

Feasibility Analysis Model for Mini Hydropower Plant in Tioman Island, Malaysia

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ABSTRACT

This study focuses on the technical, theoretical and financial analysis of a hydro power plant, which is considered as dependable and sustainable among all other forms of renewable energy. Hydropower energy is broadly used all over the world, whether in the form of mini-hydro for a single village or a massive dam to serve the entire country. Industrialized countries have utilized their hydro potential extensively. However, in the developing world, particularly in the equatorial zone, hydropower remains an option with considerable potential for satisfying energy needs. The study was conducted using the RETScreen Clean Energy Project Analysis software. Based on hydrology analysis, the design of mini hydro is optimized by considering costing, efficiency, expected operating and capacity factor. In addition, plant design and size are evaluated by using capacity factor, NPV and payback period. From the financial analysis, a NPV value of RM3.5 million and payback period of 10.8 years is obtained for the underlying project.

Keywords: Mini hydropower plant, Net present value (NPV), Payback period, Retscreen Analysis software, Renewable Energy, Turbine

INTRODUCTION

The most viable and sustainable energy in Malaysia is hydropower. It is a renewable energy technology that requires high investment (capital cost) and can be highly profitable when it has been done large scale by Tenaga Nasional Berhad (TNB), the sole utility provider in Malaysia. Hydropower is Eco-friendly and reduces minor amounts of greenhouse

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gases compared to other large scale power plants. In addition, it supplies amounts of power at little marginal operating cost and it can be attuned—to some extent—to meet consumer demand.

The scope of this mini hydropower plant study includes:

- a. Technical aspects and design
- b. Financial and cost analysis
- c. Economical feasibility
- d. Environmental impact
- e. Payback period and NPV value

In the early 1920s, several mini hydropower projects were undertaken in Malaysia. It is recorded that the first hydroelectric plant was constructed on the Sempam River near Raub, Pahang in 1900 by the Raub-Australian mining company [1]. This plant continues to operate today [1]. This source of energy feeds the national grid, operated by Tenaga Nasional Berhad (TNB) which accounts for 20% of its total generation capacity [1].

To date, there are 12 large-scale hydropower stations (10 plants in the Peninsular Malaysia, 1 plant in Sabah and 1 plant in Sarawak) and 58 mini-scale hydropower stations (36 in Peninsular, 5 in Sabah and 9 in Sarawak) [1]. The Bakun project is one example of large-scale hydropower projects in Malaysia with a total generating capacity of 2.4GW [1].

MINI HYDROPOWER PLANT POTENTIAL IN PULAU TIOMAN

Table 1 shows some identified proposed locations for mini hydro power plants in Tioman Island. From these collected data, it can be inferred that Tioman Island has a good prospect in developing reliable and sustainable mini hydropower plants. Thus mini hydro power plants can replace the existing diesel generators which are classified as fossil fuel power plant.

The reconnaissance study identified 6 sites for mini hydro sites on Tioman Island, for off grid generation to supply specific villages. Currently, the island is powered by diesel generators which are expensive to operate and require an unsafe diesel fuel delivery method. There is a mini hydro power plant of Sg. Mentawak. This stream is also suitable for mini hydro generation. The existing plant may need to be re-sized for the mini hydro generation which will greatly reduce the installation

Table 1: Identified Mini Hydropower Potential Sites in Pulau Tioman [2]

| No. | Stream Name | Site | Available head, m | Catchment Area, km ² | Annual Flow rate, m ³ s ⁻¹ | Available Power, kW |
|-----|---------------|------------|-------------------|---------------------------------|--|---------------------|
| 1 | Sg. Air Besar | Kg. Tekek | 260 | 3 | 0.126 | 192.8 |
| 2 | Sg. Lalang | Kg. Lalang | 160 | 4 | 0.17 | 160.1 |
| 3 | Sg. Paya | Kg. Paya | 160 | 2 | 0.08 | 75.3 |
| 4 | Sg. Nipah | Tg. Nipah | 120 | 7 | 0.29 | 204.8 |
| 5 | Sg. Keliling | Kg. Juara | 120 | 4 | 0.17 | 120.1 |
| 6 | Sg. Mentawak | Kg. Juara | 220 | 5 | 0.21 | 272 |

cost. All the sites were feasible for a mini hydro generation because the island has good terrain characteristics with Mount Kajang and Seperuk and plenty of streams flowing year around through these hilly regions. Using the study as a basis, Tioman Island has sufficient rainfall for a viable hydro generation. And a potential new site at Sg Riak with lower head (60m) was explored.

