Preliminary Study for Development of Hydro Energy Harvesting in an Open Channel Irrigation System

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Keywords: Hydro Energy, Water Wheel, Open Channels, Irrigation System.

Abstract: Open channel irrigation system developed for agricultural irrigation in Bali. The availability of water resources in Bali was sufficient for agricultural and domestic utilization. The open channel irrigation system is typically the ultra-low head of flowing water. The purpose of this study is to identify the design for extracting hydro energy in open channel irrigation systems and we carried out several activities i.e., designing a water wheel, proposed initial testing for their application on open channel hydro energy system, and commissioning test for the mechanical performance of the water wheel as an energy extraction in an open channel. Water wheels are conventional technology and low efficiency, nevertheless, this technology is the most common and simple application for energy harvesting in open channel irrigation systems. In this project, it had known that waterwheel provided their performance for energy harvesting in an open channel irrigation system. After some modification of technical and design aspects on commissioning test, this water wheel has performed mechanical parameters as a rotations speed and torque. The rotation speed of the water wheel is about 64-95 rpm and the rate of maximum torque has determined 0,03 Nm. However, this preliminary study has known many technical considerations to another stage in the designing of hydro energy harvesters for an open channel irrigation system.

1 INTRODUCTION

Open channel irrigation system had developed for agricultural irrigation in Bali. Bali is a small island. The topography of Bali is composed of various mountain ranges which extend throughout Bali Island and divide the island into two sections. Volcanic mountains influence to rise of natural water resources. Several rivers are formed by existing of these natural water resources.

The availability of water resources in Bali is sufficient for domestic and industrial needs. This natural water resources have been utilized as agricultural and domestic only. The utilization of hydro energy has also been a concern in the last decades. An open channel irrigation system is typically the ultra-low head of flowing water. In this study, we concluded several activities i.e. designing a water wheel, proposed initial testing for an open channel hydro energy system, and commissioning mechanical performance of the water wheel as an energy extraction in an open channel. Water wheels are traditional technology and minimum efficiency. however, this technology is the most commonly used and easy to apply in harvesting hydro energy in an open channel irrigation systems. (Quaranta, 2018).

Microhydro power plants are becoming very attractive, especially in the rural area and decentralized, also developing countries. Indonesia is the biggest archipelago country. Large distances areas

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is one of the problem in the distributed electrical energy.(Quaranta, 2018) It is usually required decentralized electricity production and off-grid power plants. Micro hydropower plants can provide simple energy access to small and local communities, or remote industrial sites. Micro-hydro schemes can use existing open channel/hydraulic structures to minimized total installation costs. (Niebuhr et al., 2019).

2 LITERATURE REVIEW

In the hydropower field different machine types can be used to convert hydro energy into mechanical energy.(Quaranta and Revelli, 2018) Hydropower machines can be classified into: action turbines, includes stream water wheels and vertical axis water wheels, Turgo, Pelton and Cross Flow turbines; Reaction turbines, such as: Kaplan and Francis turbines; and have been exist also an axial hydro-turbine, includes water wheels and screws turbine of Archimedes. The action turbine extracts the kinetic energy of the water flow, hence momentum of the water flow. The reaction turbine also uses water pressure because it is installed in a closed pipe and pressurized. The hydrostatic pressure converter is driven by the hydrostatic force of water and operates in the open air. This type of design in the field of micro hydro power plants, river waterwheels, gravity waterwheels and archimedes screw turbine is the most suitable choice.(Yuebo et al., 2018)

