based on Archimedes screw turbines as a source of electricity for areas near river flows that are not yet accessible to river flows. The focus of the research is to study the effect of the turbine elevation angle on the output electrical power of the MHPP. This research aims to determine the optimum values of rotation, torque, voltage, current and electrical power produced by an Archimedes screw turbine MHPP design with variations in turbine elevation angles of 20°, 25°, 30°, 35° and 40°. The MHPP design studied consists of 3 blades, a gearbox ratio of 2.8:1, a water flow rate of 6.34 liters/second, and a low rpm BLDC generator type. The optimum rotation is 1001.38 rpm at an elevation angle of 35° and the optimum torque is 1,738 Nm at an elevation angle of 40°. The optimum voltage is 14.84 V, the optimum current is 0.670 A, and the optimum electrical power is 7.861 W at an inclination angle of 40°.

Keywords: River flow; Microhydro energy; MHPP; Archimedes screw turbine; Turbine elevation angle.

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I. INTRODUCTION

Energy needs are currently very important and continue to be utilized. Its use can be said to be quite broad and covers various aspects such as primary energy sources (including petroleum, coal, and natural gas), electricity generation, transportation, industry, households. This causes the need for new and renewable energy as an alternative solution for providing energy on a regular and sustainable basis. One of the energy potentials that is safe, does not damage the environment, makes good use of renewable energy processes, and is practical is hydroelectric power generation. By considering aspects such as the demand for low-cost electrical energy and the specific characteristics of the type of generator, other generators are more feasible to meet electricity needs in remote areas. The plant is known as the *Microhydro Power Plant* (MHPP). MHPP is a type of small to medium scale power plant that uses hydropower to produce electricity. Technically, microhydro consists of three main components, namely water as an energy source, turbine and generator. Apart from these three main components, there are several microhydro units and components including dams, rapid pipes, turbine houses, calming channels, open channels, and cable networks on turbine generators and house cable installations [1].

An Archimedes screw turbine consists of a helical surface surrounding a central cylindrical shaft inside a hollow tube. When used as a pump, the screw is rotated manually or using a generator. When the axis rotates, the lower end rolls up the volume of water. The water flows into the spiral tube until the water flows out the top. The open trough and overall design of the screw allow debris to pass without obstruction [2]. This Archimedes screw turbine is very suitable for use at low heads or where the elevation difference between upstream and downstream is low or even zero [3].

Sukamta's research results explain that the shape of the screw design can influence the performance of the turbine screw, such as the number of angles, angle distance, and tilt. And from testing it was found that the rotation increased with an increase in the height of the turbine screw inclination [4]. The research results of Saroinsong Tineke et al stated that the design or model and manufacture of the Archimedes screw turbine was made using plexiglass material with a geometric shape of three corners, a thread angle of 30°, several turns of 21, a radius ratio of 0.54 with a range of 2.4 Ro [5]. Rahmawaty et al have researched the effect of elevation angle on the rotation, current, and voltage produced by the turbine [6].

Nasrul Ma'ali succeeded in designing the MHPP building to obtain optimal discharge, power, and energy. The MHPP

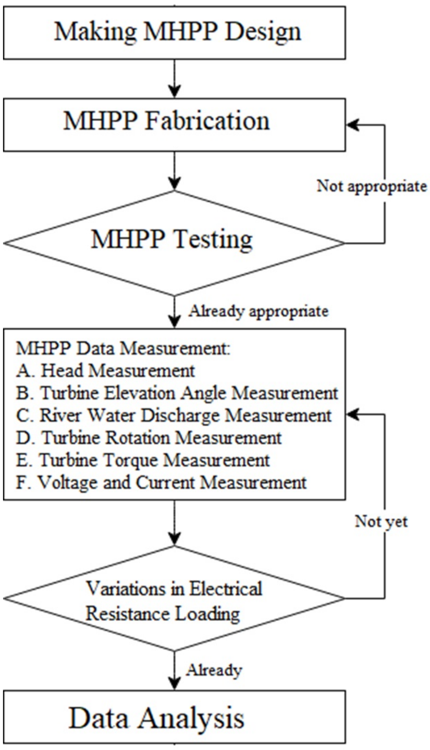

FIG. 1: Research Flow Chart.

design was carried out by redesigning the old MHPP so that it could accommodate the current discharge. This research contributes to knowledge about the influence of MHPP discharge, head, and power parameters [7]. Widnyana Putra et al succeeded in creating an easy way to test the parameters that influence the performance of the Archimedes screw turbine. One of these parameters is water pressure [8]. Indarto *et al.* has researched the MHPP design based on Archimedes Screw Turbines to obtain the optimum elevatin angle of the turbine. MHPP uses a 2 blade turbine with variations in the elevatin angle of the turbine [9].

