Design of Pico Hydro Power Plant (PLTPH) Using Morphology Chart and Pugh Matrix Methods

Ir. Trio Yonathan Teja Kusuma, ST, MT and M Zulhan Iswanda
Industrial Engineering
Faculty of Science and Technology
Sunan Kalijaga State Islamic University
Yogyakarta, Indonesia
trio.yonathan@gmail.com , agamiswanda@gmail.com

Abstract

The increasing demand for electricity is not matched by an increase in the use of renewable electricity sources, causing climate change due to the use of fossil fuels to generate electricity. In addition, there are areas with remote and deepest access that do not yet enjoy electricity for their daily activities. This research uses the morphological chart method and the Pugh matrix, so that a portable and modular hydroelectric power plant can be produced to help people in remote areas enjoy electricity. From the results of the design and manufacture of a hydroelectric power plant, an output power is generated that can be used for home lighting. The power released from the power plant reaches 30W with the resulting efficiency reaching 2.382%. By utilizing river currents with a larger discharge and directing the river flow to the equipment, greater electrical energy can be generated. The electrical energy produced can be directly used or accommodated in an electrical reservoir such as a battery with a voltage of 12V DC.

Keywords
Renewable Electricity, Morphological Chart, Pugh Matrix.

1. Introduction

The use of fossil fuels such as coal brings many problems such as the impact on the environment, economy, health, and unstable prices in the market. There is a strong relationship between energy consumption, air pollution, water resources, and natural resource costs(Martins et al., 2019). The process of producing electrical energy is believed to have an impact on climate change and the use of fuel in motor vehicles and machinery in factories also has a negative impact on the environment.(Lott et al., 2017). The geography of Indonesia which is an archipelagic country, contours that have various low and highlands, and regular hydrological cycles with various springs in Indonesia make the potential for renewable energy from water in Indonesia more and more. Around 75,000 MW of energy that is still available as potential comes from water and only about 9% is utilized(Kholiq, 2015). The conversion of kinetic energy into electricity will be converted using an electric generator. An electric generator will convert kinetic energy into electricity by utilizing the electromagnetic force from the rotor and stator on the dynamo. Picco and micro scale generators can be an alternative in areas that have less electricity infrastructure such as in remote areas and leading, underdeveloped, and remote areas because of their compact size and the electricity generated is sufficient to power household electricity needs.(Fortaleza et al., 2018). Morphological map is a table that contains alternatives of a function that can be arranged to become several alternative solutions in the design stage of an item(Smith, 2007)

1.1 Research purposes

The purpose of doing research by applying this morphological map is as follows:

1. To design PLTPH by applying a morphological map before designing PLTPH
2. To make a prototype of PLTPH as a result of the design
3. Knowing the output power of the PLTPH made
4. Making PLTPH with a portable design so that it can be used in hard-to-reach areas

2. Study of literature

The conversion of kinetic energy from flowing water into electrical energy is a concept that exists in hydroelectric power plants. Water energy will be converted into electrical energy by using turbines and generators in the hydroelectric power plant. System efficiency is the ability of the device to convert energy from the flow of water into electrical energy. Electrical energy generation using turbines can be done with PLTPH. The extraction of electrical energy from the flow of water is the result of converting the energy of the water flow into electrical energy which is then used to drive a turbine. The working system of PLTPH is the same as other hydropower plants, namely the flow of water will rotate a turbine which is connected to a generator to convert kinetic energy into electrical energy.(Basar et al., 2011). Generator is an electrical generating device that works by converting mechanical energy into electrical energy(Prasetijo et al., 2012).

Morphological maps are one of the methods used based on basic morphological analysis developed by Fritz Zwicky to investigate complex non-quantitative problems.(Borekci, 2019). This method is used to solve problems by dividing them into sub-functions (problem decomposition), generating many sub-solutions for each sub-function (design differences), and selecting and combining suitable sub-solutions into a final alternative solution.(Magrab et al., 2009).

