THE STUDY OF 1KW PICO TURGO WATER TURBINES FOR HIGH-RISE BUILDING ELECTRICITY USED IN PUBLIC AREA

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Abstract - Thailand is one of the developing countries with High buildings constructed to meet the increasing populace. The country is located in the tropical zones which abundant rainfall during the rainy season. The rain water over the roof top of the building are left used and considered as the Waste and the Problems. This study will get use of the invaluable rain water from the rooftop of a High-Rise Building creating Head and Flow to drive a suitable Pico Turgo Turbine machine. The experiences of the gravity flow hydropower from a natural water and water fall resources is the primary concern and re-considered in this study. In the building under study, the rooftop has a tendency to store rainwater of 57.6 m3 at the building height 21 meter which is adequate Head and Flow of water stream down to run a Pico Turgo Turbine machine which is directly drive a 1 KW permanent magnet generator. The experimental Pico Turgo Turbine is consisting of a runner unit with 430 mm diameter, 4 water nozzles 10 mm diameter which have 17-degree angle of attack between water jet and bucket and 21 buckets with totally bucket area of 0.0072 m3. The power generated by the device was analyzed and compared with the theory. The theoretical calculation yielded 1,310 Watts of electricity and the experimental result indicated 950 Watts. This output was analyzed with experimental result yielded the efficiency of 72.51%. The output efficiency of this study model was respect to flow design and presented in the recommendation for future optimization use of rain water above ground surface that have a significant volume of water Head and Flow.

Index Terms - Pico Turbine, High-Rise Building, Turgo Turbine

I. INTRODUCTION

A. General

The real estate business in Thailand, especially residential buildings in Bangkok Metropolitan and vicinity area, has significantly increase building projects across the city since the year 2000 till now. Developers have shifted the housing design project from 2-3 bedroom houses to high building housing designs. In 2015 the number of housing units completed in Bangkok area alone was over 52,000 units and most of the erected structures were condominium, with a good number of more project completion scheduled in 2016 and 2017 [1]. The research study was conducted using a High-Rise Pier 93 Building located at Klong 4 district of Thanyaburi, Phathumthani which show in Figure 1. This location is at the east side of Bangkok, and is classified as one of the central districts. The region experiences raining season that can span from July to October of each year [2], and occasional rainfalls from November to December in some cities. Table 1 shows a distribution of rainfall amount expectations in the year.



Figure 1 (a)Phathumthani province, Thailand (b)High-Rise Pier 93 Building located at Phathumthani

Part	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total.(1 Y)
North	130-210	190-280	210-280	100-140	20-40	<10	1226.3
Northeast	210-320	200-300	240-330	100-140	15-30	<10	1395.6
Central	110-190	130-210	260-340	160-200	30-50	<10	1229.7
East	260-360	190-310	290-400	200-250	40-60	<10	1903.4
Southern	90-160	100-170	110-170	230-280	330-380	210-260	2724.2

Table 1: Thailand rainfall in different district (mm)[2]

These rainfalls over the roof top of the building bring to this attention. The Head and Flow of the rain water over this high building is adequate kinetic energy to drive the impulse electrical turbine machine as Pico Turgo Turbine.

B. Turbine Selection:

Turbines are differentiated according to their operational principles [3], and these are: 1. The reaction turbine in which the rotor of the turbine is fully immersed in water and enclosed in pressure casing. The imposed pressure exacts a lifting force on the rotor causing the rotation of the runner. 2. The impulse turbine that are driven by high speed water

jets. The impulse turbines is widely used for Micro hydro and Pico hydro power installation compared to the reaction turbines because the impulse turbine has several advantages such as simple design, greater tolerance of sand and other water particles [4]. 3. The gravity turbine which is driven simply by the weight of water entering the top ofthe turbine and falling to the bottom. The impulse turbine is further classified into 3 main types: the Pelton, the Turgo, and the Crossflow turbine. The crossflow turbine has low running speed requiring substantial speed to drive the generator and efficiency of the cross flow turbine has been measured in laboratory to be around 80% while the efficiency of the Turgo turbine has been reported to be closed to 90% [5]. The Turgo turbine is similar to the Pelton but the jet strikes the plane of the runner at an angle (typically 15° to 25°) so that the water enters the runner on one side and exits on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner and rotate faster than a Pelton for an equivalent flow rate [6].

