KKU Engineering Journal

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Feasibility study of VLH hydro turbine installation at Nam Pung hydropower plant, Thailand

Weerapon Nuantong[1)], Sirivit Taechajedcadarungsri*[2)] and Narong Khampool[3)]

[1)]Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand
[2)]Department of Mechanical Engineering, Faculty of Engineering, Ubon Ratchathani University,
Ubon Ratchathani 34190, Thailand
[3)]Mechanical Maintenance Section, Power Plant Maintenance Department, Northeastern Region Hydro Power Plant Division, Electricity Generating Authority of Thailand, 40250, Thailand

Received June 2016
Accepted August 2016

Abstract

The aim of this research was to study the feasibility of installing a very low head (VLH) hydro turbine downstream of the Nam Pung hydropower plant thereby increasing the potential of renewable energy resources of the Electricity Generating Authority of Thailand (EGAT). The water head level was limited to less than 2 meters and the flow rate to below 5 m^3/s due to site constraints. The selected hydro turbine was an axial flow turbine with an efficiency of 86.4%. The power output was 84.61 kW. Investment analysis was subsequently applied to estimate feasibility of the project. Analyses of results showed that the project is worthwhile in terms of investment. The payback period of actual price was 0.83 and 0.88 years and for the general price, it was 3.68 and 4.04 years, with annual interest rates of 6.75% and 12.625% respectively. The projected project lifespan is 25 years.

Keywords: Hydropower, Very low head hydro turbine, Investment analysis, Feasibility

1. Introduction

The downstream areas of hydropower plants are considered as valuable renewable energy resources. Nonetheless, sites with a low water head level and high flow rate must be carefully considered. The installation of a Very Low Head (VLH) hydro turbine has a significant role in the development of the downstream area of hydropower plants in order to generate electricity. In addition, the VLH hydro turbine project is a solution to lack of energy and reduce pollutants in the environment from electricity generation using fossil fuels or coal.

Previously, development and study of low head hydro turbines has been a solution to a lack of energy in rural and remote areas. In particular, a low head water source is acceptable for hydropower production with the installation of an axial flow turbine at a project site (irrigation weir and river) [1-3]. This variety of turbine is applied for a low head range of less than 5 meters [4]. For instance, in the research of Sutikno and Adam, an axial flow turbine was developed in order to be run on river sites, alongside a water head level of no more than 1.2 meters. The turbine exhibited efficiency of 90% and power output of 2,071 Watts, which a rotating speed of 180 rpm [5]. Additionally, a study by Adhikari et al. in Nepal, displayed a low head turbine implemented for use amid rural electricity. The power output of 1 kW for the prototype turbine was designed at a rotation speed of 1,058 rpm and a flow rate of 25 l/s. The efficiency of the turbine was estimated to be in the range of 60% [6].

At present, in general of the VLH axial flow turbines are acceptable. In the above researches, energy was converted from very low head water sources, including irrigation, wastewater, and drainage systems. The hydraulic turbine, showing the relationship between the flow conditions and the operating system was applied to analyze the cost-effectiveness of implementation amid the project [7]. Notably, investments in hydropower plants are evaluated using the indices B/C and net present value (NPV) [8-9]. For example, in dam-toe schemes in India, the cost of small hydropower projects had been estimated [10].

Accordingly, the objective of this research was to perform a feasibility study for installing a VLH hydro turbine project downstream of the Nam Pung hydropower plant, Amphoe Phu Phan, Sakon Nakhon of Thailand. Turbine efficiency was used to evaluate the power output of the project, without considering the loss from generators and gear transmission. Power output is applied for investment analysis with the aim of comparing the total estimated cost of installation with the economic evaluation of the project (payback period (PB), benefit cost ratio (B/C) and net present value (NPV)). Despite this being a project for hydropower below 500 kW (micro hydro), it is effective in nature and produces clean energy for the development of renewable energy sources as a solution to a lack of energy in the future.

*Corresponding author. Tel.: +66 4535 3309
Email address: sirivit.t@ubu.ac.th
doi: 10.14456/kkuenj.2016.26

This is coupled with decreasing pollutants in the environment arising of electricity generation from fossil fuels or coal.

2. Evaluation of hydropower

2.1 Downstream hydro-energy potential evaluation at hydropower plant

The potential downstream evaluation at Nam Pung hydropower plant in Thailand was based on the water flow into the reservoir using average volume over a five year period. This study intended to evaluate turbine types suitable for installation downstream of the hydro power plant with the limitation of a low water head source. One particular constraint of this turbine project is that, the turbine installation must not affect the present efficiency of the original power plant, as shown in Figure 1.

