Investigation of the Utilization of Kaplan Turbines for PLTMH Power Plants

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ABSTRACT
The potential of water in Indonesia to generate electrical energy is quite large. This water potential is very suitable for generating small-scale energy. Water is sent through the penstock to drive the turbine. The turbine is coupled with a generator to produce electrical energy. The turbines used vary widely. For this research, the Kaplan turbine is used. The Kaplan turbine was chosen because of the low head required, which is suitable for conditions in Indonesia. The diameter of the Kaplan turbine tested was 25 cm. It is equipped with a guide vane arrangement. To obtain the Kaplan turbine output, the turbine is coupled to a generator. The test refers to the IEC standard. The turbine is operated at a constant speed and the generator voltage is fixed and the discharge varies. The results showed that the larger the guide vane opening, the higher the flow rate; the greater the flow rate of the resulting power, the greater. Efficiency for guide vane 30 openings occurs at 6.65m head and 0.065m^3/sec volumetric flowrate with efficiency 50,13%. The highest efficiency is obtained for the guide vane 40 opening, which is 57.14% at 4.15 head and 0.074m3/sec flow rate.

Keywords: *Turbine Kaplan, PLTMH, efficiency*.

1. INTRODUCTION

Micro-hydro Power Plant (PLTMH), commonly called micro-hydro, is a small-scale power plant that uses hydropower as its driving force, for example from irrigation channels, rivers, or natural waterfalls, by utilizing the height of the falls (head, in meters) and the amount of discharge water (m^3/second). Generally, the MHP (Micro-hydro Power Plant) that is built is a run-off river type where the head is obtained not by building a large dam, but by diverting the river water flow to one side of the river and dropping it back into the river at a place where the required height difference has been obtained. By using a pipe, water is channeled to a powerhouse, which is usually built on the edge of a river. Through the guide vane, the water will flow to rotate the turbine wheel (runner), then the water is returned to the river. The mechanical energy of the turbine shaft rotation will be converted into electrical energy by a generator. The potential for the water of that magnitude will certainly be very beneficial if it can be realized.

There are many potential water resources in Indonesia since it has many rivers that have sufficient head. The rivers have the potential to generate electricity. The hydropower potential in Indonesia according to the Hydro Power Potential Study (HPPS) in 1983 was 75,000 MW [1] [7].

The Kaplan turbine was selected to be studied because it has advantages over other turbines. Hydropower is the most efficient and most primarily available renewable power source to produce electricity [2]. Kaplan turbine works under a broad range of flow rates [3]. The Kaplan turbines have adjustable blades so it is more suitable for the variable head system. The Kaplan turbine is the most appropriate for operation with a low head and a large amount of discharge. The ability of the Kaplan turbine to change both runner and guide vane angles simultaneously enables it to achieve maximum efficiency under varying flow conditions [4]. The Kaplan turbine is a reaction type. It is most suitable for large flow and low head situations [5].

The head required for the Kaplan turbine is low and the required flow rate is large. This is very suitable for the hydrological topography conditions in Indonesia. In this study, the effect of head and flow on the power generated by the generator and its efficiency is studied.

2. MATERIALS AND METHODS

Hydropower plants can be equipped with different types of turbines depending on the head and discharge.

These turbines can be divided into three major types: Francis, Kaplan, and Pelton turbines. In addition, they can be classified as reaction and impulse types. Kaplan Turbine is a reaction-type turbine.

The shaft of the turbine is directly coupled to the electric generator which converts mechanical energy into electrical energy. The Kaplan turbine was developed by Viktor Kaplan in 1913. A Kaplan turbine with adjustable runner blades and adjustable guide vanes is double regulated. Figure 1 shows the configuration of the Kaplan turbine.