Turgo Turbine: This turbine is selected for the design installation because it is able to function normally under variable seasonal flows and efficiently at different range of heads [7] . The machine is ideal for remote home-sites. In this study, the direct-drive generator is used because it is suitable for sites from 6 m to 21m head. The pressurized water emerging from the end of nozzle creates the force of water to impact the cup of Turgo turbine and drives the runner which is connected with runner shaft to produce electrical power.

Type of Turbine	Capacity(kW)
Pico Hydro	2 to 30
Micro Hydro	31 to 100
Mini Hydro	101 to 2,000
Small Hydro	2,001 to 2,500
Large Hydro	>2,500

Table 2: Classification of hydro power of capacity [8]

Quantity of electricity is depend on head and flow rate: this means that quality electricity is produced from steady flow from such head. The pressure or head is generated by the difference in elevation between the water storage and the turbine. General classification of hydro power turbine can be stated in terms of capacity of each machine. Table 2 shows the different ratings of the hydro turbine classes[8]. The hydro power plant classifications can also be further grouped according to water head as shown in Table 3.

Type Hydro Turbine	Head(m)
High head	>100
Medium head	30 to 100
Low head	2 to 30

Table 3: classification of hydro power according to head[9][10]

Hence the research study was conducted with a Low Head Pico Hydro Turbine. Turbine type selection depends mainly on characteristics head and flow situation available at the site. Running speed of the generator is depended on turbine type and the electricity demand. A penstock pipe connects the water from the reservoir to the machine. There are expectation of losses in penstock pipe: The head loss due to friction or roughness of pipe wall, length and diameter of pipe, and losses resulting from changes in geometry. These losses contribute to pressure loss in the system design. The hydrostatic pressure(P_g) created from the head is given by Equation (1)

$$P_g = \rho g H \quad (1)$$

Where ρ is the water density, g is acceleration due to gravity and H is head of water. Continuity equation can be developed by Bernoulli's equation, assuming that the flow is steady, laminar and the fluid is incompressible. Considering negligible viscosity, the Bernoulli equation is given by Equation (2)

$$P + \frac{1}{2}\rho v^2 + \rho g z = \text{const} \quad (2)$$

C. Runner Design & Parameterization

The hydraulic head H can be calculated at any location where elevation z, pressure p, and velocity v are known, using:

$$H = z + \frac{p}{\rho g} + \frac{v^2}{2g} \quad (3)$$

where ρ is the density of the fluid and g is gravity. Mean velocity of the free jet from the nozzle is determined from the net head, using:

$$c = \varphi\sqrt{2gH} \approx 0.97\sqrt{2gH} \quad (4)$$

Where the efficiency of the nozzle is φ , generally equal to $0.97 - 0.98$. The flow rate Q at the jet diameter d, can be calculated using:

$$Q = \frac{\pi}{4} d^2 c \quad (5)$$

At the best efficiency point the circumferential speed of the runner is connected with the jet velocity.