Water flow on the local site exhibiting a low head at downstream of Nam Pung hydropower plant was chosen for this project. Figure 2 shows, for installation purposes, the Very- Low-Head (VLH) hydro turbine.

Figure 1 Downstream water flow at Nam Pung hydropower plant

Figure 2 Local turbine installation site

The water flow into the reservoir at Nam Pung hydropower plant displays an average volume, over a five year time frame, of approximately, $127x10^6$ m^3/ year. As shown in Figure 3, water flow into the reservoir has been recorded every month from the year 2010 till 2014.

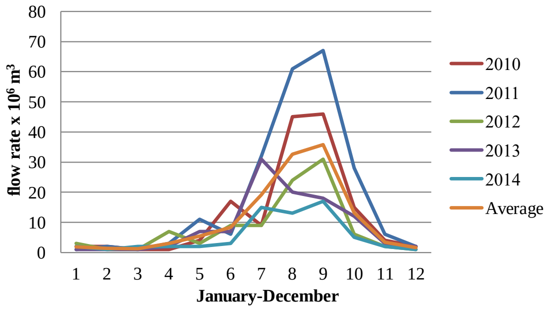

Figure 3 Water flow record into the Nam Pung hydropower plant resevoir

From Figure 3, the average flow of water in September displayed a maximum volume of roughly $35.8x10^6$ m^3, and a minimum of $1.2x10^6$ m^3 in March.

Consequently, the VLH hydro turbine flow rate $(Q_{\sec})$ for this design was under the limitation of not exceeding average water flow into the reservoir, i.e. in the region of $127x10^6$ m^3/year, as defined in Eq. (1).

$$Q_{\sec} = \left(Q_{year} \Big/ TxP_f \right) \quad (1)$$

From Eq. (1), Q_{year} accounts for average volume water flow into the reservoir per year and T signifies time (seconds in one year). Furthermore, the common plant factor (P_f) was defined as 80%. In this case, therefore, the evaluation of the flow rate initially for design and selection of the turbine was set to around 5 m^3/ s. For the water head, conditions were based on less than 2 meters, where the local site was located at the downstream area of Nam Pung hydropower plant in the north-east of Thailand, as shown in Figure 2.

2.2 Selection of turbine types

From application of the turbine range chart, turbine types were selected as seen in Figure 4.

From the range chart in Figure 4, turbine types were selected based on the conditions found at the project area. As per matching from the range chart, the propeller turbine (axial flow turbine) was decided upon as the prototype model. Besides that, the condition of the local site was approximated from the neighboring range chart.

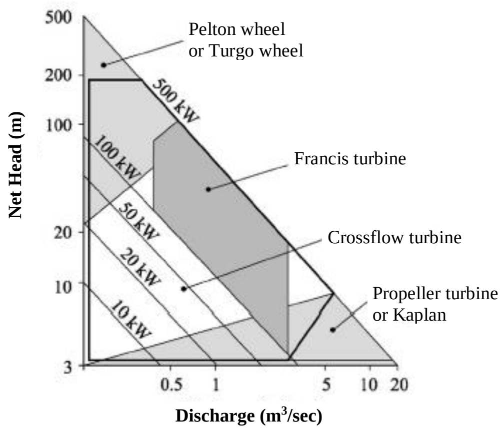

Figure 4 Range chart showing typical turbines [11]

Table 1 Estimated cost of VLH axial flow turbine project

Parts	Item	Unit cost (THB)		Difference (%)
		General cost	Actual cost	
1	Civil work	2,436,768.00	411,000.00	83.13
2	Control equipment	1,340,222.40	322,000.00	75.97
3	Turbine generator set	1,827,576.00	439,000.00	75.98
4	Management	487,353.60	293,000.00	39.88
	Total	6,091,920.00	1,465,000.00	75.95

2.3 Axial flow turbine and power output

With regards to an axial flow turbine, for instance, in the research of Wei et al., efficiency was approximately 91% at rotation speed of 210 rpm [12]. As mentioned in the work of Yang et al. [13] and Ge et al. [14], this turbine type was evaluated as exhibiting efficiency of 89.36% and 86.4% respectively, under operation of a runner speed of 200 rpm at a water head level of 2.5 meters [13-14]. Moreover, due to this project taking place on a local site, it was therefore based on a water head level of 2 meters. The axial flow turbine efficiency was evaluated at in the region of 86.4%. This figure corresponds with operating conditions of local sites similar to that of work by Yang et al. [13], and Ge et al. [14]. The scheme of the initial turbine model is shown in Figure 5.