TECHNICAL ASPECT AND DESIGN OF MINI HYDRO POWER PLANT

Turbines can be categorized mainly in two types: Impulse and Reaction. Table 2 shows the difference between Impuls and Reaction type turbines [3].

Table 2: Types of Turbine

| Turbine Type | Head Classification | | |
|--------------|-------------------------------------|--|---|
| | High (>50m) | Medium (10-50m) | Low (<10m) |
| Impulse | Pelton Turgo Multi-jet Pelton | Crossflow Turgo Multi-jet Pelton | Crossflow |
| | | Francis (spiral case) | Francis (open-flume) Propeller Kaplan |
| Reaction | | | |

The selection of a proper turbine for a specified head (Z) and flow rate (ϕv), turbine diameter (D) and rotational speed of the turbine (ω) play a significant role. Diameter are related to head and flow rate by [3]:

$$\Phi_v = \frac{\pi d^2 \sqrt{2gz}}{4} \quad D = 7,7 \quad \frac{\Phi^{1/2}}{(gz)^{1/4}} 7,7 = \Delta, \text{ specific diameter} \quad (1)$$

Angular velocity is related to head and flow rate by:

$$\omega = \frac{2u}{D} = \frac{20,48 \sqrt{2gz}}{D} \quad \omega = 0,178 \frac{(gz)^{1/4}}{\Phi^{1/2}} 0,178 = \Omega, \text{ specific angular velocity} \quad (2)$$

Pelton and Kaplan turbines retain very high efficiencies when running below the design flow. In contrast, the efficiency of the cross flow of Francis turbines falls down more sharply if it runs below half of its normal flow.

Proposed Mini Hydro Plant Model

Figure 1 shows weir constructed to channel the river water into a screening channel before entering the penstock. For remote area, automatic racking system installed to periodically remove the leaves and pieces of wood that block the screening gate. If the screening gate gets choked, the turbine will trip if the water intake drops below the minimum volume. To restore is time consuming, need to mobilize personnel to the intake site for screen cleaning, time taken will cause water loss and opportunity loss for energy generation.



Figure 1: The Intake of River Water and Automatic Racking System

Figure 2 shows a valve is installed at the intake to isolate the penstock for the purpose of maintenance. Level gages are installed to monitor and control generation as to maintain the residual flow (when the inflow is below the maximum plant capacity) as per the JPS requirement the downstream of the intake will not be totally dry.



Figure 2: Control Water Valve and Steel Type Penstock

The penstock is steel pipes that are mounted on the surface (large hydro plants the penstock is underground either solid rock supported). There is a huge force acting on the pipes from the hydraulic pressure when the units run. The steepness of the mounting is limited to 45 degrees in order to manage the stability of the pipe under various operations. This cause the pipe length many times more than the head (in this research project for the head of 60m, the budgeted pipe length is 700 m). Any bending of the pipe route is reinforced by concrete.

Figure 3 and Figure 4 show that Pelton type of turbine and powerhouse for the turbine, generator transformer and control. Outdoor transformer needs to be caged to avoid animal and human intrusion which can cause flash over Station is designed for remote operation, the station will be unmanned.

FINANCIAL AND COST ANALYSIS OF MINI HYDROPOWER PLANT

According to Malaysian Hydrology Department (JPS) requirement, the residual flow rate of $0.05\text{m}^3/\text{s}$ is allocated and the site hydrology data indicate that the flow rate of $0.21\text{m}^3/\text{s}$ can be used for this project [4]. Minimum 70% availability of water required in order to carry



Figure 3: Pelton Type Turbine and Power House



Figure 4: Transformer to Step Up the Voltage

out this project. Table 3 shows Pulau Tioman Mini Hydro Scheme Project Design.

Table 3: Design Criteria for Mini Hydro in Pulau Tioman

| Site Conditions | Unit | Estimate |
|------------------|-------------------|---------------------------------|
| Project name | | Renewable Energy (Mini Hydro) |
| Project location | | Tioman Island, Pahang, Malaysia |
| Gross head | m | 60.0 |
| Residual flow | m ³ /s | 0.05 |
| Firm flow | m ³ /s | 0.21 |

Table 4 shows the Pulau Tioman site hydrology analysis (collected from the Malaysian hydrology analysis department). Based on the hydrology analysis shown in Table 4, minimum 0.26m³/s volume rate is required with 70% of the availability of water flow. The design of mini hydro is optimized based costing, efficiency, expected operating and capacity factor.