$$u_1 \approx (0.46 - 0.47)c \quad (6)$$

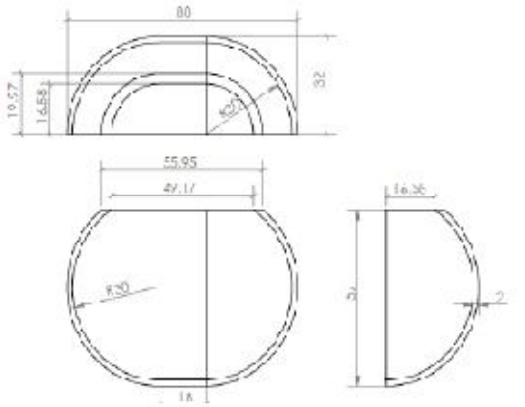
Hence the diameter of the runner is

$$D_s = \frac{60 u_1}{\pi n} \quad (7)$$

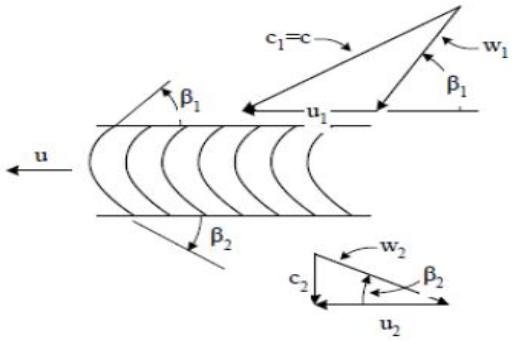
Where n is the runner speed in rpm, the bucket is drawn with the aid of a Bezier curve. At a given radial distance r, the runner peripheral velocity is u_1. At the best efficiency point the flow exits with zero circumferential velocity[11]. The basic fluid flow equations are used to derive simple performance characteristics about the turbine option for the quantitative analysis. The performance variables are turbine power P, overall turbine system efficiency η, and gross head H_g. Two variables will be defined, leaving two unknowns. These variables are combined for a general turbine system.

$$P = T\omega = \eta\rho g Q H_g \quad (8)$$

Where P is the power of the turgo water turbine, T is the torque of the turgo water turbine and ω is the angular velocity of the Turgo water turbine, ρ is density and g is the gravitational constant.



(a)



(b)

Figure 4 (a) Bucket of Turgo Turbine (b) Velocity triangles

The two unknowns are solved using a second equation, which is derived from further analysis of the turbine torque generation mechanism. This analysis may depend on the power available at a specific site and the turbine system efficiency. The efficiency and flow rate required to produce a specified power may equally depend on the variables defined.

Figure 4(a) shows Bucket of Turgo Turbine and Figure 4(a) shows velocity triangles of the water jet impacting the bucket of the turbine[12]. The head loss in the penstock can reduces the inlet jet velocity. The force is concentrated at the jet impact point, with a radius r, assuming the flow enters and exits at the same radius, causing a torque on the runner. The power is the product of the rotational speed at maximum power by the torque. In this research, the angle at which water strikes the blade is 170.

Each turbine system will have a set of requirements and specifications. This will include either site conditions, such as head and flow rate, or output power requirements. There will be environmental requirements, for example if the site may be in an inaccessible location.

D. Scope of Study

The scope of this study including; study on Pico Turgo hydro turbine which can apply to use at low head water condition. The site for this design is PIER93 High Rise Building which have maximum 21 m head of water. The flow rate of water depend on annual rain fall of Thailand at Phathumtani province.

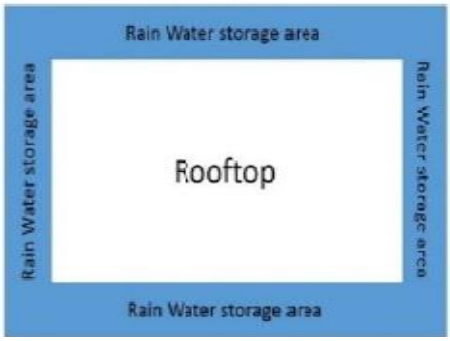
II. EXPERIMENTAL DETILES

A. The Processes in this Study

A reservoir was designed at the rooftop to collect and store rainwater before being passed to the turbine machine. The Pier93 building under study is shown in Figure 3 (a). The rooftop was initially designed as shown in Figure 3(b). The rooftop is reconstructed and enlarged for water collecting at the maximum of 60 m3 as shown in figure 3 (c). The storage can collect 354.15 m3/year of rainwater storage.



(a)Pier 93 High Building **(b)Roof gutter area**



(c) Water storage area on rooftop

Figure 3 Pier 93 High Building

The Quantitative Theoretical Analysis as below

The Pico Turgo Turbine machine has four nozzles and diameter is designed to be 10 mm. The rate of water is 0.0062 m^3/s or 22.3 m^3/h.

B.Pico Turgoturbine Testing

After the completion of preliminary calculation, the testing apparatus is shown in Figure 10 (a) turbine bucket and (b) 24 turbine bucket with runner was assembled to test the electrical power production.