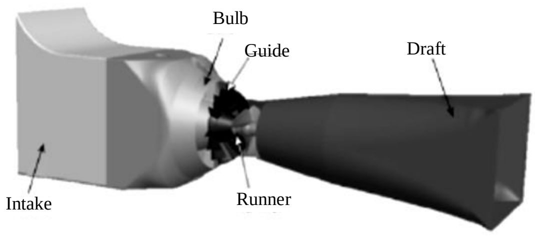

Figure 5 An axial flow turbine [12]

Power output for this project was evaluated at approximately 84.61 kW, showing the relationship as,

$$P_{project} = \rho g Q_t H_t \eta_t \quad (2)$$

where $P_{project}$ is the hydropower power output by the turbine. Q_t is the flow rate and H_t signifies the total head. ρ accounts for the density of water (998.2 kg/ m^3) and g accounts for the acceleration due to gravity (9.81 m/s^2). Note that, the turbine efficiency (n_t) was approximated from literature report (86.4%). Subsequently, in terms of this work, the energy loss from generator and gear transmission was not conducted in considering the power output.

3. Investment analysis of a VLH hydro turbine project

3.1 Estimated cost of project

In general, the major cost incurred by micro-hydro power plants consists of civil work, control equipment, turbine generator set and management; as shown in Figure 6. The total budget was proposed in accordance with the variance of $1,500 to $2,500 per kW of power capacity [11]. Notably, at the time of the study, an exchange rate of THB36 to one American Dollar was in place, and thus applied for use within the study.

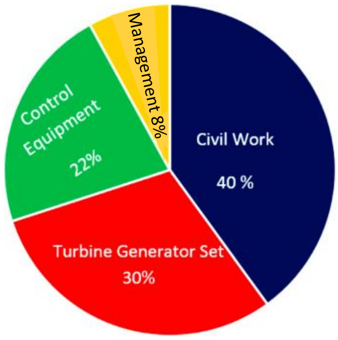

Figure 6 Estimated cost of main divisions amid micro-hydro power plants [11]

Accordingly, in section 3.1 was it was evaluated that the cost of the micro-hydro power plants for this project related to 84.61 kW, consisting of two cases as follows. In the first case, the estimated costs were evaluated using the general price according to reference from Elbatran et al. [11] by an average value of $2,000 or about THB 72,000 per kW. In the final case, the estimated costs were evaluated for the actual price of the project. Consequently, the estimated costs for both cases are compared as shown in Table 1.

As per Table 1, the comparison evaluated the cost between general price and actual price of the project according to a difference of total cost of around 75.95%. Due to the local site of the project being selected to install the VLH axial flow turbine, it is near the original hydropower plant. For the most part, the civil works and the control equipments are modified for use from the original power plant. Moreover, the structure of the weir was applied as the simple model for example, as shown in Figure 7. Furthermore, the VLH axial flow turbine was manufactured within the agency of the Electricity Generating Authority of Thailand (EGAT), which is owned by the hydropower plant. Management of action amid this project was trouble-free and had the overall effect of reducing cost as presented in Table 1.

Figure 7 Weir (Stop Log) [15]

Table 2 Economic Analysis Results

Project lifetime (25 years)				
Details	**General Price**		**Actual Price**	
Interest rate (%)	6.75	12.625	6.75	12.625
BCR	3.63	2.29	15.08	9.51
NPV (THB)	15,996,853.59	7,833,767.85	20,623,773.59	12,460,687.85
PB (years)	3.68	4.04	0.83	0.88

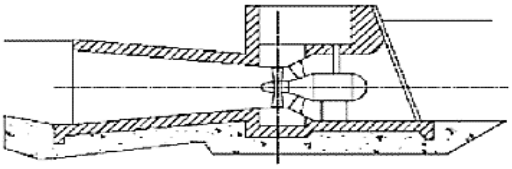

Figure 8 Side view detail of an axial flow turbine [16]

Figure 7 shows, the weir (Stop Log) selected as the optimal model for the local site of the project in Figure 2, which is simplified and cost reducing. An axial flow turbine was installed on the weir for side section detail as shown in Figure 8. In addition Figure 5 presents initial detail of an axial flow turbine, consisting of five parts: the intake, the bulb, the guide vane, the runner and the draft tube. In accordance with the principle of torque transmission on an axial flow turbine, the generator was arranged on the bulb, and the shaft was connected on the runner. For the VLH axial flow turbine, the rotation speed was given as low speed. As a consequence, gears were applied to increase the rotation speed of the generator in order to transmit the mechanical energy from the shaft axial on the runner.