This research was conducted to test the performance of an MHPP design based on an Archimedes Screw Turbine which will be used as a source of electricity in rural areas near rivers and not yet reached by the PLN network. MHPP testing is only based on variations in turbine elevation angle parameters. The characteristics of the MHPP studied are turbine rotation, torque on the turbine, electric voltage, electric current, and electric power on the generator. The research aims to see the effect of variations in turbine elevation angle on turbine rotation, torque on the turbine, electric voltage, electric current, and electric power on the generator. The novelty of this research is the use of research data for the application of micro-hydro generator technology in rural areas that are not yet covered by the PLN network.

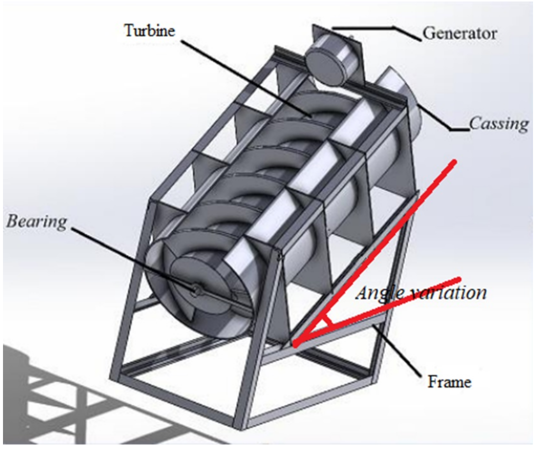

FIG. 2: MHPP Design.

II. METHODOLOGY

Fig. 1 is a flow diagram of the stages of the research process. The MHPP design is made by field measurement parameters. The tool design was created with SolidWorks software. The tool design sketch is shown in Fig. 2.

Testing of the tool system is carried out at this stage. Then proceed with testing the tool system to see whether the tool is running properly with the power generation system or not. The systems tested include turbine performance, generator transmission systems, and generator use. This test is carried out to assess whether the designed system can work and run well.

A. MHPP Data Measurement

The data measured in this research are turbine rotation, torque on the turbine, electric voltage, and electric current produced by the generator.

1. Head Measurement
   Measuring the height of the waterfall (head) is carried out using a spirit-level hose and a roll meter. The hose is used to determine a straight line reference on the weir and the roll meter is used to measure the height of the waterfall.

2. Turbine Elevation Angle Measurement
   Measurement of the turbine elevation angle (elevation) using a spirit level and woolen thread or meter. The hose is used to determine a reference or straight line reference for the turbine angle when installed. After the straight line reference is obtained, the wool thread is installed straight according to the angle being tested. The angles used are 20°, 25°, 30°, 35°, and 40°.

3. River Water Discharge Measurement
   Water discharge measurements were carried out using a 100-liter drum and a stopwatch as a time recorder. The drum used is marked inside using a marker. Then the

FIG. 3: Archimedes Screw Turbine MHPP Fabrication Results.

FIG. 4: Archimedes Screw Turbine MHPP Fabrication Results.

water flows into the drum at the same time as the time counting begins with a stopwatch. Counting time with a stopwatch is stopped when the water reaches the limit mark on the drum. Time data and water volume are obtained which are then used to calculate water discharge.

4. Rotation Measurement in Turbines
   Turbine rotation measurements are carried out using a digital tachometer. In this tool, there is a sensor that is used to read the rpm value of the generator and turbine rotation. Readings are taken by turning on the sensor and pointing it at the object to be measured [10, 11].