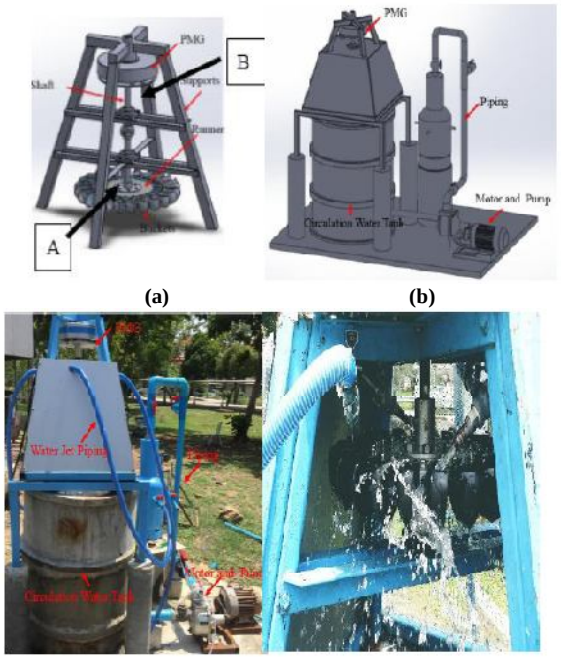
Figure 11 shows the complete picoTugo turbine testing. The testing buckles in Figure 11 (a) are connected to the runner shaft. The measurement of Energy and Efficiency obtained from the test

apparatus were done by installing the Torque sensor at point A and Rotation Sensor at point B. The Torque sensor at point A is used to measure the Torque that is obtained from nozzle water jet impact to the buckets. The rotation revolution of the turbine shaft in RPM at point B can measure when the turbine shaft is turning by this Torque. The torque from the rotation is transmitted to the permanent magnet generator (PMG) in Figure 11 (b). The water circulation from the testing apparatus by using water motor and pump creating water pressure by four of 10 mm nozzles in Figure 11 (c). Figure 15 (d) is the water from nozzle attack to buckets. The power from testing of water turbines $P_{out} = T\omega$ where T , ω is acquired form the water turbine.



(a) Prototype Buckets (b) Prototype Buckets with Runner

Figure 10 Pico Turgo Turbine



(a) (b)

(c) (d)

Figure 11 Pico Tugo turbine testing

(a) 3D the testing buckets connected to PMG(b)the pressure water circulation system(c) the water circulation system connected to the nozzles(d) Water from nozzle attack to buckets

The Building has 21 meters height therefore the water jet velocity is

$$c = \varphi\sqrt{2gH}$$

$= 0.97\sqrt{2x9.81x21} = 19.7$ m/s where $H = 21$ m , $\varphi \approx 0.97$

The flow rate of four nozzles

$$Q = \frac{\pi}{4}d^2c$$

$$Q = \frac{\pi}{4}x0.01^2x19.7$$

$Q_K = 0.0015\ m^3/s$ x $4 = 0.0062 m^3/s$

The Velocity of runner

$$u_1 \approx (0.46 - 0.47)c$$

$$u_1 \approx (0.46 - 0.47)x19.7 \approx 9.1\ m/s$$

Using the generator 400 rpm, therefore the runner diameter is

$$D_s = \frac{60u_1}{\pi n} = \frac{60x9.1}{\pi x400} = 0.43\ m$$

Water can generate power

$$P = \rho gQH$$

$$= 998x9.81x0.0062x21 = 1{,}310\ kW$$

Annual water is 354.15 m^3

Therefore $1.31kW \times 15.87h = 20.78\ kWh/year$

III. RESULTS AND DISCUSSION

A. Data of Power Quantities

Table 7 shows data quantities of 10 mm nozzle diameter with power of the water turbine dependent on flow rate and head water. The result shows that at lowest height of 5 meters, the flow rate is 11.21 m3/h, this generates 152.24 watts of theoretical power, and 101.39 watts of testing result.

