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Designs and Implements the 'nHy-Fall' Pico-Hydropower For Waterfall and Canal

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***Abstract*—The Hydropower is considered as the most efficient power generation of sustainable energy. This type of technology is commonly based on the falling and flowing of the water, and hence the characteristic of the water can be considered as a potential of kinetic energy. Moreover, this technology is relatively most economic, low emission, sustainable, high flexibility and response to the peak demand. It is capable of rapid response to the demand because it can immediately generate the power, when the water falls and/or flows through the turbines. This means that it can contribute the stability of electricity.**

Nowadays, the nano-technology and characteristic of materials is continually growth and developed, respectively, and hence it is also effected the technology of hydropower turbine such as large construction site, high investment, and then long term of payback period. Therefore, it is necessary to classify the sizing of the Hydropower in order to specify the suitable requirement of design and installation. It is known that there are no international standards and regulations consensus on the definition of sizing the Hydropower. However, it can be approximately classified into as follows; Pico-Hydropower (rated less than 5 kW), Nano-Hydropower (rated less than 10 kW), Micro-Hydro (rated less than 100 kW), Mini-Hydropower (rated less than 1,000 kW), Small-Hydropower (rated less than 6,000 kW) and the upper limit of Hydropower (rated from 6,000 kw up to 30,000 kW), respectively.

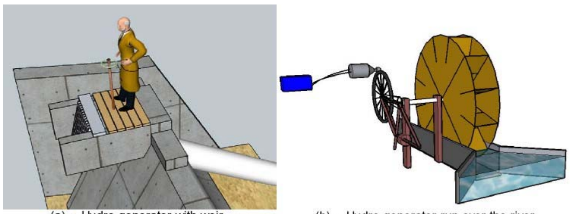
The paper has been designed and implemented the Pico-Hydropower for waterfall and canal, which calls 'nHy-Fall' devices. The prototype devices were carried out at the Sai Yok National Park, Kanchanaburi, Thailand in order to validate and ensure its performance. To achieve the Pico-Hydropower turbine, the mathematic modelling, computer simulation (as MATLAB/Simulink software), computer design (as AutoCAD and/or SolidWorks software) and implementation the prototype was carried out. The proposed 'nHy-Fall' devices can mainly support at the waterfall and canal, while it can also install at the riverbank, in the middle of river, bays, shoreline and coastal estuaries. The proposed generator should be easy to install and maintenance, while the chosen material structure of generator has the corrosion resistance. The generator was also followed the standards and regulations in order to ensure its safety.

Keywords*—Distributed generator, Hydropower, MATLAB/Simulink, Pico, Small-scale,

I. INTRODUCTION

The Hydropower is explained by the flow of the water falls from the higher to the lower levels and/or the stream of the canal and/or river that runs down a hillside. In the means time, it is also included the man-made weir or the dam, which allows the water to reservoir and flows back into the main river. To provide the electricity, the maximum available in the vertical fall of the water can be called 'Gross Head (H)', where it can be also considered as the water flow from the upper stream to the lower stream levels. The 'H' can be divide into 3 main categories as follows; Low Head (less than 10 m), Medium Head (between 10 m-50 m) and High Head (more than 50 m). In addition, the essential of the water flow rate (Q) is described by the volume of the water flowing per second (m^3/s).

According to the characteristic of the Hydropower, the average life span of its facility is more than the other types of sustainable energy resources such as wind turbine and Photovoltaic (PV) etc. The other benefits are supported the water supply, flood control and agriculture. These benefits must also face the challenge impacts of environment as well. Thus, the type of the Hydropower is divided into the dam-based (closed system) and the run-of-the river (open system). The dam base type is most commonly used in the world wide as it can generate a large amount of the power, where it is needed large construction site and investment. While, the run-of-the river type is generally used in agriculture area (not requires the formation of the reservoir), and hence it is necessary to consider the disruption of the ecosystems between the upper stream and lower stream levels of the river as shown in Fig. 1.