3.2 Estimated revenue of the project

The hydropower of the VLH axial flow turbine project at 84.61 kW was appraised to estimate the revenue from electricity sales as per the following:

$$revenue = P_{project} \times hr_{year} \times Unit\_price\_sale \quad (3)$$

Where hr_{year} is the time in one year (hours), *Unit_price_sale* is the average unit price of electricity sales of EGAT for voltage levels of 230 kV (THB 2.5 from wholesale tariff given by MEA and PEA [17]). Hence, the revenue of electricity sales per year is in the region of THB 1,852,959.

3.3 Economics analysis

The economics assessment of the VLH hydro turbine project was the key point of the investment decision amid this project. The revenue of project as a cash flow diagram is presented in Figure 9.

For a cash flow diagram of a 25 year project lifespan with a capital cost of (a) THB 6,091,920 (general cost) and (b) THB 1,465,000 (actual cost), a fixed annuity per year of THB 1,852,959, and a salvage value of THB 0 are the case study of this investment. Analysis comprised of benefit cost ratio, net present value and payback period.

a. Benefit Cost Ratio (BCR)

BCR is the analysis to compare between present value of benefit and cost of an investment on a ratio basis as follows:

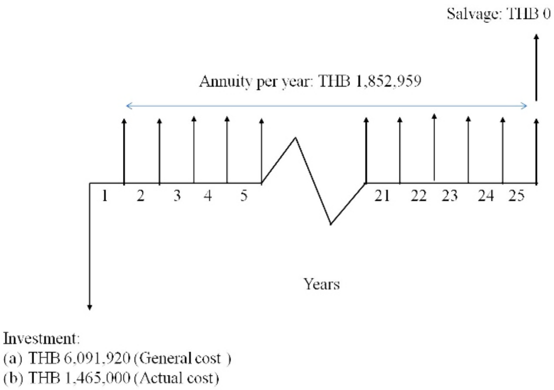

Figure 9 Project cash flow diagram

$$BCR = \frac{\sum_{0}^{n} \frac{R_n}{(1+r)^n}}{\sum_{0}^{n} \frac{I_n}{(1+r)^n}} \quad (4)$$

where R is revenues of project, I is cost of an investment, r is interest rate and n is the lifespan of the project. Note, BCR is equal to or higher than 1, i.e. suitable for investment.

b. Net Present Value (NPV)

NPV signifies the difference between revenues and cost of investment. For this project, NPV is analyzed to model the present value of future returns according to the following relationship:

$$NPV = \sum_{i=0}^{i=n} \frac{R_i - I_i}{(1+r)^i} \quad (5)$$

where i is period of project [18].

c. Payback Period (PB)

PB resulted as the repayment period of all costs as calculated by taking into account the number of years [19].

4. Results and discussion

This work, an investment decision criteria; for an adjustment of time, was put forward to analyze engineering economics. Total estimated cost and revenue of the project were applied in order to evaluate the benefit cost ratio, net present value and payback period. The analyses of results are presented in Table 2.

Interest rates of 6.75% and 12.625% were utilized, and a project lifespan of 25 years was inducted into the study. As shown in Table 2, the total estimated cost and revenue of the project were financially evaluated and employed to compare the price of a micro-hydro power plant between general price and actual price of work.

In the initial case, the general price and revenue of the project were analyzed economically via interest rates of 6.75% and 12.625%. BCR was evaluated as 3.63 and 2.29 respectively, with a difference of 36.91%. NPV was appraised for a difference of 51%. Difference of PB was 9.78%.

In the ultimate case, the actual price and revenue of the project was applied as interest rates of 6.75% and 12.625%. BCR was appraised as 15.08 and 9.51 respectively, with a difference of 36.93%. The difference of NPV was 39.58%, and PB was 6.02%.

Thus, by comparing the two cases, difference in percentage was shown amid the BCR and PB, with both results close to being equal. Nonetheless, the NPV exhibited a significantly higher difference. Notwithstanding, both cases were calculated according to interest rates of 6.75% and 12.625%. What's more the benefits of the project, when viewed using engineering economics are cost effective. Considering that BCR >1 and NPV >0, this demonstrates that the benefits are greater than the cost of the project. Meanwhile, the payback period is lower than 5 years, bearing in mind a project lifespan of 25 years. Besides that, the actual price case of this project was estimated the best at THB 1,465,000 as seen in Table 1. A PB of 0.83 and 0.88 years was given when the interest rates used were 6.75% and 12.625% respectively.