The Pugh matrix is a technique used to take the best solution from a variety of alternative solutions from the results of the evaluation of alternative solutions(Joshi et al., 2019). It is a basic tool for choosing solutions in the process of choosing the right decision during the product development process. This matrix relates the process of concept formation and concept selection. The concept formation process is carried out by describing the alternative concepts that exist and will then be evaluated at the concept selection stage. Each concept that has been evaluated will be compared with the specified criteria.

3. Method

3.1 Instruments and Data Collection

Data collection was carried out in the river using simple tools such as stopwatch, styrofoam, RPM counter, digital multitester, and spirit level. The data taken are river condition data, floating object travel time, head size, water discharge, hydraulic potential, and generator output power. Taking directly in the field to produce valid data, the travel time data is tested using the data adequacy test. Data collection was carried out by a river located in the village of Paddymulyo, Leksono District, Wonosobo Regency, Central Java, Indonesia.

3.2 Data processing

Processing of data taken from the field using minitab to calculate descriptive statistics and calculation of data uniformity in order to facilitate data processing. Calculations to determine water discharge and graphing using excel.

4. Data collection

4.1 Water discharge

The water discharge data can be known by calculating the cross-sectional area of the river times the speed of the river flow.

Table 1. River Condition

Day	Width(m)	Depth (m)	Current Speed (m/s)	Water Discharge (m3/s)
Monday	2.33	0.32	0.4974	0.3709
Tuesday	2.33	0.33	0.5028	0.3866
Wednesday	2.33	0.35	0.5103	0.4161
Thursday	2.33	0.32	0.5055	0.3769
Friday	2.33	0.42	0.4999	0.4892
Saturday	2.33	0.41	0.5057	0.4831
Sunday	2.33	0.34	0.5061	0.4009

4.2 Hydraulic Potential

The hydraulic potential can be determined by calculating the density of water multiplied by gravity times head and multiplied by water discharge. The following is the hydraulic potential data on the river:

Table 2. River Hydraulic Potential

Day	**Water discharge (m3/s)**	**Hydraulic potential (Watts)**
Monday	0.3709	3561753
Tuesday	0.3866	371.2934
Wednesday	0.4161	399.6701
Thursday	0.3769	361.9755
Friday	0.4892	469.8297
Saturday	0.4831	463.9646
Sunday	0.4009	385.0555

4.3 Morphological Table

The preparation of the morphology table for PLTPH has 5 sub-functions with each alternative available in the market listed in the table below.

Table 3. Morphology Table of Each Sub-Function Alternative

Function	**Alternative**				
	1	**2**	**4**	**5**	**6**
Frame Material	aluminum	Galvalume	Iron	Zinc	Steel
Frame Material Shape	Box Tube	Solid Cylinder	“L” shape	Empty Cylinder	Solid Box
Turbine Type	Kaplan	Pelton	Francis	Thread	-
Turbine Material	aluminum	Iron	PVC	Plastic	Zinc
Drive Type	*pulley*	Gear Wheel	-	-	-

From the existing alternatives, they are arranged into 5 concepts to be compared and selected to be used as prototypes. The drafting of the concept is done randomly to find the best concept. The concepts compiled are listed in the table below

Table 4. Conceptual Alternative Morphology Table

Function	**Alternative Concept**				
	1	**2**	**3**	**4**	**5**
Frame Material	aluminum	Iron	Steel	Galvalume	Zinc
Frame Material Shape	Box Tube	L shape	Box Tube	Empty Cylinder	Solid Box
Turbine Type	Francis	Thread	Pelton	Thread	Thread
Turbine Material	Iron	PVC	Zinc	Plastic	Iron
Drive Type	*pulley*	*pulley*	Gear Wheel	Gear Wheel	Gear Wheel

4.4 Pugh Matrix

The preparation of alternative concepts in the morphology table has been made and then an assessment of each concept by comparing each concept with the selected basic concept. The basic concept chosen is concept 1 with the results of the concept assessment listed in the table below