Nozzle Dia. (mm)	Head (m)	Flow rate (m^3/h)	Power Theory (W)	Power Exp. (W)
10	5	11.21	152.24	101.39
	7	13.21	252.19	182.86
	9	15.02	367.66	266.59
	11	16.61	496.78	360.22
	13	18.05	638.25	462.80
	15	19.39	791.07	573.61
	17	20.64	954.45	692.07
	19	21.83	1127.74	817.72
	21	22.95	1310.41	950.18

Table 7 shows data quantities of 10 mm nozzle diameter

At the highest head of 21 meters, the flow rate is 22.95 m^3/h, and this head of and water flow rate can convert the power 1310.41 watts of theoretical power, and 950.18 watts of testing result.

The testing result can measure two main resultsincluding; the rotation of the runner (ω) and torque (T) of turbine. Hence, Power (P) can calculated using the formula (P=Tω). In addition. The preliminary design of Pico Turgo Turbine is validated by actual testing that shows the efficiency is 72.5% of power result.

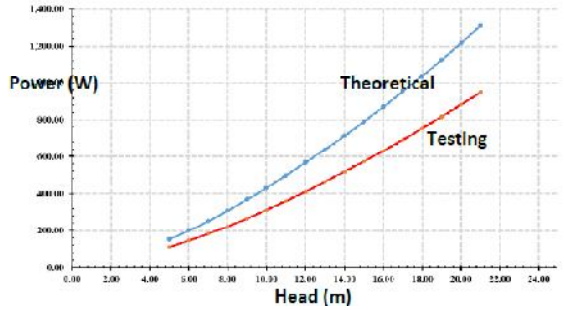


Figure 12 Comparison of Power output between Theoretical and Testing result

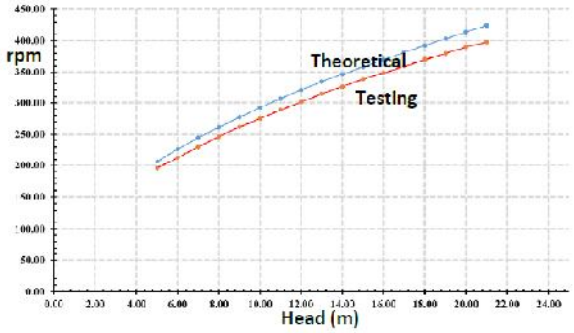


Figure 13 Rotational of runner and water head

Figure 13 shows the relationship between rotational of runner and water head. The turbine operate at about 200 to 420 rpm. The theoretical and testing result has 206.86 rpm, and 195.53 rpm respectively.

From the power of testing result and annual rain water collected is 350 m^3 , this can generate 950.18W x 15.87h = 15.08 kWh/year.

In addition the PIER 93 building has 79 rooms, if waste water from each apartment is channeled to the turbine, it can be estimated that each apartment equipped with about 150L storage facility is capable of generating electricity as shown in Table 8.

Head (m)	Floor	Volume (m^3/year)	Power (kWh/day)	Power (kWh/year)
6	3	711.75	0.0231	8.42
9	4	711.75	0.0424	15.47
12	5	711.75	0.0652	23.82
15	6	711.75	0.0912	33.29
18	7	711.75	0.1198	43.76
			Total	124.76

Table 8: Power form Waste Water

CONCLUSIONS

The effectiveness of the selected Pico Turgo hydro turbine type was seen by the close-range output resultderived from theoretical calculation. This result shows that this experimental Pico Turgo Turbine is suitable for a HighRise Building hydro power design application. A bucket of Pico Turgo Turbine was designed by applying the hydrodynamics theory. This study is a project to develop a low head turbine that may convert rainfall or waste water generate from the building inhabitants towards electric power production for High-Rise Building reducing grid dependence. The research considers annual rain water droops to the designed rooftop storage facility of 354.15 m3 and a building height of 21 meters: it was found that at a constant discharge rate of 22.95 m3/h of water. The theoretical calculation of the design of design of Pico TurgoTurbine generated 1,310.41 W of electricity, the experimental prototype testing generated 950.18 W. The efficiency of Pico Turgo Turbine testing result is 72.51%. The lower value of the testing results due to loses, design system,head loss, friction loss and etc.

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