(a) µ-Hydro generator with weir (closed pipe system) (b) µ-Hydro generator run over the river (open channel system)

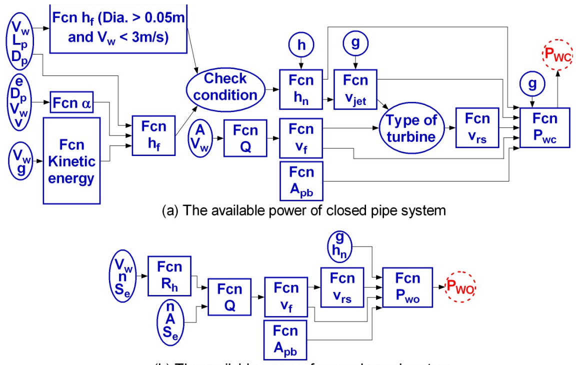
Fig. 1 Simplified constructed model of closed and open system

In Fig.1 shows the simplify construction of the closed system and open system. It is well known that the characteristic of the water flowing in closed and open system is different. And therefore, the proposed mathematical modelling both closed and open system were studied and implemented into the simplified model, and hence the following assumptions are required;

1. The flowing of the water is considered uniformly and identically in the closed system.
2. In the closed system, the losses of head due to friction that has a proportional function to its length is considered (h_f). The other losses such as bend in pipe, valves, cavitation and turbulence are neglected. As these type of losses had a minor effected to the Pico-Hydro, Nano-Hydro, Micro-Hydropower [1-2].
3. The flowing water is considered uniformly through the length of open channel, and this means that the absolute pressure is equal to the atmospheric pressure.
4. The depth of the water, water velocity, area, cross section and gradient slope of open system are considered uniformly as same as the bottom line parallel to each other.
5. The losses due to mechanical transmission and gearbox is estimated as output power performance term.

II. Reviews Mathmetical Modelling of Pico-Hydropower for Closed and Open Systems

The simplified mathematical modelling of hydropower can be divided into 2 main types; closed and open systems. The schematic of the proposed model is summarised in Fig. 2.



(a) The available power of closed pipe system

(b) The available power of open channel system

Fig. 2 Schematic of the proposed model

A. Closed System (Dam Type)

The Bernoulli's equation of steady frictionless is chosen to estimate the total energy (H), and hence it is described in the term:

$$H = h_n + \left(\frac{P}{\gamma}\right) + \left(\frac{V_W{}^2}{2g}\right) \quad (1)$$

When, h_n is the summation of the potential energy, P is the pressure in kPa. γ is the specific weight of water per unit volume in 9,790 N/m^3, V_W is the average velocity of water in m/s and is g the gravitation acceleration in 9.81 m/s^2 [1] and [3]. In practice, the pressure energy is shown in the term of $\left(\frac{P}{\gamma}\right)$ is and the kinetic energy is presented in the term of $\left(\frac{V_W{}^2}{2g}\right)$.

The proposed simplify model of closed system is also considered the ratio of the inertia force to the viscous force. Because the flowing of the water also effects to the diameter of the pipe and the viscosity of the fluid as well. It is commonly known that the circular pipe is mostly used in the closed system, and hence the Reynolds number pipe (N_R) is defined as [1] and [3]:

$$N_R = \frac{(D_p)(V_W)}{v} \quad (2)$$

Where, D_p is the diameter of the pipe diameter in meters, v is the kinematic viscosity of the water at 20°C in 1.005x10^{-6} m^2/s

It is normally estimated the friction factor of the pipe (f) with the principle of conservation of mass to control the volume, which involves the friction in the pipe line at the steady-state. Then, the friction loss in the pipe line at the steady-state with the laminar flow that has the N_R is equal or less than 2,300 can be explained as follows (h_f) [1] and [3]:

$$h_f = \frac{32(L_p)(V_W{}^2)}{(N_R)(g)(D_p)} \quad (3)$$

When, L_p is length of pipe in metres.

However, the friction loss in the pipe line neither completely smooth nor completely rough (as shown in Table 1) at turbulent flow that has N_R more than 2,300 can be described as [1-3]:

$$h_f = \left(\frac{1}{\alpha^2}\right)\left(\frac{L_p}{D_p}\right)\left(\frac{{V_W}^2}{2g}\right) \quad (4)$$

$$\alpha = -2\log\left[\left[\frac{\left(\frac{e}{D_p}\right)}{3.7}\right] + \alpha\left(\frac{2.51}{N_R}\right)\right] \quad (5)$$

Conversely, the proposed model is applied the Hazen-Williams coefficient (C) as shown in Table 2 to estimate the pipe diameter more than 0.05 m and water velocity under 3 m/s, and hence it can be expressed as:

$$h_f = \left[\frac{6.87(L_p)}{{D_p}^{1.165}}\right]\left(\frac{V_W}{C}\right)^{1.85} \quad (6)$$