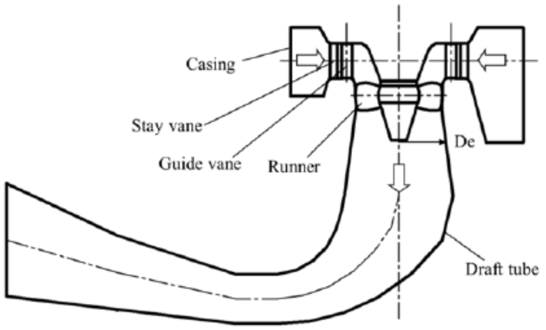

Figure 1. Kaplan Turbine [6]

The research was conducted in the Energy Engineering laboratory, Politeknik Negeri Bandung. The test was conducted using IEC standards. PLTMH conditions are simulated with existing equipment.

2.1. Kaplan turbine arrangement.

The turbine is connected to a swinging field generator consisting of a DC Generator. The power of the generator is dissipated in the resistance load bank. An electrical inductor is located near the end of the shaft to measure the rotational speed of the turbine.

The water is circulated through each unit by a horizontal shaft axial flow pump. The volumetric flow rate is measured by calibrated orifice plate located in the pipeline between the pump and the turbine inlet. Static pressure taps are located in the pipeline upstream and downstream of the orifice plate and equipped scales calibrated in of volumetric unit flowrate (l/sec). The circuit configurations are shown in the installation drawing in figure 2.

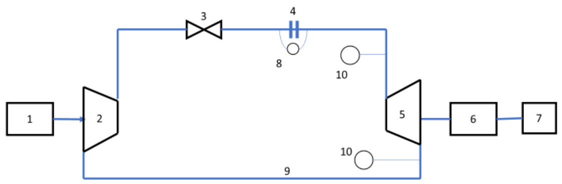

Figure 2. The arrangement of the Kaplan turbine test circuit

Figure description:

1. Motor
2. Axial flow pump set
3. Butterfly valve
4. Orifice plate
5. Kaplan Turbine
6. Dynamometer generator
7. Resistor bank
8. Pressure gauges
9. Interconnecting pipework
10. Pressure gauges

A 400 mm diameter, manually operated, butterfly valve is located on the discharge of the axial flow pump. The butterfly is used to regulate the volumetric flow rate through the circuit.

2.2. Instrumentation

The Kaplan turbine test circuit is equipped with several instruments. All the meters are digital and consist of the following:

- D.C. voltmeter armature
- D.C. ammeter armature
- D.C. voltmeter excitation
- D.C. ammeter excitation
- Tachometer indicator to measure turbine speed
- On the D.C. generator set a 200volt 2 Ampere chopper unit is used to control the field excitation supply to the generator.

2.3. The dynamometer generator

The generator is a 5kW, separately excited D.C. machine, and is mounted in a dynamometer frame. The rotor is excited by a D.C. 200volt 2amp supply derived from the chopper unit. The output generator is 5kW 220 V D.C. on full load. The Machine data specification is listed as follows:

- Generator efficiency 98% at full load
- 5kW 220V at full load
- The full load current is 23A
- Field current is 0.39A-0.49A

2.4. Load bank

When running the generator dynamometer, a resistive load bank should be used.

2.5. Method of measurement and Kaplan test procedure

2.5.1. Method of measurement[9]

a. Pressure gauge
   Pressure is measured before the inlet to the turbine and calculated after the draft cone. According to the

IEC standard, the pressure must be measured in undisturbed flow.

b. Flowmeter
The volumetric flow rate is measured by calibrated orifice plate located in the pipeline between the pump discharge and the turbine inlet. Static pressure taps are located in the pipeline upstream and downstream of the orifice plate. The Incline manometer is used to measure flow rate.

c. Constant of gravity
The constant of gravity is measured based on the test location.

d. Density of water
The water density is taken $1000 kg/m^3$.

e. Generator output power
The generator output power is calculated by multiplying the generator output voltage and current.

f. Efficiency test
Efficiency tests were done by keeping the rotational speed and voltage constant.