The annual energy production graph in Table 5 indicates that the water flow is being used by the turbine considerably very large, estimated at 82.5% of the total availability of water. The adjustment of flow factor is essential to study the risk factor of the project if the hydrology profile doesn't materialize as forecasted in Table 5 above. System characteristics have been used to calculate the overall plant efficiency to derive the forecasted energy generation. The parameters have been used are typical numbers for the plant size between 100kW to 500 kW.

The parameters that have been used to determine the plant design flow are:

- a) The size of the plant
- b) Capacity factor
- c) Net Present Value (NPV)
- d) Payback period

Table 4: Hydrology Analysis for Pulau Tioman

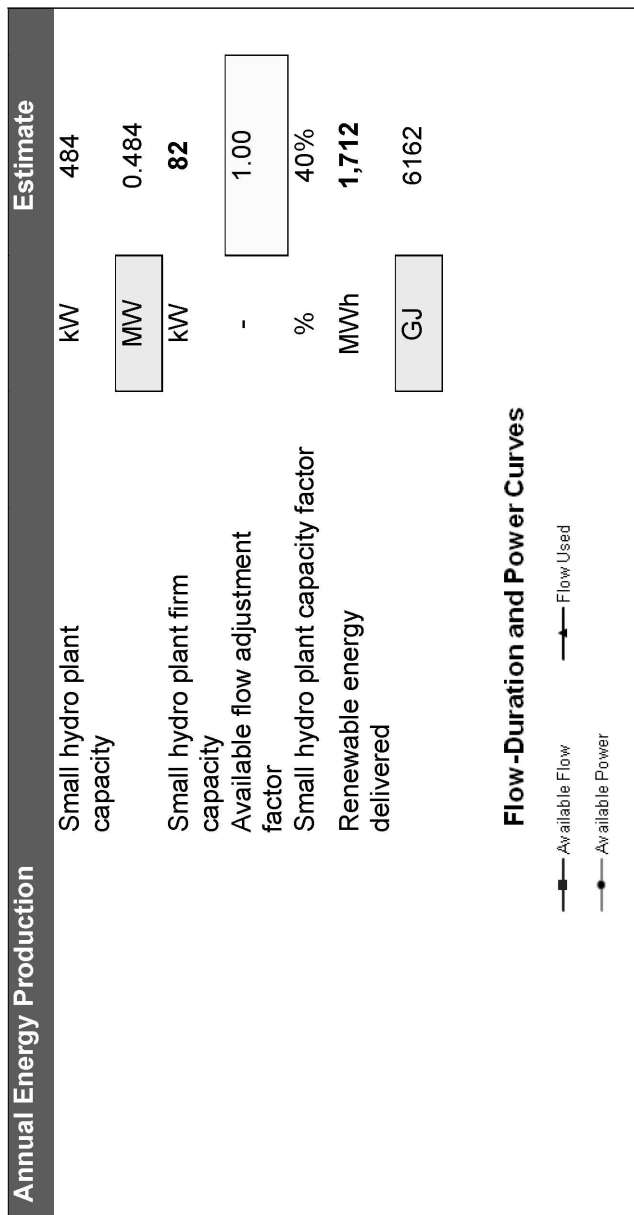
| Hydrology Analysis | | Estimate |
|---------------------------------|-----------------|-------------------------------|
| Flow-Duration Curve Data | | |
| Rated capacity flow | Time (%) | Flow (m³/s) |
| | 0% | 2.58 |
| | 5% | 1.72 |
| | 10% | 1.44 |
| | 15% | 1.20 |
| | 20% | 1.00 |
| | 25% | 0.78 |
| | 50% | 0.40 |
| | 55% | 0.36 |
| | 60% | 0.32 |
| Design firm flow | 65% | 0.28 |
| | 70% | 0.26 |
| | 75% | 0.22 |
| | 100% | 0.06 |

As the plant size increases, the demand of water flow increases. The complexity of this project is the capital cost may vary. The cost will increase, if the availability of water flow decreases and it may affect the plant capacity factor as generated energy may not be sufficient to cover the project cost.

According to Table 6, design flow of 0.7 m³/s gives the shortest payback period. The size of the plant shall be 305 kW, 53% CF and energy generation of 1.409 million kWh. Since the higher size machine can provide higher energy with only one additional year for payback, NPV method is used to calculate the optimum design. According to the NPV calculation, the optimum design flow is 1.1m³/s which the maximum plant capacity is around 484KW and the firm capacity is 82KW. This will be most suitable proposed capacity for mini hydro power plant.