2.1 Hydropower in an Open Channel Irrigation System

Generally, the feasibility of the proposed hydropower generated system is based on the following potential input and output power equation:

$$P_{in} = H \cdot Q \cdot g \quad (1)$$

$$P_{out} = H \cdot Q \cdot g \cdot \eta \quad (2)$$

Where,
P_{in} = hydropower input (Watts), P_{out} = Rotation's shaft output (watts), H = Determination of water head (meter) Q = Water flow rate (meter cubic/second) g = gravity constant, and η = efficiency. According to the equation (1) and (2), both head and volumetric of water flow rate are parameters in hydropower system which have to determinate firstly. Head is a measure of falling water from higher site, i.e., vertical distance (head) from the top of the penstock to the turbine or water wheels at the bottom. Water flow rate is the amount of water (volumetric) flows within one second. Normally, water flow available is more than needed since the flows for pico-hydro are small. (Cleynen et al., 2018). Thus, it is important to measure the head exactly because higher head can adjust more power and the higher speed of the rotation. Basically, power produced by a hydropower system is converted from one form to another and a few of them is lost.

In the open channel irrigation system, the velocity head was small and the potential head was dominant with regard to the specific energy of the flowing water volumetric (Nishi et al., 2014). In this case, the modification of this channel irrigation system is needed to increase the velocity of flowing water. Weir structures have been to utilize increasing the water head and bypass flow when the channel is overflowing.

Generally, a hydropower unit were composed a turbine, a generator and also others site constructions. Despite of their variety, several turbines, based on their main working principles, can be categorized as either a reaction, impulse, or hydrokinetic turbines. A reaction turbine, such as Francis and Kaplan turbines, uses both pressure and kinetic energy of the water to generate a hydrodynamic force to rotate the runner blades. Pelton, Turgo and crossflow turbine are categorized as an impulse turbine. It uses runners, nozzle and also guide vane that are rotated by water jets at higher velocities. Reaction turbines are generally more applicable to low head systems, whereas impulse turbines are more suitable for medium-high head applications. However, it was considerable overlapping for their practical applications. (McKinney et al., 1983).

2.2 Design of Hydro Energy Harvester for Open Channel Irrigation System

Type of Low-head hydropower has the potential to generate a significant amount of electricity from an open channel irrigation system that was traditionally and unsuitable for developing hydraulic power plants. A new concept offers a new paradigm for small hydropower technology development based on the premise of standardization, modularity, and preservation of stream functionality. It was proposed in another country to gain hydropower utilization on a river, open channel system, and others type of hydropower site. (Chen and Engeda 2020).

Hydraulic turbine based on axial design turbine have been proposed for hydro energy harvester in flowing water. This technology has been used to meet standardization on their application by minimization the weir structure on the river. (Chen and Engeda 2021). Advancing impulse turbines were developed quickly than the others type of reaction turbines, over the last decade since they are low-cost manufacture and easier to maintain. Similar to reaction turbines, it is still modularity as the key element in the design of new impulse turbines. A new generation of impulse turbines which had developed such as modular water wheel, Archimedean screw turbine, etc. (Sari et al., 2018)

The water wheel has been utilized for centuries to generate a low-cost mechanical and electrical power. However, the conventional water wheel is considered to be less efficient than other turbines designed specifically for electricity production. Therefore, modification is necessary for the waterwheel to generate enough power for a commercial use. The modification can include the incorporation of a high-ratio gearbox and specialized control to increase the speed. A new generation of water wheel is smaller in size, also more modular design, and can be employed in existing infrastructure such as canals or open channel irrigation systems, concrete-lined chutes, industrial water loops, etc (Cleynen et al., 2021)

The choice of hydro energy harvester will depend on the topographical site, debit of water and head available. If there is higher head then a Pelton turbine would be suitable to applied. However, it is probably the most common choice for small Francis turbines based on the on-site flow and head availability. Another consideration, Kaplan or propellers turbines may be preferable for very low heads.

3 EXPERIMENTAL APARATUS AND METHODS

3.1 Designing an Open Channel for Water Wheel Testing

In this study, the design of equipment for harvesting water energy was developed using water wheel technology. The characteristics of the water flow in the irrigation system greatly affect the design of the hydro energy harvester. Proposed a hydro energy development project, it will need requirements i.e., overall cost project, the project feasibility, social and environmental considerations, etc.