Therefore, the available mechanical power of the simplified hydropower in the closed system (P_{WC}) is:

$$P_{WC} = \gamma(h - h_f)A_{pb}[(v_{jet}, v_f) - v_{rs}] \quad (7)$$

It can be noted that, the A_{pb} depends on the site installation system, either closed or open systems. In the closed system, the circular pipe is considered, and therefore the A_{pb} is the cross section area at the outlet of nozzle.

$$A_{pb} = \pi {r_j}^2 \quad (8)$$

It is well known that the types of hydro turbine are divided into impulse and reaction turbines. The impulse turbine uses the nozzle to eject the jet water and strike the blades in the air, and hence the rotates blades is rotated, then v_{jet} is:

$$v_{jet} = \eta_{jet}\sqrt{2(g)(h_n)} \quad (9)$$

Where, η_{jet} is efficiency of nozzle.

While, the reaction turbine is immersed the blades within the flow of water, and hence the kinetic energy of water is converted via the shaft power (based on linear momentum). Hence, v_f is:

$$v_f = \frac{Q}{(b_k)(b_W)[2(\pi)(r_r)]} \quad (10)$$

When, b_k is the blades factor that is estimated from the number of blades, b_w is the width of the blade of the runner and r_r is the radius of the runner in metres. Where, the v_{rs} is typically equal to or less than 47 percent of water velocity that strikes the blades [2]:

$$v_{rs} = 0.47(v_{jet}, v_f) \quad (11)$$

B. Open System (Run-Of-The River Type)

It can be noted that the average water velocity (V_W) in the open system is kept within the limits that depends on the type of channel. This is due to avoid the erosion and plant growth at the gradient area. The V_W of the natural channel is lower than 0.7 m/s, while the sandy soil channel has 0.4-0.6 m/s. In the means time, the V_W of the artificial (concrete) channel is up to 10 m/s. However, the V_W of typical should be within 0.3-0.5 m/s [2]. Then, the V_W in an open system is given by:

$$V_W = C\sqrt{(R_h)(S_e)} \quad (12)$$

Where, C is the Chezy's resistance factor, R_h is hydraulic radius of the channel and S_e is the hydraulic gradient of channel (head loss due to slope per 100 m e.g. if the channel falls 0.5 m every 100 m, then S_e is equal to 0.5). According to the C in the open system, it can be estimated by using the Manning roughness coefficient (n) as shown in Table 3 [2].

$$C = \left(\frac{1}{n}\right) R_h^{\left(\frac{1}{6}\right)} \quad (13)$$

Where, the R_h can be described as:

$$R_h = 10^{\left[\frac{\log\left[\frac{(V_W)(n)}{\sqrt{S_e}}\right]}{\left(\frac{2}{3}\right)}\right]} \quad (14)$$

Then, the available mechanical power of water turbine in an open system (P_{WO}) is:

$$P_{WO} = \gamma(h_n)A_{pb}[v_f - v_{rs}] \quad (15)$$

When, h_n is the depth of flow and A_{pb} is the cross section area of blades (bucket) that immerses the water.

Table 1: The roughness factor (e) of various commercial pipes [1-3]

Pipe Material	*e* (mm)
Stainless steel (new)[3]	0.002
Polyethylene[2]	0.003
Fiberglas with epoxy[2]	0.003
Seamless commercial steel (new)[2]	0.025
Asbestos cement[2]	0.025
Commercial steel (new)[3]	0.046
Cast iron (enamel coated)[2]	0.120
Asphalt cast iron[3]	0.120
Iron (galvanised)[3]	0.150
Seamless commercial steel (galvanised)[2]	0.150
Concrete (steel forms, with smooth joints)[2]	0.180
Seamless commercial steel (light rust)[2]	0.250

Table 2: Hazen-William coefficient (C) for various pipes [1-2]

Pipe Material	*C*
Cast iron (10 years)	107-113
Steel (Riveted)	110
Cast iron (new)	130
Steel (brush tar and asphalt)	150
Steel (new uncoated)	150

Table 3: Manning roughness coefficient (n) for open channel system [2]

Channel	Type of channel	*n*
Natural	Clean	0.022
	Gravelly	0.025
	Weedy	0.030
	Stony, cobbles	0.035
Artificial	Brass	0.011
	Steel (smooth)	0.012
	Steel (painted)	0.014
	Cast iron	0.013
	Concrete (well finished)	0.012
	Concrete (unfinished)	0.014
	Planed wood	0.012
	Clay tile	0.014
	Brickwork	0.015
	Asphalt	0.016