2.5.2. Kaplan Turbine test procedure

a. Ensure the mains power supply and the circuit breaker switch are on.
b. Ensure that the pump inlet valve is fully opened.
c. Ensure that the pump discharge valve is fully closed.
d. Start the pump at normal speed.
e. Set Kaplan blade to desire angle.
f. Set guide vane to desire angle.
g. Open discharge valve slowly until the turbine begins to rotate then continue to open the valve until speed 1000 rpm.
h. Turn excitation supply switch and the load switch.
i. Introduce a small load to the generator.
j. Adjust the excitation potentiometer to obtain an output voltage of 220V while the output voltage is increased, turbine speeds will decrease. Turbine speed is maintained at 1000 rpm by increasing the butterfly valve opening.
k. Wait a few minutes for the system to settle.
l. Record the measurement results on the turbine test sheet.
m. Introduce another increment of load. Speed and output voltage should decrease.
n. Adjust discharge valve and excitation potentiometer to obtain output voltage of 220V and speed of 1000 rpm.
o. Record the measurement results on the turbine test sheet.
p. Repeat steps m, n and o until the system is at maximal load.

2.6. Performance test

The fluid quantities involved in all hydraulic machines are volumetric flow rate (Q) and head (H). The mechanical associated with the machine itself are power (P), speed (n), and efficiency.

The following sections describe the calculation and experimental procedure to obtain these characteristics [8].

2.6.1. Turbine power input

$$P_{in} = \rho\ g\ H\ Q\ (W) \qquad (1)$$

Where ρ = mass density of water (kg/m^3)
g = gravitational acceleration (m/s^2)
H = net head across the turbine (m)
Defined as the difference in total head between the inlet to spiral casing and the draft tube outlet.
Q= volumetric flowrate (m^3/s)

2.6.2 Power output

The mechanical power output developed by the turbine is given by:

$$P_{out} = T.2Л.n/60\ (W) \qquad (2)$$

Where T= output torque
n=rotational speed of turbine (rpm)

2.6.3 Turbine efficiency

$$\eta = P_{out} / P_{in} \qquad (3)$$

2.6.4 The electrical power output

$$P_{out\ El} = I.V\ (W) \qquad (4)$$

Where I= generator armature ampere
V=generator armature volt

2.6.5 Turbine generator efficiency

$$\eta = P_{out\ el} / P_{in} \qquad (5)$$

3. RESULTS & DISCUSSION

The results of the test are as follows:

Table 1. The result of the test

impeller turbine angle	guide vane position	speed (Rpm)	Q input (l/s)	Hin (MH₂ O)	Hout (MH₂ O)	V (Volt)	I (A)	H total (m)	Q (m³/s)	Nh (Watt)	Np (Watt)	Pout Generator (Watt)	η Sistem (%)
3	30	1000	45	2.8	0.25	209	0	2.55	0.045	1,123.45	1,011.08	-	-
		1016	51	3.9	0.25	205	2.7	3.65	0.051	1,822.48	1,666.37	553.50	30.37
		1005	56	4.8	0.25	202	5.3	4.55	0.056	2,494.59	2,256.33	1,070.60	42.92
		1014	60	5.8	0.25	205	7.8	5.55	0.06	3,260.20	3,003.54	1,599.00	49.05
		1008	65	6.9	0.25	204	10.4	6.65	0.065	4,231.89	3,839.29	2,121.60	50.13
		1000	70	7.8	0.25	201	12.9	7.55	0.07	5,174.22	4,656.62	2,592.90	50.11
		928	71	8.1	0.25	181	13.7	7.85	0.071	5,456.67	4,557.37	2,479.70	45.44
	40	1030	56	2.1	0.25	212	0.2	1.85	0.056	1,014.28	940.07	42.40	4.18
		1030	63	2.9	0.25	209	2.9	2.65	0.063	1,634.50	1,514.68	606.10	37.08
		996	68	3.6	0.25	201	5.5	3.35	0.068	2,230.25	1,999.48	1,105.50	49.57
		1023	74	4.4	0.25	207	8.3	4.15	0.074	3,006.63	2,767.86	1,718.10	57.14
		1004	80	5.5	0.25	200	11.5	5.25	0.08	4,111.96	3,715.82	2,300.00	55.93
		997	84	6.3	0.25	196	13.8	6.05	0.084	4,975.47	4,464.21	2,704.80	54.36

In this test, the head size changes depending on the valve opening.

