Prototype design of waterwheel micro hydro power plants for small water discharge

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Abstract. The findings of this study was the Prototype Model of Micro Hydro Power Plant (MHPP) for small water discharges (less than 10 Liters per Second), namely MHPP waterwheel and the Speed Converters from waterwheel to Dynamos, named "Converters" MHPP. This study was aimed to produce a prototype design of a wind turbine-based MHPP for small water discharge. This study used an engineering-based approach to the design of prototype MHPP. The design of the prototype MHPP for small water discharges (less than 10 liters per second) consists of 6 components, a wheel diameter of 4-5 meters, the turning machine from a pinwheel to a dynamo given the name "converter", Dynamo, House where the prototype MHPP, Conductor Network of MHPP to homes, and safety tanks and waterways.

1. Introduction
Electricity is the most important aspect to supporting the activities of human life. With the existence of electricity, the existence of electrical energy is able to light lights along the road, at home, offices, malls, and other important places.

Electricity generator is a device that can generate and produce an electrical voltage by converting certain energy into electrical energy. In addition, a power plant can also be called all machines that convert motors, light, and petroleum or other chemical objects into propulsion.

Micro-hydro is a term that consists of the word micro which means small and hydro which means water. Micro Hydro Power Plant (MHPP) is a small-scale power plant that uses hydropower as its driving force, such as irrigation channels, rivers or natural waterfalls by utilizing potential energy from high heights (heads) and the amount of time from water discharge. Micro hydro power (MHP) system could be an option of additional renewable energy technology at many locations around the world to supplement universal access to modern energy stipulated by the Sustainable Development Goals (SDG) [1]. Assessment study on the impact of techno socioeconomic on the sustainability indicator of MHPP was done by Purwanto and Afifah [2].

Potential utilization of water flow from water sources in the mountains especially in the Village of Kwadungan, Kalikajar Wonosobo has been explored by researchers to build a micro hydropower plant (MHPP). MHPP that was built using waterwheel because the water discharge is relatively small, and based on observations of the use of turbine in MHPP found that MHPP was not durable and easily damaged by flooding. Water wheels are a sustainable and efficient way for the production of energy [3]. Since the nineteenth century, the water wheel has become highly efficient [4]. It was found that
the wind supercharging technology is one of the effective ways to improve the power generation efficiency, improve the economic performance of SCPP and realize the commercial application of SCPP [5]. Study on the micro-hydropower plant concluded that it has a good potential in the north-eastern hilly regions of Bangladesh since the system needs terrain and availability of high stream flow rate [6].

A small power plant that can use hydropower by utilizing the height of the head (in meters) and the amount of water discharge (m³/sec). The greater the flow capacity and height of the installation, the greater the energy that can be used to produce electricity. MHPP is generally a run of river type power plant where the height is obtained not by building a large dam, but by diverting the flow of river water to one side of the river then flowing it again into the river at a place where the required high difference has been obtained. Hydroelectric power plants below 200 kW are classified as MHPP [7]. Study on the development of small hydropower sources was carried out by Adebayo et al. [8]. The MBSH could also benefit from a clearer plan for scaling up the number of microhydro dams from the original pilot projects producing 3.2 MW.

Turbine is the core of any micro hydro project since it capable of generating electricity through the rotation of the shaft [9]. Study of Michael and Jawahar [10] revealed that there was a huge potential at the site to develop a mini hydro power plant which would meet the energy demand of the tribal settlement and thereby improving their living condition. The problems faced by the Micro Hydro Power Plant (PLTMH) Business is the PLTMH prototype has not been registered with patents or industrial designs in Ministry of Law and Human Rights of Indonesia. The purpose of this research was to design a prototype PLTMH based on a waterwheel for small water discharges (less than 10 liters/second), which generates electrical energy from 3000 to 5000 Watt/unit. The design of the PLTMH prototype will subsequently be registered with an Industrial Patent or Design at Ministry of Law and Human Rights of Indonesia.

2. Methods
Development of prototype design of waterwheel-based MHPP for small water discharges (less than 10 liters/sec) was done [11]. It was able to produce electrical energy of 3000-5000 Watt/unit. PLTMH prototype design procedures consist of prototype engineering drawings of MHPP, description of the components of MHPP and its functions. The MHPP prototype technical drawings was done based on measurements of three MHPP units that have been built since 2010 and have been utilized by the community in Kwidungan Village.