5. Turbine Torque Measurement
   Turbine torque measurements are carried out using grain scales. Scales are hung as brakes on the turbine shaft. The grain scale functions as a brake on the turbine shaft. When water flows into the turbine, the turbine rotates until it stops due to braking by the drag force. The product of the radius and the pulling force is the torque value produced by the turbine [10, 11].

6. Measurement of Electric Voltage and Electric Current
   Voltage and current measurements are carried out using a multimeter. Generators used in alternating current (AC) research. Therefore, the voltage and current produced are AC. For measurements, it is necessary to convert to direct current (DC). Electrical conversion is carried out by adding a rectifier circuit after the generator consisting of diodes, capacitor resistors, or other loading components [10, 11].

B. Data Analysis

The data that has been obtained from measurements is the size of the turbine rotation, torque on the turbine, electric voltage, and electric current at turbine elevation angles of 20°, 25°, 30°, 35°, and 40°. These data are then processed to determine the effect of the turbine elevation angle on the MHPP characteristics of the Archimedes screw turbine. From the results of data processing, it is hoped that we can obtain the elevation angle of the turbine that can produce optimum values of turbine rotation, turbine torque, electric voltage, electric current, and generator electric power.

III. RESULTS AND DISCUSSION

A. Making Archimedes Screw Turbine MHPP Design

Based on the MHPP design that has been carried out and referring to the calculations carried out by Rorres [12], the Archimedes screw turbine MHPP is then fabricated. The fabrication results are shown in Fig. 3.

Fig. 3 shows the entire components of the MHPP Archimedes screw turbine with the main parts of the device namely the screw turbine, turbine housing frame, and turbine casing, penstock pipe, gearbox. Figure 4 shows the fabrication results of the Archimedes screw turbine according to the design that has been made.

Fig. 4 shows the Archimedes screw turbine used in this research with specifications, namely the distance between the blades is 25.67 cm, the outer diameter (Do) is 23.90 cm, the inner diameter (Di) is 14.02 cm, and the turbine shaft length is 51.34 cm. The results of making the turbine casing components, the screw turbine, and the frame housing the screw turbine are shown in Fig. 5.

Fig. 5 shows the three components, namely the casing, screw turbine and turbine housing frame. The turbine casing is half cylindrical and made of plastic with a length of 100 cm and a diameter of 26 cm. The frame for the turbine uses angle iron with a length of 100 cm, width of 30 cm and height of 30 cm.

B. Mechanical Characteristics Measurement Results

The results of turbine rotation measurements measured for each variation of 20°, 25°, 30°, 35°, and 40° tilt angles are presented in the graph in Fig. 6. The largest turbine rotation value was obtained at an angle of 35°, namely 1001.38 rpm,

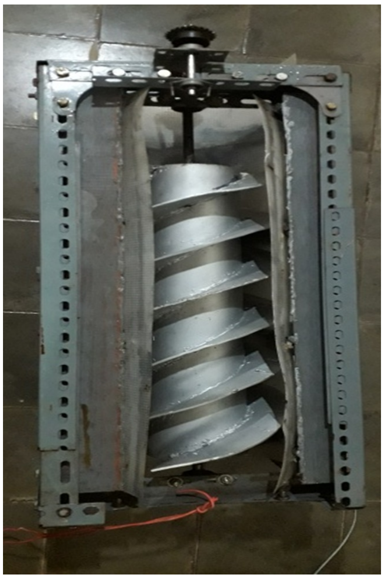

FIG. 5: Turbine Casing and Frame Manufacturing Results.

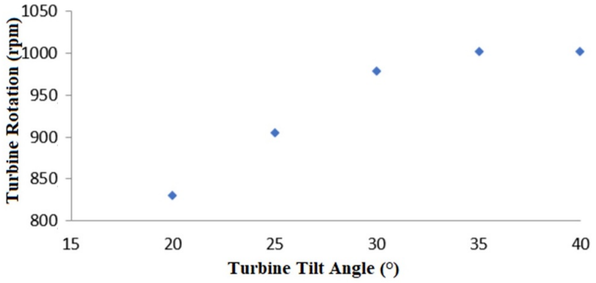

FIG. 6: Graph of Turbine Rotation vs Tilt Angle.