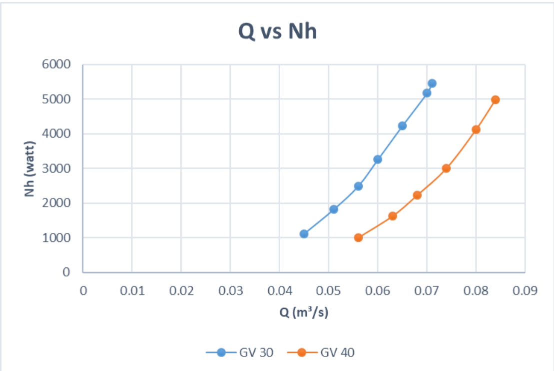

Figure 3. Relations of flow rate to hydraulics Power

The greater the volumetric flow rate, the greater the hydraulic power generated. This corresponds to formula 1. This result applies to guide vane openings 30 and 40. The relationship between discharge and hydraulic power is linear for fixed heads. This hydraulic power is used as input to the Kaplan turbine.

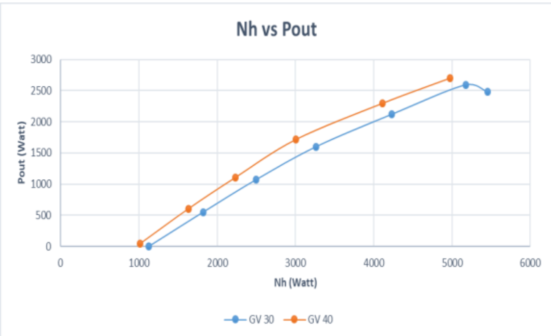

Figure 4. Relations of hydraulics Power to Kaplan turbine power

For a constant turbine rotation, the greater the hydraulic power, the greater the torque produced. This corresponds to formula 2. For a constant rotation, the greater the torque will produce the greater turbine output power. The greater the hydraulic power entering the Kaplan turbine, the greater the turbine output power. The greater the hydraulic power, the greater the generator output. For guide vane 40 openings, the turbine output power is greater than 30 openings.

The generator output power will be greater if the flow rate is greater.

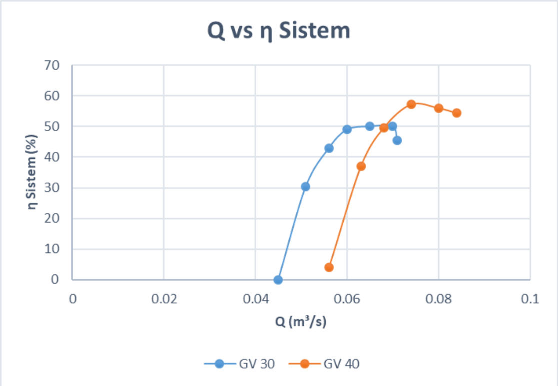

Figure 5. Relations of volumetric flow rate to the efficiency of the system

The greater the flow rate, the greater the efficiency of the system, and at a certain amount it will decrease, this occurs at the guide vane openings 30 and 40. In Figure 5 the relationship between discharge and efficiency is not linear anymore. This is because the greater the flow rate, the greater the loss will be. This will result in reduced generator output which will lead to reduced system efficiency. It can be seen from Figure 5 that the larger the guide vane opening, the higher the efficiency of the system.

The highest efficiency for guide vane 30 openings occurs at 6.65 m head and 0.065 m^3/sec volumetric flowrate, for guide vane 40 openings occurs at 4.15 m head and 0.074 m^3/sec volumetric flowrate.

4. CONCLUSION AND CONTRIBUTION

This study concludes that the flow of water flowing from the valve to the turbine greatly affects water power, generator output, and system efficiency.

The highest efficiency is obtained for the guide vane 40 opening, which is 57.14% with a head of 4.15 and a discharge of 0.074m^3/sec at a certain impeller position (3).

To produce optimum output, it is necessary to pay attention to the discharge settings according to the turbine design.

From test results, The Kaplan turbine can produce a generator output power that is large enough for a low head. It is suitable for use in rural areas in Indonesia which have river flows with low waterfall height.

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