III. PROPOSES 'NHY-FALL' DEVICES THE PICO-HYDROPOWER

The proposed design and implementation has been verified the effectiveness with the prototype of 'nHy-Fall' devices (bases on Pelton Turbine and Cross Flow Turbine). According to [1] and [4-7], the Permanent Magnet (PM) Generator was chosen, designed and implemented. The structure of 'nHy-Fall' was developed from Superlene Nylon plastic (Polyamide; PA6), Acrylic plastic (Poly Methyl Meth Acrylate; PMMA), and/or stainless steel 316L, which prevents the oxidation and corrosion, respectively. The proposed devices were generated the electricity up to 0.6 kW (each segment unit generate at least 0.3 kW, max. 3A) as shown in Fig.3 to Fig.5. The proposed devices have considered as the light weight (around 3 kg) due to its approximate sizing of each segment unit is 0.5m x 0.5 m 0.5m.

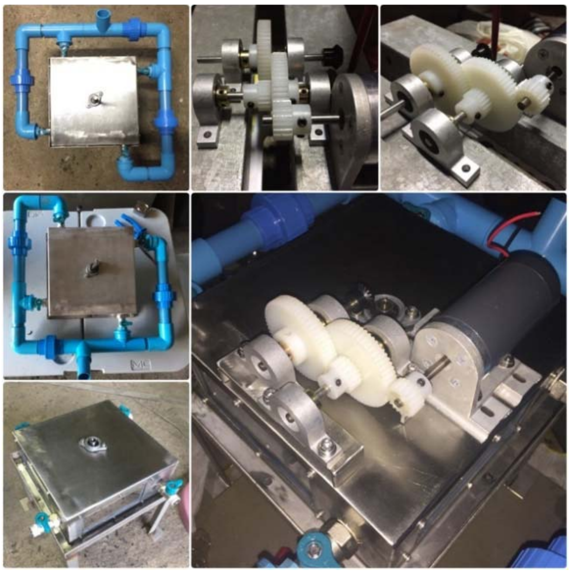


Fig. 3 'nHy-Fall' device with Pelton Turbine

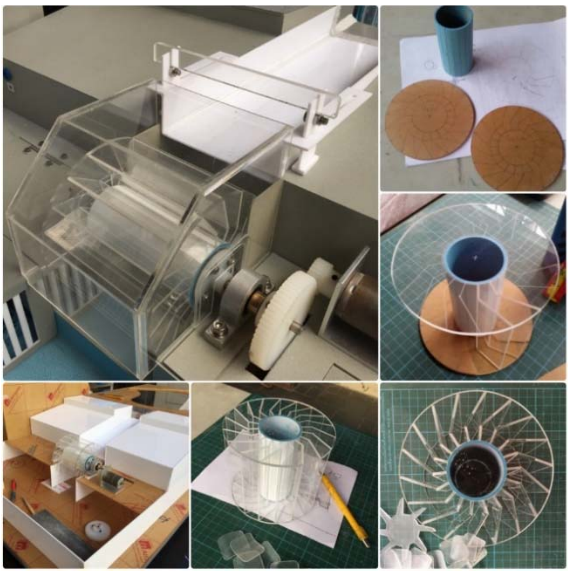


Fig. 4 'nHy-Fall' device with Cross Flow Turbine

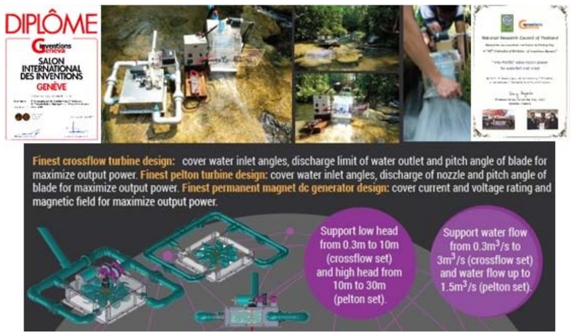


Fig. 5 'nHy-Fall' installs at the Sai Yok National Park Thailand

IV. CONCLUSION

It is necessary to consider the location of installation in order to design and develop the 'nHy-Fall' devices. These will be ensuring that the suitable type of materials and structure are chosen. To implement and analyse the characteristic of turbine, the Bernoulli's equation and the friction losses are required. Thus, the most and commonly design is based on the Pelton Turbine and Cross Flow Turbine.

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