and the smallest turbine rotation value was obtained at an angle of 20°, namely 830.95 rpm. Fig. 6 shows that at a turbine tilt angle of 35° the highest rotation of the turbine is obtained. With an inclination angle of 30° downwards, the resulting turbine rotation is quite low and at an inclination angle of 40° there is also a slight decrease in turbine rotation. The greater the tilt angle of the turbine used, the higher the turbine rotation produced. The amount of water used greatly influences the resulting turbine rotor rotation. Apart from that, the position of the water falling on the turbine wall also affects the resulting rotor rotation. At turbine tilt angles of 30°, 25°, and 20°, the resulting turbine rotation is lower. At an inclination angle of 30° the turbine rotation produces 979.449 rpm, at an angle of 25° the turbine rotation produces 906.032 rpm, and at an inclination angle of 20° it produces 830.95 rpm.

The torque measurement results are presented in graphical form in Fig. 7 with variations in turbine tilt angles of 20°, 25°, 30°, 35°, and 40°. A turbine tilt angle of 40° produces the highest torque of 1,738 Nm and a turbine tilt angle of 20° produces the lowest torque of 1,537 Nm.

Fig. 7 shows that the greater the tilt angle of the turbine used, the greater the torque produced. The greater the head (height of the falling water), the greater the hydraulic force, which affects the torque value. The head (height of the falling water) is influenced by the tilt angle of the turbine used.

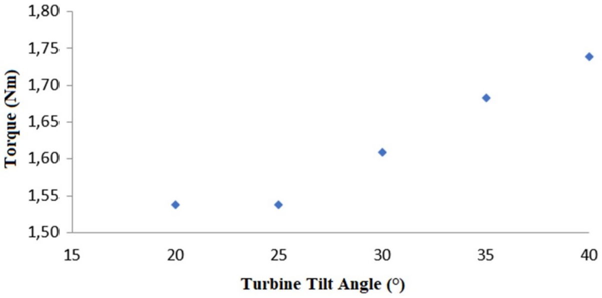

FIG. 7: Graph of Torque vs Tilt Angle.

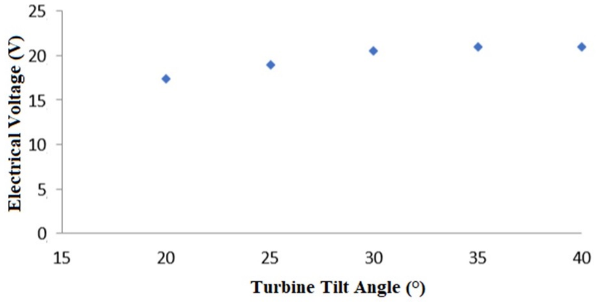

FIG. 8: Graph of Electric Voltage vs Tilt Angle.

C. Electrical Characteristics Measurement Results

The results of measuring electric voltage and electric current at each variation of turbine tilt angle are presented in graphical form in Fig. 8. The results obtained show that the largest electric voltage value of 21.01 V is produced at a turbine tilt angle of 35°.

Fig. 8 shows that the electric voltage value at each variation in tilt angle increases. The largest electric voltage of 21.01 V is produced at a turbine tilt angle of 35° and the smallest electric voltage of 17.43 V is produced at a turbine tilt angle of 20°.

The value of the voltage and current of a power source is also influenced by the value of the electrical resistance of the circuit connected to the power source. The value of the electrical resistance of this circuit is called the loading resistance. Data on the value of electric voltage and electric current at each load resistance are presented in graphical form in Fig. 9. The largest electric current value of 0.670 A was obtained at a turbine tilt angle of 40° with a load resistance of 3.25 kΩ and the smallest electric current of 0.251 A was obtained at a turbine tilt angle of 20° with a load resistance of 10 kΩ. The largest electric voltage value of 14.84 V was obtained at a turbine tilt angle of 40° with a load resistance of 10 kΩ and the smallest electric voltage value of 10.262 V was obtained at a turbine tilt angle of 20° with a load resistance of 3.25 kΩ. Graphs of the results of measuring electric voltage and elec-

