Financial Sustainability of a Grid Tied Micro Hydro Power Plant at Varying Penstock Diameter and Design Flow Rate

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Abstract: Micro hydro power is a renewable source of energy and is commonly utilized for remote communities for electricity generation. However, micro hydro power can also be grid tied system supplying energy to a distribution utility as a viable commercial power producer. Sustainability relies on the financial and other benefits brought about the micro hydro power plant during its operation. Financial sustainability is evaluated using simple financial indicators such as net present value, internal rate of return and payback period. However, financial indicators are affected by the design of the micro hydro power plant as the capital investment is dependent upon this. Using cost analysis models available in literature and adjusted to local standards, a method for determine the financial sustainability of a micro hydro power plant has been developed. This method is then tested in a case study proposed micro hydro power plant. With varying penstock diameter and design flow rates, financial indicators where generated and then compared. From the results, it is evident that the lowest cost micro hydro power plant may not be as desirable for a grid tied system as compared to community-based system.

Key Words: micro hydro power, financial sustainability, penstock variation, design flowrate

1. INTRODUCTION

Micro hydro power or MHP mostly belongs to hydroelectric power plant with a capacity between 1kW to 100kW (Bracken, Bulkeley, & Maynard, 2014). MHP has been utilized for electricity generation in remote areas in many countries as practical solution for both off-grid and grid connected systems (Khan, 2015). Off-grid systems are mostly intended for rural electrification provided electricity to communities. In off-grid system, the least capital cost is mostly desired. However, in the grid-tied systems, the least cost may not be optimum indicator for financial sustainability and therefore a more thorough financial evaluation method is necessary. Zema et al. (Zema, Nicotra, Tamburino, & Zimbone, 2016) have developed methodology to evaluate the feasibility of low head MHP plants installed in irrigation systems. Similarly, another methodology presented by Signe et al. (Bertrand, Signe, Ferrão, & Fournier, 2017) is based on a linear approach to identify the feasibility of the MHP project. Financial indicators are affected by many factors and among this is the hydrology. Hydrology is the assessment of the available water flow rate for the MHP project and from the hydrology a design flowrate is determined. In off-grid system, the design flowrate is often selected based on the lowest flowrate in a year while some MHP utilize the annual average flow rate. (Harvey, Brown, & Hettiarachi, 1993). The lowest flow rate approach provides simple and cheap controls as the flow rate is assured to be almost constant. The annual average flowrate approach on the other hand will require some manual seasonal control but with the added benefit of more power to the community. In grid-tied system, annual average flow and maximum flow may be chosen. The decision is based on optimum power generation with acceptable capital cost. It is therefore crucial that the different flow rate design schemes must be financially evaluated. Another important factor that affects the financial sustainability is the MHP system design. Among the many components of the MHP, one of the biggest contributors in terms of cost and power output is the penstock (Kumar & Singal, 2015). Given the same gross elevation head, penstock size variation in terms of diameter effects the net head and thus affects the power output. Furthermore, the larger the penstock diameter, more financial resources are needed. In this study, variation of penstock diameter is considered.

The financial analysis is applied to a proposed MHP case study with a gross head of 60m and with annual flowrate variation shown in figure 1. The analysis will utilize two flowrate design data with (1) annual average flowrate and (2) maximum flowrate. The financial analysis will also consider two penstock sizes: larger penstock will result in higher cost but with lower losses and small penstock with lower cost and with higher losses. The losses in the penstock affects the net head. Table 1 shows the summary of the financial analysis case scenarios.

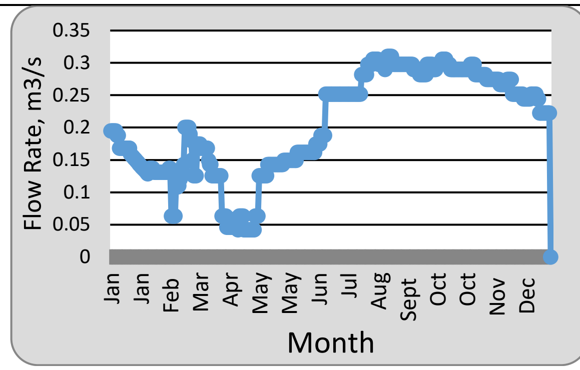

Fig. 1. Annual flowrate variation for proposed MHP case study

Table 1. Case study specifications

Case Study	Abbre-viation	Flow Rate m3/s	Gross Head, m	Net Head, m
Small Penstock - Average Flow	SP-AVE	0.206	60	46.5
Large Penstock - Average Flow	LP-AVE	0.206	60	54
Small Penstock - Maximum Flow	SP-MAX	0.310	60	46.5
Large Penstock - Maximum Flow	LP-MAX	0.310	60	54

2. METHODOLOGY

The financial analysis requires the calculations of capital costs, annual revenues and annual cost. A cash flow given an assumed operational life is then generated. From the cash flow the net present value PV, internal rate of rerun IRR and payback period P is calculated.