On-site commissioning tests will need more cost when this system failure occurs. Designing an open channel is needed to reduce an overall project cost and propose to investigate the characteristic of water flow on an open channel. Testing of mechanical performance is more specific to indicate measurement on rotation speed and torque of water wheel or another type design for hydro energy harvester in an open channel irrigation system.

The width of an open channel irrigation system in Bali is about 80-120 cm. This open channel irrigation system has a water depth of about 10-40 cm. there are several types of flowing water in an open channel with a variable velocity of flow and stream. Based on the survey of the open channel irrigation system in Bali, we have decided to design an artificial open channel water system that has dimensions about 0,6 x 1 x 3 meters.

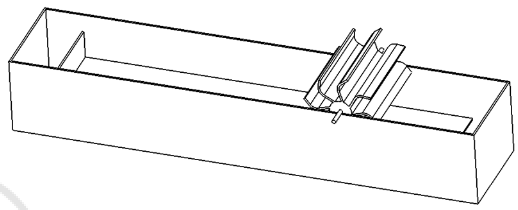

Figure 1: Water wheel installation test on an open channel system.

Water flow characteristics in an open channel can be shown on this design testing. Figure 2 indicates simulation of water flow in open channel design test. Water flows upside of this channel that is simulated to hydro energy extraction. Below the channel utilized to the circulated water flow by a submersible pump. Type submersible pump is Jebao lp 35000. This submersible pump has a specification of power input of 100 watts and a flow rate maximum of 35000 lph. The maximum head of this submersible pump is about 4 m depend on their specification data.

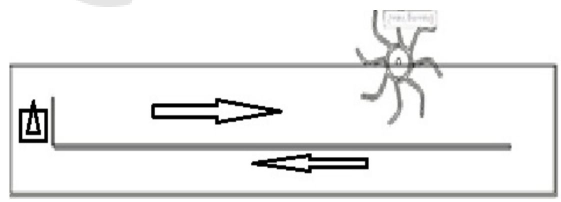

Figure 2: Simulation of Water Flow Characteristic on Open Channel System.

Water flows above side of the channel and counterflow in the bottom side of the channel. This channel configuration has been made to optimize water flow. The cross-sectional area of the bottom side of the channel purposed to preventing the bottleneck effect occurrence. Pumping of water affected debit of water circulation and it has to meet the level of water in the bottom of submersible pump.

Simulation of water flows in an open channel will be a necessary in an approaching debit and velocity of water flow. In this study, we are only installed one submersible pump to simulated volumetric water flows about 0,3 -0,5 m^3/s, instead of this, it will be necessary to use more than a single pump or choose another high flow pumps. It's also depended on the site conditionally, the flow rate of the irrigation system in Bali can be simulated only by one submersible pump.

3.2 Waterwheel Design

The design of the water wheel has been composed of the stationary shaft, 2 supported bearings, and the water wheel construction. This fixed shaft design causes the force acting on the waterwheel to be less friction than the waterwheel with a rotating shaft.

This waterwheel is designed using materials from wood, PVC, and also uses glue and screw nails. This waterwheel shaft uses a 2.5-inch PVC pipe and is reinforced by using a PVC flange. it is a rotating shaft along with a water wheel construction. This waterwheel is designed with an outer diameter of 60 cm, with a pedal holder diameter of 40 cm. There are 8 waterwheel paddles with a total width of 90 cm.

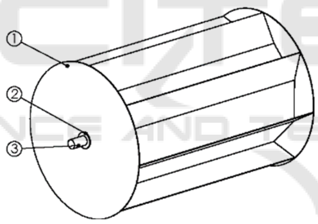

Figure 3: Design of water wheel.