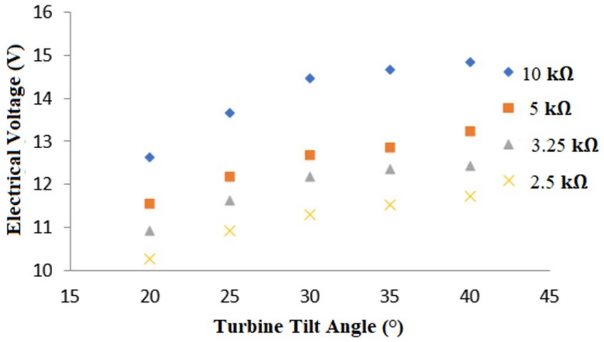

FIG. 9: Graph of Electric Voltage vs Tilt Angle for each Load Resistance.

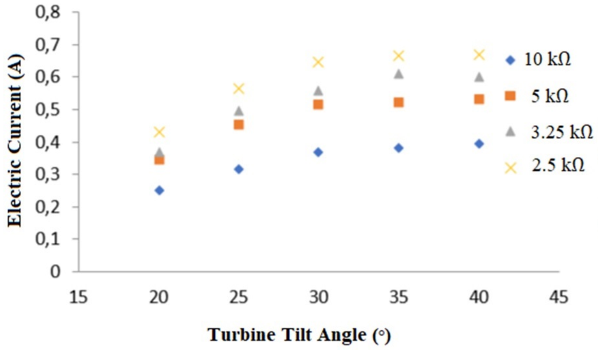

FIG. 10: Graph of Electric Current vs Tilt Angle for each Load Resistance.

tric current at each variation of turbine tilt angle with electrical load resistance are shown in Fig. 9 and Fig. 10.

Fig. 9 and Fig. 10 show the relationship between electric voltage and electric current and the angle of inclination for each electrical load resistance used. Figure 9 shows that the greater the electrical load resistance provided, the greater the electrical voltage produced. On the other hand, Fig. 10 shows that the greater the electrical load resistance provided, the smaller the electric current produced.

The generator's electrical power is obtained from the product of the electric voltage and electric current at each variation in turbine tilt angle and each variation in electrical load resistance, namely 10 kΩ, 5 kΩ, 3.25 kΩ, and 2.5 kΩ. The largest electrical power value of 7,861 W is produced by an angle of 40° with a load resistance of 2.5 kΩ. The graph of the calculation results for each variation of slope angle is shown in Fig. 11. Based on the graph in Fig. 11, the electric power curve increases with decreasing electrical load resistance from 10 kΩ to 2.5 kΩ. This shows that the smaller the electrical load resistance used, the greater the electrical power produced.

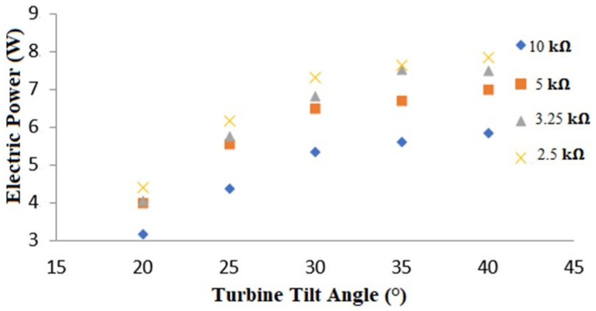

FIG. 11: Graph of Electric Power vs Tilt Angle for each Load Resistance.

D. Discussion

The angle variations used in this research are 20°, 25°, 30°, 35° and 40° with the main aim of obtaining maximum values of torque, rpm, voltage, current, and power from variations in the tilt angle of the turbine. The research results show that the tilt angle of the turbine influences the volume of water in the space between the two blades. Based on the measurement data, it was found that a turbine tilt angle of 40° produces the greatest value in turbine rotation, torque, electric voltage, electric current, and electric power compared to other turbine tilt angles. The turbine tilt angle of 35° produces the largest value in turbine rotation and electrical voltage. In general, the greater the tilt angle of the turbine, the greater the turbine rotation produced. This can be caused by the large flow of water passing through the turbine and the position of the water falling on the turbine wall.