2.1 Capital Cost

The investment cost of the Pilar Hydro project can be calculated given the design head and flow rate and using available empirical formulas based on literature. Agiddis et al. (Aggidis, Luchinskaya, Rothschild, & Howard, 2010) capital cost model is based on a data from hydro sites from northwestern region of the UK in the range 25–990 kW. Equation 1 is used to calculate the capital cost given the head, H and power output P.

$$Cp = 1100000\left(\frac{P}{H^{0.35}}\right)^{0.65} \quad \text{(Eq. 1)}$$

2.1 Revenue

The revenue is a function of the annual average flow rate, net head, system efficiency, operating hours and tariff rate. Equation 2 is used to calculate for the yearly revenue.

$$R = SG(Q)(H)(EFF)(hr)(Rate) \quad \text{(Eq. 2)}$$

Where:
SG = Specific Weight of Water = 9.8KN/m3
Q = Annual Average Flow rate in m3/s
H = Net head in meters
EFF = system efficiency
hr = Hours in operation per year
Rate = fixed tariff rate in Php/KW-hr

The net head H is the difference of the gross head and head loss. For the case study, the gross head is measured at 60 m while the head loss was calculated to be 6 m and 13.5m for large penstock and small penstock case study, respectively.

2.1 Annual cost

The annual cost for the case study is based on the operation and maintenance cost (CCOM), depreciation cost (CDE) and Cost to operate agricultural machineries (CAG). COM is split into fixed maintenance cost FC and variable maintenance cost VC. FC is calculated as a fraction m1 of the electromechanical cost CEME plus a fraction m2 of the civil engineering cost CCE shown in equation 3 (Kaldellis, Vlachou, & Korbakis, 2005). The electro mechanical cost CEME can be calculated based on the KW capacity and the hydraulic head given by equation 4 in USD (Aggidis et al., 2010)

$$FC = (m_1)C_{EME} + (m_2)C_{CE} \quad \text{(Eq. 3)}$$

$$C_{EME} = 13560\left(\frac{P}{H^{0.2}}\right)^{0.56} \quad \text{(Eq. 4)}$$

Civil engineering cost C_{CE} can be evaluated as fraction of the total investment cost *Cp* shown in equation 5. This is with the assumption that the *Cp* is the sum of the C_{EME}, C_{CE} and, C_{ED}; where C_{ED} is the engineering and design cost. C_{ED} can be evaluated as a percentage f of C_P between 5 – 10% (Kaldellis et al., 2005).

$$C_{CE} = (1-f)Cp - C_{EME} \quad \text{(Eq. 5)}$$

The variable operation and maintenance cost VC is the cost incurred by repair or replacement of major components of the power plant that has shorter life as compared to the entire power plant. VC can then be evaluated as a fraction of the CEME with a life span n_k shown in equation.

$$VC = C_{CE}(r_k) \quad \text{(Eq. 6)}$$

For all the four case studies, a cash flow is generated using the previously discussed equations. The cash flow is assumed to operate for 20 years.

3. RESULTS AND DISCUSSION

The calculated results of the financial analysis are shown in table 2. The values shown are both for large penstock case study and small penstock case study. Values for both maximum flow rate as well as average flowrate are also shown.