Table 5. Pugh Matrix

Criteria \ Draft	Concept 1 (DATUM)	Concept 2	Concept 3	Concept 4	Concept 5
Care	S	+	-	+	++
Processing	S	++	S	-	S
Transfer	S	-	-	S	-
Portability	S	-	-	+	+
Modularity	S	+	+	S	-
Maintenance costs	S	-	-	++	+
Purchase Fee	S	+	--	-	S
Total Positive		5	1	4	4
Total Negative		-2	-6	-2	-2
Total Same		0	1	2	2
Total value		3	-5	2	2

Information:

\+ = Value +1

++ = Value +2

S = Same or value 0

\- = Value -1

-- = Value -2

Based on the results of the assessment on the Pugh matrix concept 2 has the highest value, that is, therefore the concept was chosen to be used as a prototype for PLTPH with prototype specifications, namely

1. Frame specifications

- Material = Iron
- Material shape = L
- Long = 85 cm
- Wide = 41 cm
- Tall = 43.5 cm

2. Thread Specification

- Material = PVC
- Inner Diameter = 15.24 cm (6 in)
- Outside diameter = 30 cm
- Long = 80 cm
- Number of threaded fins = 2 pieces
- Pitch = 40 cm
- Round = 2

3. Mover

- Large pulley diameter = 25.4 cm (10 in)
- Small pulley diameter = 7.62 cm (3 in)
- Vanbelt = A-43
- Large and small pulley ratio = 1:3

5. Results and Discussion

5.1.River hydraulic potential

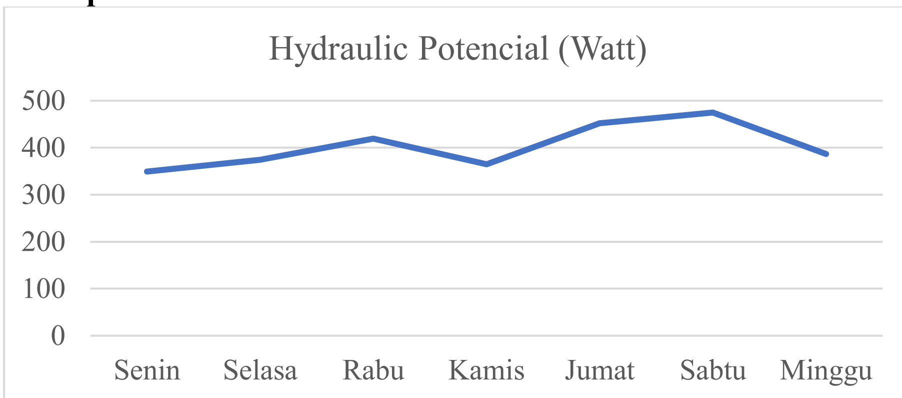

Figure 1. River's Daily Hydraulic Potential Chart (Watts)

Based on field data collection that has been carried out and data calculations obtained daily hydraulic potential data for one week as shown in Figure 1 starting from Monday, which is equal to 349.3045 watts, Tuesday is 374,3164 watts, Wednesday is 419,6346 watts, Thursday is 364,5999 watts, Friday is 451,9366 watts, Saturday is 474,8810 watts, and Sunday is 386.5214 watts. The average hydraulic potential in river 2 for one week is 403,0278 watts.