The efficiency of a microhydro power plant can be obtained from a comparison of the generator output power with the water hydraulic power. It was found that the efficiency of microhydro power plants is influenced by water discharge and turbine tilt angle. The generator output electrical power is influenced by the electric voltage and electric current produced by the microhydro power plant [13]. Meanwhile, the hydraulic force is influenced by the height of the falling water (head). The height of the water fall (head) is influenced by the tilt angle of the turbine. Hydraulic power can be measured from the torque and turbine rotation values. This means that if the torque and turbine rotation are large, then the generator output power is also large. The highest efficiency of 21% was obtained at turbine tilt angles of 35° and 40°.

The results of this research can be compared with the results of previous research on small-sized micro-hydro generators (laboratory scale size) with variations in turbine tilt angles of 20°, 25°, 30°, 35°, and 40°. From the results of previous research, it was found that turbine rotation, torque, electric voltage, electric current, and the maximum electric power occur at a turbine tilt angle of 30° [9]. This means that changing the size of a microhydro generator from a laboratory trial scale to a field implementation scale will produce characteristics that are not the same. Therefore, measurements of the characteristics of micro-hydro power plants that will be used as a source of electricity for areas near river flows that are not yet reached by the PLN network must still be carried out. Measuring these characteristics is important to ensure the suitability of the plant before being used as a source of electricity in the area.

Regarding the turbine tilt angle that produces maximum characteristics, the results of this research can be compared with the theoretical results of Muller and Senior's research. Muller and Senior have formulated a simple theory that can be used to calculate the effect of the number of blades on turbine efficiency. Muller and Senior's research results show that increasing the number of turbine blades can increase turbine efficiency [14]. Next, Delinger et al experimented to measure the effect of the number of turbine blades on the efficiency of an Archimedes screw turbine. Delinger et al examined the relationship between the number of turbine blades and the tilt angle of the turbine that produces maximum characteristics. Dellinger's research results show that using more blades can reduce the inclination angle of the turbine thereby providing maximum performance. This is because increasing the number of blades on the turbine will maximize the flow of water hitting the turbine [15].

IV. CONCLUSION

The results of measurements for testing the feasibility of micro-hydro power plants as a source of electricity in rural areas near river flows with variations in turbine tilt angle parameters showed that the optimal turbine tilt angles were 35° and 40°. The largest turbine rotation of 1001.38 rpm occurs at a turbine tilt angle of 35° and the largest torque of 1.738 Nm occurs at a turbine tilt angle of 40°. The largest unimpeded electrical voltage of 21.01 V occurs at a turbine tilt angle of 35°. The greatest value was obtained for the electric voltage and electric current with load resistance at a turbine tilt angle of 40°, namely 14.84 V with a load resistance of 10 kΩ and 0.670 A with a load resistance of 2.5 kΩ. The largest electric power of 7.861 W occurs at a turbine tilt angle of 40°.

Acknowledgments

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[1] H.Y.S.H. Nugroho, and M.K. Sallata, "PLTMH (Pembangkit Listrik Tenaga Mikro Hidro) Panduan Lengkap Membuat Sumber Energi Terbarukan Secara Swadaya,"' CV Andi Offset, Yogyakarta, 2015.

[2] K.J. Songin, "Experimental Analysis of Archimedes Screw Turbines," Thesis Master of Applied Sciences in Engineering, University of Guelph, 2017, https://atrium.lib.uoguelph.ca/server/api/core/bitstreams/-be85-4c92-a0b0-e6986dc5da55/content

[3] A.T. Saputra, A.I. Weking, and I.W. Artawijaya, "Eksperimental Pengaruh Variasi Sudut Ulir Pada Turbin Ulir (Archimedean Screw) Pusat Pembangkit Listrik Tenaga Mikro Hidro Dengan Head Rendah," Majalah Ilmiah Teknologi Elektro, vol. 18 (1), pp. 83-90, 2019, https://ojs.unud.ac.id/index.php/jte/article/view/45313

[4] S. Sukamta, and A. Kusmantoro, "Perencanaan Pembangkit Listrik Tenaga Mikro Hidro (PLTMH) Jantur Tabalas Kalimantan Timur," Jurnal Teknik Elektro, vol. 5, no. 2, p. 58-63, 2013, https://journal.unnes.ac.id/nju/index.php/jte/article/view/3555