3. Results and Discussion
3.1. MHPP Prototype Design
The working principles and the standard components of the three PLTMH are the same. The principle works as follows:
(1) The potential energy from water originating from the mass (water discharge) and the difference in height (head) is converted into kinetic energy in the form of a spinning wheel.
(2) Rotating the wheel turns the Wheel Converting Machine from the Wheel to the dynamo.
(3) The dynamo rotates at a fixed speed of an average of 1800 RPM (revolutions per minute).
(4) This dynamo rotation of 1800 RPM produces electricity.
(5) Electrical energy from PLTMH is channeled through conductors to homes that use electricity.
The PLTMH prototype raw components consist of:
(1) PLTMH Ferris wheel
(2) Rotating machine from the mill to Dynamo
(3) Dynamo
(4) Supporting buildings or houses for PLTMH prototypes
(5) The network of conductors of PLTMH to PLTMH user houses.
(6) Safety Channels to prevent damage to PLTMH due to flooding.
The design of PLTMH components will be explained in the description below. The design of PLTMH is based on the third prototype of PLTMH that has been built and proved to be functioning well for more than nine years.

3.2. Waterwheel design
MHPP waterwheel wheel has a diameter of about 400-500 centimeters. The larger the diameter, the smaller the energy needed to drive the wheel, but the cost of making the wheel is more expensive. The energy or force needed to move the wheel follows the "Lever" law in Physics. Based on experience and observation of the optimal waterwheel, diameter for MHPP in quadrants with such conditions as the above conditions is 450 centimeters.

In this research, technical drawings were made from the waterwheel. This technical drawing was planned to be used as a basis for submitting Intellectual Property Rights in the form of Patents. Waterwheel engineering drawings are presented below. Waterwheel used in all three PLTMH is made of steel. The design of the PLTMH waterwheel was inspired from models of our ancestors' wheels used to flow or move water. The application of hydraulic pumps running as turbines offers several benefits with respect to traditional turbines. The possibility of predicting the performances of a pump running as a turbine and of selecting the suitable machine for a given hydropower site, in an easy and reliable way was studied [12].

The use of waterwheel for MHPP is a solution to the problem of the easily damage turbine-based MHP prototypes due to flooding. Based on observations, most of turbine-based MHPP dormant functions as expected. By using a waterwheel, MHPP is expected not to be easily damaged by flooding. Of the three wind turbine-based MHPP units used at BUMDES, Kwadungan Village provided evidence that the MHPP waterwheel system was truly resistant to the effects of flooding; this was evidenced by the fact that PLTMH I, II, III remained well and functioned normally for more than nine years. In this study, improvements were made to the dynamo, waterways, and conductor networks of the MHPP function to become more tangible, namely to produce electrical energy used by the people in Kwadungan Village. Channel geometry plays an important role in the wheel performance [13].

The technical drawing of waterwheel for MHPP is given in Figure 1.

![Figure 1. Technical drawing of waterwheel for MHPP](image_url)
waterwheel. The shape of the fins of the waterwheel is in the form of a bowl. This fin receives water exposure from the outlet pipe of the water channel with the application of these fins spinning wheel. The rotation of the wheel rotates the engine converting rotation and is continued by turning the dynamo to produce electrical energy.

In theory, the water hits the waterwheel can be divided into two, namely:

1. Water outlets are placed on the side of the wheel. This modeling is called "Over Shock". This water treatment model in MHPP turns out to produce unfavorable conditions, which is water splashed everywhere. Splashes of water can hit the pinwheel. Inside the wheel axis, there is a bearing component (Bearing) that is easily damaged when splashed with water so that the durability of the axis and bearing is reduced.

2. Water outlets are applied to the bottom of the wheel. This modeling is called "Under Shock". The reason for this water application model used in MHPP is that water splashes do not wet the pinwheel components so that the axis and bearing become more durable and undamaged. Besides that, in the Under Shock air acceleration model, potential energy is obtained because of the higher head height difference.

3.3. Design of a Round Convert Machine from waterwheel to Dynamo (Inverter)

Rotating machine from the waterwheel to Dynamo is a series of Pulley with various diameters connected to each other so that it can convert the rotation speed of the wheel to Dynamo speed. The magnitude of the dynamo rotation is 1800 RPM. The number of Pulleys (wheels) and Pulley diameters and the arrangement of their circuits are determined by the principles of physics formulas regarding Angular velocity. The formula is:

\[ \omega_1 r_1 = \omega_2 r_2 \]  

Note :

\( \omega_1 \) = Angular speed of the wheel 1  
\( r_1 \) = radius of wheel 1  
\( \omega_2 \) = Angular speed of the wheel 2  
\( r_2 \) = radius of wheel 2

The design of the Round Conversion Machine from waterwheel to dynamo in this study is based on the model of the Round Conversion Machine from Windmill to dynamo that has been applied to MHPP in BUMDES MHPP Kwadungan. The basis for the use of the design of the Wheel Conversion to Windshield Dynamo Engine is the fact that the Wheel to Windshield Conversion to Dynamo Machine has been successfully applied for more than 9 years until now on the above mentioned micro hydro power plants. The round converter machine from the waterwheel to dynamo is made from several types of materials as follows:

1. In MHPP one, the material for the Round Conversion Machine from the waterwheel to Dynamo is a pulley or wheels made of steel. Between the pulleys connected by a belt Pulley besides functioning as a spin transmission, also functions as a flywheel.