Table 2. Large and small penstock calculated cost

Parameter	Units	Large Penstock	Small Penstock
head Net	meters	54	46.5
Flowrate Ave	m^3/s	0.206	0.206
Flowrate Max	m^3/s	0.31	0.31
Operation hours	hr	7920	7920
Power AVE	KW	63	54
Power MAX	KW	95	82
Energy MAX	KW-hr	537,073	462,479
Energy AVE	KW-hr	443,314	381,742
Capital MAX	PHP	14,989,213	14,076,792
Capital AVE	PHP	12,212,682	11,499,710
EME Cost MAX	PHP	4,883,751	4,567,305
EME Cost AVE	PHP	3,879,471	3,628,099
Engineering MAX	PHP	1,049,245	985,375
Engineering AVE	PHP	854,888	804,980
Civil Cost MAX	PHP	9,056,217	8,524,111
Civil Cost AVE	PHP	5,280,040	4,996,684
OEM Cost MAX	PHP/year	257,937	242,044
OEM Cost AVE	PHP/year	137,393	129,372
Var Cost MAX	PHP/n_k	976,750	913,461
Var Cost AVE	PHP/n_k	775,894	725,620

Referring to table 2. It is shown that significant differences can be noticed for the power output for the different case studies. This is an obvious result as large penstock will have less head loss compared to small penstock and given the same flow rates, the larger penstock will have greater power output. It can also be observed that the capital cost as well as annual cost are higher for the case study with higher power output. Although the differences in annual cost is usually attributed to larger equipment for larger capacity powerplants, the differences maybe smaller in the actual power plants as the capacity differences is due to differences in head and not in flow rate. For each of the case study, a cash flow diagram was developed to calculate for the financial indicators namely the net present value, internal rate of return, and payback period. Sample cash flow diagram is shown in table 3 while the summary of the financial indicators for all four case studies are shown in table 4.

Table 3. LP-AVE Cash flow diagram in millions of Philippine Pesos

Year	1	2	3	4	5	. . .	20
Rev	2.66	2.66	2.66	2.66	2.66	. . .	2.66
OEM	.14	.14	.14	.14	.14	. . .	.14
Dep	.12	.12	.12	.12	.12	. . .	.12
Net income after tax	2.38	2.38	2.38	2.38	2.38	. . .	2.38
Net cash	2.27	2.27	2.27	2.27	2.27	. . .	4.21

One of the simplest financial indicators is the payback period in which the lowest value is desired. Among the case studies, the Large penstock with average flow (LP-AVE) has the lowest payback at 5.4 years. This is followed by the Large penstock with maximum flow (LP-MAX) with a payback period of 5.7 years. However, it can be observed that the large penstock with maximum flow has negative present value assuming a 16% interest rate. Among all the case studies the large penstock with average flow (LP-AVE) provides the highest financial returns. Aside from the financial indicators mentioned in the study, the weighted average cost of capital or WACC can also be used to determine the financial sustainability of the project. However, this requires the identification of other variables such as cost of equity and cost of debt in which does not covert in this study. Using assumed values for the value of equity and debt of 30% and 70% of capital cost respectively, the WACC for the case studies is at 5.94%. This is assuming a cost of equity and debt of 10% and 6%.

Table 4. Summary of financial indicator

Case Study	Capital Cost Php	NPV at 16% Php	IRR %	Pay -back years	Present Value
SP-AVE	11.50M	.80M	17.1%	6.0	12.30M
LP-AVE	12.21M	2.31M	19.0%	5.4	14.52M
SP-MAX	14.08M	.32M	16.4%	6.3	14.40M
LP-MAX	14.99M	-1.46M	13.9%	5.7	13.53M

4. CONCLUSIONS

A method in the evaluation of the financial sustainability of a micro hydro power plant has been presented. The method utilizes cost analysis from literature from which was adjusted for the Philippine standards. For micro hydro power systems, it can be concluded that the maximum power approach in the design may not result in financial sustainability as shown in table 4. There are many factors attributed to this behavior and one of the clear evidences is the capital cost model shown in equation 1. The capital cost is indirectly propositional to the head and thus as the head increases, the capital cost decreases given the same power output. This can also be attributed to the annual cost. The assumption of higher power output will result in higher revenues in which should result in more favorable financial sustainability may not necessarily be true due to higher annual costs as the annual cost is a function of power output. It should be noted that the capital cost used in this study are based on empirical data for large hydro power schemes. Although adjustments are made to match Philippine standards, the models do not account for specific micro hydro site characteristics. This characteristic ranges from having natural resources available at the site in which will decrease capital cost to lower logistical cost as micro hydro equipment are smaller. It is then recommended that further studies should be made to account for micro hydro specific characteristics in the determination of financial sustainability. Furthermore, weighted average cost of capital should also be considered as a financial indicator as it considers many aspects of financial resources such as investors and debt.

5. ACKNOWLEDGMENTS

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