1. Stationary shaft of water wheel
2. Bearing 1609zz
3. Wheel constructions

3.3 Measurement Methods

In physics and mechanics, torque is the rotational equivalent of linear force. It is also referred to as the moment, moment of force, rotational force, or turning effect. The measurement of rotations velocity of shaft and torque have to be indicated on preliminary study for the development of a hydro energy power plant. Angular velocity or rotational velocity (ω) on the shaft would be measured by a digital tachometer. It is also utilized to indicate the torque of the waterwheel's rotational shaft. The power (P) of the rotational shaft is indicated by torque (τ) and angular velocity of the water wheel's rotational shaft. It's shown by the equation below:

$$P = \tau \cdot \omega \quad (3)$$

Where; P is a power of the rotational shaft in watts, τ is a torque of shaft in Nm, and ω is an angular velocity in rpm. Torque could be indicated by equation below:

$$\tau = r \cdot F \quad (4)$$

Where r is equal to distance between centre gravity of load (F). load (F) is given by assemble additional load in rotational shaft of water wheel. This procedure has been utilized to investigate the effect of braking/friction in supporting bearing. Then, torque would be indicated by the measurement of the reduction of shaft rotational velocity. Dynamic rotations of mass had been indicated by Newton's third law to calculated moment inertia of force.

Figure 4: a. Water wheel installation in an open channel (left) b. Rig test to simulate hydraulic behaviour of waterwheel in open channel system. (right).

4 RESULT AND DISCUSSIONS

Pump operations in this open channel system have been shown a shallow flow of water. An open channel system needs to modify into increasing water flow velocity. If water wheel is still a choice for energy harvester in an open channel irrigation system, then it would need to modification (Du, Shen, and Yang 2020). Pump specifications give a maximum flow of 35000 lph. Measurement of water flow indicates the flow of water only 0,2-0,3 m^3/s. Others, head optimum of flow only 2 m. It showed that the water wheel's rotation speed was slow and the head is classified as ultra-low head of water flow.

In designing a turbine, penstock and guide vane would be several technical designs to modify in regimes of water flow (Niebuhr et al. 2019). However available design of an open channel irrigation system would be difficult to modify. It is a zero head of water flow and a weir structure will need to employ in gaining the head of water and also the velocity of water flow. If we concluded testing by flowing water directly to the water wheel, it would be shown an increase of rotational speed of this water wheel. This is indicating that the kinetic energy of flowing water will be more easily harvest than the potential energy of flowing water.

After some modification of technical aspect on commissioning test, this water wheel has been performed mechanical parameters as a rotations speed and torque. The rotation speed of the water wheel is about 64-95 rpm and the rate of maximum torque has been determined 0,03 Nm. In this project, it had been known that waterwheel provided insufficient performance for energy harvesting in an open channel irrigation system. Although it has been performed many technical considerations for another stage in the development of open channel irrigation technology for hydro energy harvester.

The choice of hydro energy harvester will depend on the site and head available. This study had been presented which characteristic of flowing in an open channel and also application of water wheel still meets difficult effort on their applications. Strategy in the development of modular hydro-energy power plant has to move on the choice of turbine design. It has improved their utilization for gain in velocity of flowing water. Several papers had been also presented availability technology and technical modification to meet in increasing water head availability for installation other type turbine..

5 CONCLUSIONS

This paper provided a preliminary study and short review of the currently available hydro-turbine technologies that are suitable for an open channel irrigation system in Bali. The information provided can be used to assist the ultra-low head of flowing water utilities that are considering capturing hydrokinetic/hydrostatic energy. However, it is important to note when hydropower was generated from an existing open channel irrigation system.

After this study, the water wheel in the mechanical aspect had been performed to rotational velocity about 65-95 rpm and maximum torque rate about 0,3 Nm. However, this result indicates low performance for hydroelectricity application but it had given information to design hydro energy harvesting on an open channel irrigation system.

Design types an impulse turbine could be applied to perform better results in the mechanical aspect. Even though, it had been required a high head of water source, modifications of water flow would be solutions for this requirement. these modifications could be increasing efficiencies of hydro energy harvesting in an open channel system

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