[5] T. Saroinsong, A. Thomas, and A.N. Mekel, "Desain dan Pembuatan Turbin Ulir Archimedes untuk Pembangkit Listrik Tenaga Mikrohidro," Prosiding Sentrinov (Seminar Nasional Terapan Riset Inovatif), vol. 3, no. 1, p. 159-169, 2017, http://proceeding.sentrinov.org/index.php/sentrinov/article/view/283

[6] R. Rahmawaty, S. Suherman, S. Dharma, and A. Sai'in, "Kajian Eksperimental pada Turbin Screw Archimedes Skala Kecil," Jurnal Rekayasa Mesin, vol. 17 (1), p. 95-102, 2022, https://jurnal.polines.ac.id/index.php/rekayasa/article/view/3065

[7] N. Maali, "Perencanaan Pembangkit Listrik Tenaga Mikro Hidro (PLTMH) Kepung Kabupaten Kediri," Tugas Akhir Terapan, Program Studi Diploma Tiga Teknik Sipil, Institut Teknologi Sepuluh Nopember, 2017, https://repository.its.ac.id/47366/1/3112030121-Non-Degree.pdf

[8] I.G.W. Putra, A.I. Weking, and L. Jasa, "Analisa Pengaruh Tekanan Air Terhadap Kinerja PLTMH dengan Menggunakan Turbin Archimedes Screw," Majalah Ilmiah Teknologi Elektro, vol. 17, no. 3, p. 385, 2019, https://doi.org/10.24843/mite.2018.v17i03.p13

[9] B. Indarto, A.M.K. Putra, and M.A. Bustomi, "Analysis of the Characteristics of the Archimedes Screw Turbine Micro-hydro Power Plant with Variation of Turbine Elevation Angle," Jurnal Fisika dan Aplikasinya, vol. 17, no. 2, p. 56-61, 2021, https://iptek.its.ac.id/index.php/jfa/article/view/17%282%2905

[10] B. Indarto, D.A. Ramazhoni, and M.A. Bustomi, "Characteristics Analysis of Archimedes Screw Turbine Micro Hydro Power Plants with Variations in Water Discharge," Proceedings of the SNF 2020, Surabaya Indonesia, 17 Oktober 2023, J. Phys.: Conf. Ser., https://iopscience.iop.org/article/10.1088/1742-6596/1805/1/012029

[11] B. Indarto, B. Yusuf, and M.A. Bustomi, "Characteristics of Archimedes Screw Turbine Microhydro Power Plant in Various Gearboxes," Proceedings of the 2nd International Symposium On Physics And Applications, 13-14 November 2021, Surabaya Indonesia, AIP Conf. Proc., https://pubs.aip.org/aip/acp/article/2604/1/060001/2889972/Characteristics-of-Archimedes-screw-turbine

[12] C. Rorres, the Turn of the Screw: Optimal Design of an Archimedes Screw, J. Hydraul. Eng., vol. 126, no. 1, p. 7280, 2000, https://doi.org/10.1061/(ASCE)0733-9429(2000)126:1(72)

[13] B. Indarto, A.W. Ilhami, and M.A. Bustomi, "Testing Low rpm BLDC Generator as Power Plant for Remote Areas," Proceedings of the 7th International Conference on Research, Implementation, and Education of Mathematics

and Sciences (ICRIEMS 2020), 25-26 September 2020, Yogyakarta Indonesia, Atlantis Press, https://www.atlantis-press.com/proceedings/icriems-20/125953701

[14] G. Muller and J. Senior, ”Simplified Theory of Archimedean Screws,” J. Hydraulic Research, vol. 47, no.5, p. 666-669, 2009, https://www.tandfonline.com/doi/abs/10.3826/jhr.2009.3475

[15] G. Dellinger, *et al.*, ”Effect of slope and number of blades on Archimedes screw generator power output,” Renewable Energy, vol. 136, pp. 896-908, 2019, https://www.sciencedirect.com/science/article/abs/pii/S0960148119300606