2. In MHPP two, the material for the Speed Converting Machine from Ferris wheel to Dynamo is pulley or wheels made of wood. Between the pulleys connected by a belt

3. In MHPP three, the material for the Round Conversion Machine from the waterwheel to Dynamo is pulleys or wheels, some are made of wood and some are made of steel. Between the pulleys connected by a belt

Based on the observation of pulley made from wood, it works better than steel because it produces a larger pulley mass/weight so that its function as a flywheel becomes better which ultimately results in a more stable spin. Making pulley from wood is relatively difficult so special skills are given. The use of pulleys in the machine to convert the Wheel from Windmill to Dynamo from iron is relatively easier because the market has available various sizes of steel wheels so there is no need to make it.
3.4. Dynamo Circuit Design
Dynamo is a conversion of kinetic energy into electrical energy. In the construction of MHPP dynamo that are already on the market are used. The dynamo used in the MHPP in Kwadungan is the dynamo which has a standard rotating speed equal to 1800 RPM. MHPP 1 uses a 5000 watt dynamo, MHPP 2 uses an 8000 Watt dynamo and MHPP 3 uses a 3000 Watt dynamo. The power of the dynamo installed on the MHPP is adjusted to the estimated potential energy obtained from water discharge and height differences.

3.5. Design of Conductor Networks from MHP to Residents' Homes
The conductor network of MHPP to houses made of insulated electric cables with a conductor diameter of about 1.0 mm. The required electrical cable length is around 2000 m. In addition to the conductor cables, supporting poles are needed so that they are not harmful to the community. The support poles are made of parallels with a diameter of 3 inches and height ranges from 2 to 3 meters in which they are filled with cast concrete. The cost of making these poles is much cheaper than those made of iron or wood.
4. Conclusions
The prototype design of MHPP is as follows. MHPP for small water discharges (less than 10 liters per second) based on windmills. The use of these wheels is a solution so that the MHPP prototype has high sustainability that is durable not easily damaged by flooding. Evidence that MHPP is based on waterwheel is more durable, ie prototypes MHPP one, two, and three have been used for more than 9 years and still produce stable and undamaged electricity. The MHPP component of the millwheel consists of six components, namely: 4-5 meter diameter, the reversing wheel from the mill to the dynamo is named "converter", Dynamo, the house where the MHPP prototype is, the Conductor Network from MHPP to the houses, and the safety cistern and conduit.

References
[1] Poudel RC, Manwell JF, McGowan JG 2020 Performance analysis of hybrid microhydro power systems Energy Conversion and Management 215 112873
[2] Purwanto WW and Afifah N 2016 Assessing the impact of techno socioeconomic factors on sustainability indicators of microhydro power projects in Indonesia: A comparative study Renewable Energy 93, 312-322
[3] Quaranta E and Revelli R 2015 Performance characteristics, power losses and mechanical
power estimation for a breastshot water wheel *Energy* **87** 315-325

[4] Viollet P-L 2017 From the water wheel to turbines and hydroelectricity. Technological evolution and revolutions *Comptes Rendus Mécanique* **345** 570-580

[5] Zuo L, Qu N, Liu Z, Ding L, Dai P, Xu B, Yuan Y 2020 Performance study and economic analysis of wind supercharged solar chimney power plant *Renewable Energy* **156** 837-850

[6] Razan JI, Islam RS, Hasan R, Hasan S, and Islam F 2012 A Comprehensive Study of Micro-Hydropower Plant and Its Potential in Bangladesh *International Scholarly Research Notices*

[7] Anjarani. 2011. *Pengembangan Pembangkit Listrik Tenaga Mikrohidro (PLTMH) di Lampung*. UNILA, Lampung.

[8] Adebayo E, Sovacool BK, Imperiale S 2013 It's about dam time: Improving microhydro electrification in Tanzania *Energy for Sustainable Development* **17** 378–385

[9] Jawahara CP and Michael PA 2017 A review on turbines for micro hydro power plant *Renewable and Sustainable Energy Reviews* **72** 882-887

[10] Jawahara CP and Michael PA 2017 Design of 15 kW Micro Hydro Power Plant for Rural Electrification at Valara Energy Procedia **117** 163-171

[11] Suryatna BS, Yuwono C, Sugianto 2010 KKN PPM Berbasis Kerja Sama Mahasiswa-Masyarakat Membangun Mikrohidro dan Lembaga Usaha Kampung di Kalikajar, Wonosobo Laporan KKN PPM Semarang: UNNES

[12] Barbarelli S, Amelio M, Florio G 2017 Experimental activity at test rig validating correlations to select pumps running as turbines in microhydro plants *Energy Conversion and Management* **149** 781-797

[13] Paudel S and Saenger N 2018 Effect of channel geometry on the performance of the Dethridge water wheel *Renewable Energy* **115** 175-182