5. Conclusions

This research set out to study the feasibility of installation of a Very Low Head (VLH) turbine at Nam Pung Dam in Thailand; an important undertaking in the development of the downstream area of the hydro power plant. The local site, hydro head level was limited to 2 meters and the flow rate to 5 m^3/ s. The turbine type chosen was a propeller turbine (axial flow turbine). Turbine efficiency was subsequently assessed according to literature, where performance was 86.4%. The outcome of the power output was 84.61 kW as based on the condition limit of the local site as well as the efficiency of the turbine. Ultimately, the engineering economics exhibited the benefits of the project, thus allowing for the decision regarding investment to take place. By processing the study of investment analysis, two cases were compared and presented; expressly, the cost of the micro-hydro power plants and general and actual price. Both cases illuminated the benefits of the projects, and the fact that they were indeed, worthy of investment. Specifically, the actual price or budget of the project showed that the payback period was 0.83 and 0.88 years, the interest rates were 6.75% and 12.625% respectively and the project lifetime was 25 years.

6. Acknowledgements

This research was financially supported by Rajamangala University of Technology ISAN (RMUTI), Thailand.

7. References

[1] M. Ramos H, Simão M, Borga A. Experiments and CFD analyses for a new reaction microhydro propeller with five blades. J Energ Eng. 2013;139:109-17.

[2] M. Ramos H, Simão M, N. Kenov K. Low-head energy conversion: A conceptual design and laboratory investigation of a microtubular hydro propeller. Mech Eng. 2012;2012:1-10.

[3] Muis A, Sutikno P. Design and simulation of very low head axial hydraulic turbine with variation of swirl velocity criterion. Int J Fluid Mach Syst. 2014;7:68-79.

[4] Sangal S, Garg A, Kumar D. Review of optimal selection of turbines for hydroelectric projects. Int J of Emerg Tech Adv Eng. 2013;3:424-30.

[5] Sutikno P, K. Adam I. Design, simulation and experimental of the very low head turbine with minimum pressure and free vortex criterions. Int J Mech Mechatron Eng. 2011;11:9-16.

[6] Adhikari P, Budhathoki U, R. Timilsina S, Manandhar S, R. Bajracharya T. A study on developing pico propeller turbine for low head micro hydropower plants in Nepal. J Inst Eng. 2013;9:36-53.

[7] M. Ramos H, Borga A, Simão M. New design solutions for low-power energy production in water pipe systems. Water Sci Eng. 2009;2:69-84.

[8] Forouzbakhsh F, Hosseini SMH, Vakilian M. An approach to the investment analysis of small and medium hydro-power plants. Energ Pol. 2007; 35:1013-24.

[9] Ilak P, Krajcar S. Assessment of investment in small hydropower plants. Energ Environ Res. 2013;3:33-44.

[10] Singal SK, Saini RP, Raghuvanshi CS. Optimization of low-head, dam-toe, small hydropower projects. J Renew Sustain Energ. 2010;2(4):1-13.

[11] Elbatran AH, Yaakob OB, M. Ahmed Y, Shabara HM. Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: a review. Renew Sustain Energ Rev. 2015; 43:40-50.

[12] Wei Y, YuLin W, ShuHong L. An optimization method on runner blades in bulb turbine based on CFD analysis. Sci China Technol Sci. 2011;54:338-44.

[13] Yang C, Zheng Y, Zhou D, Ge X, Li L. Bidirectional power performance of a tidal unit with unilateral and double guide vanes. Adv Mech Eng. 2013;2013:1-11.

[14] Ge X, Feng Y, Zhou Y, Zheng Y, and Yang C. Optimization study of shaft tubular turbine in a bidirectional tidal power station. Adv Mech Eng. 2013;2013:1-9.

[15] Rampano B. Water control structures: designs for natural resource management on coastal floodplains. Sydney: NSW Department of Industry and Investment; 2009.

[16] Lautier P, O'Neil C, Deschenes C, Ndjana HJN, Fraser R, Leclerc M. Variable speed operation of a new very low head hydro turbine with low environmental impact. Proceeding in Electrical Power Conference; 2007 Oct 25-26; Montreal: Canada. Montreal: IEEE; 2007. p. 85-90.

[17] Electricity Generating Authority of Thailand. Wholesale tariff for MEA and PEA. Bangkok: EGAT; 2011.

[18] Bulgaria–Serbia IPA Cross-border Programme. Comparative study of small hydropower stations. Bulgaria: Bulgaria–Serbia IPA; 2011.

[19] Pasalli YR, Rehiara AB. Design planning of micro-hydro power plant in Hink River. Procedia Environmental Sciences 2014;20:55-63.