5.2 Electrical energy generated

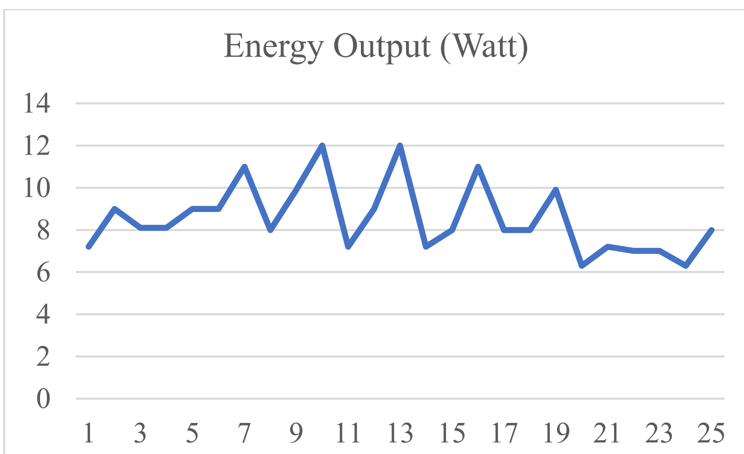

Figure 2. Tool Output Power

Based on the collection of 25 field data listed in Figure 2, the energy data that can be generated from the power plant are 7.2 watts, 9 watts, 8.1 watts, 8.1 watts, 9 watts, 9 watts, 11 watts, 8 watts, 9.9 watts, 12 watts, 7.2 watts, 9 watts, 12 watts, 7.2 watts, 8 watts, 11 watts, 8 watts, 8 watts, 9.9 watts, 6.3 watts, 7.2 watts, 7 watts, 7 watts, 6.3 watts, and 8 watts. With the average energy produced is 8,536 watts. With the average hydraulic potential in river 2 of 403,0278 and the electrical energy produced is 8,536, the system efficiency is 2.118%.

6. Conclusion

Based on the research that has been done, the following conclusions are obtained:

In the application of morphological maps, it is known that there are 5 sub-functions that need to be considered in designing the tool to be made. Of the 5 sub-functions, there are alternatives for each sub-function available in the market. From each sub-function and alternative, 6 concepts were compiled with concept 2 being selected from the basic concept, namely concept 1 as a comparison in the concept selection process using the Pugh matrix. From the selected concept, a tool specification design can be generated and drawn on the Solidworks application With the design that has been drawn on Solidworks, a prototype is made according to the chosen concept for testing and data collection.
Based on data retrieval from the prototype concept that has been designed, the resulting power is still relatively small, namely <100W. This power can be used for lighting lamps and can be accommodated in a larger container so that the power that can be used can be greater.
Making tools using morphological maps and Pugh matrices can help researchers in determining a more conical concept from the many alternative sub-functions that exist. From the chosen concept, the PLTPH design can be made and tools can be built to help people who still cannot enjoy electricity. This research resulted in a tool that can convert kinetic energy in water into electrical energy, but with low efficiency and the power generated is still small. The power generated is sufficient for lighting and can be accommodated for emergencies without paying for electricity.

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Biographies

Trio Yonathan Teja Kusuma, S.T., M.T. a lecturer in Industrial Engineering at UIN Sunan Kalijaga with a history of S1 Industrial Engineering at UIN Sunan Kalijaga which was obtained in 2011, Masters in Industrial Engineering at the Islamic University of Indonesia in 2013, and obtained the Engineer Profession in 2020. Has instructor experience in training with the title: “Workplace Management Using 5S approach by Kaizen” at PT Trubaindo Coal Mining, Melak, Kalimantan, becoming a trainer in a training entitled: “Inventory Management” at PR Chevron Indonesia, Being a Trainer in a training entitled “Warehouse Management” at PT Medco Energy. There are several research works that have been released, some of which are Posture Analysis using Rapid Entire

Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) to Improve Posture of Sandpaper Machine Operators and Reduce the Risk of Lower Back Pain, Published in the Journal of Biological Chemistry , Medicine, and Natural Materials, Vol 9 No 1, 2020, Analysis of WKSB Pump Maintenance Wktb On Well Pad 28 at PT. Geo Dipa Energi (Persero) Unit I Dieng Using Overall Equipment Effectiveness (OEE) and Reliability Centered Maintenance (RCM) published in the Xplore Industrial Journal, Vol 4 No 1 2019, Determining the Optimal Number of Workers to Increase Work Productivity (Case Study: UD Engineering Wangdi W) Published in Integrated Journal, Vol 7 No. 2, 2019, and many more including a patent on DC Current Power Generation Circuit with Voltaic Cell Method in 2016, DC Current Lamp with Clay Power Source exhibited at the 2017 International Islamic Education Exhibition, and Miser Machine Innovation taking into account the posture used on Metal Foundry SMIs (2018).

M Zulhan Iswanda industrial engineering student UIN Sunan Kalijaga who entered in 2018 and completed his studies in 2022. Has conducted several researches with related lecturers and several national and international scale events in the industrial and non-industrial fields.