Based on the total cost, NPV, and payback period, the lowest cost along with most efficient hydro power plant are the key factors to be considered while choosing the capacity of the plant. Table 7 shows the progression of the NPV over the various design flows, the optimum

Table 5: Annual Energy Production Graph



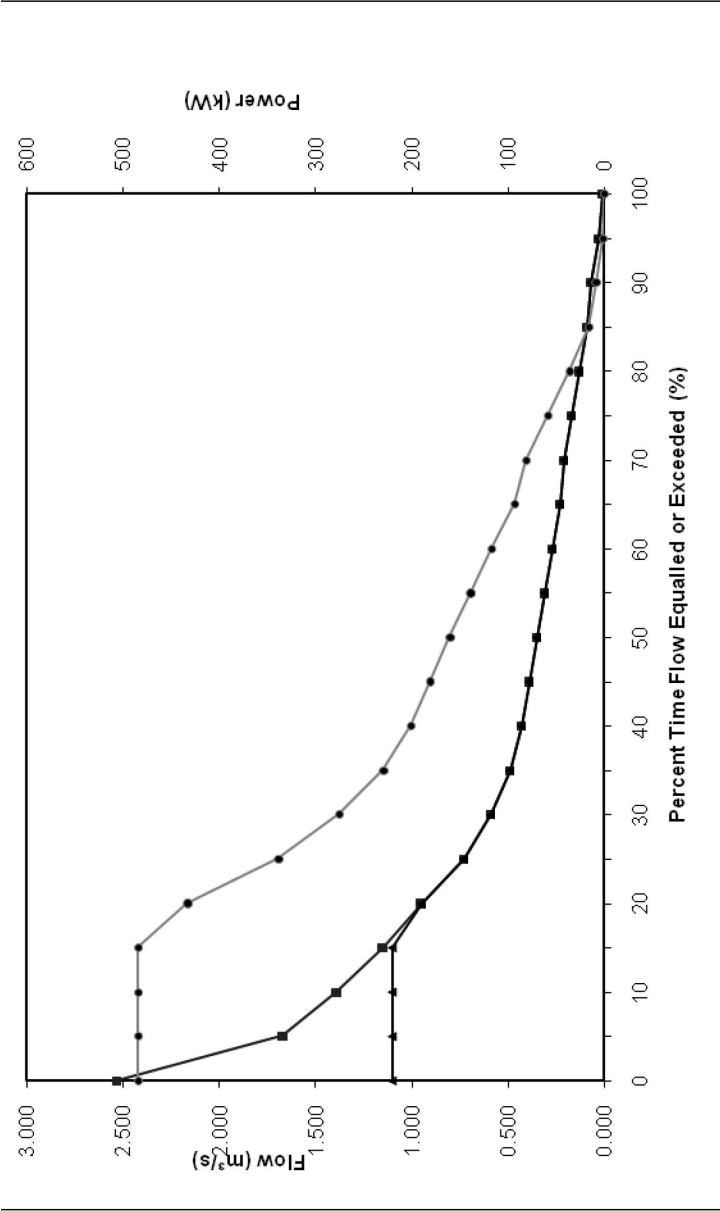


Table 6: Plant Design Flow

| Design Flow (m ³ /s) | NPV (RM) | Payback Period (Year) |
|---------------------------------|------------|-----------------------|
| 0.70 | 1240250.20 | 9.5 |
| 0.80 | 1321346.69 | 9.7 |
| 0.90 | 1389238.94 | 9.9 |
| 1.00 | 1415975.16 | 10.3 |
| 1.10 | 1416029.89 | 10.8 |
| 1.20 | 1387957.32 | 11.4 |
| 1.30 | 1327662.03 | 12.1 |

design flow is not at the highest water flow, but each combination of turbine and hydrology profile will give an optimum flow anywhere in the hydrology flow range.

The process of determining the design flow iterated between design flow and turbine selection as indicated below. Each turbine has different efficiency profile. The influential factor of the hydrology profile is the product of efficiency and duration of the time. The turbine runs at the capacity which is determined by the hydrology profile. The objective is the find the most efficient way to convert the hydro inflow into energy based on the duration curve of the hydro inflow and determine the most optimum efficiency curve that maximize the energy generation. Figure 5 shows the interaction between the inflow duration curve and efficiency curve to deliver the energy generated

Table 8 shows the best turbine type that has been selected based on maximum efficiency, design flow, capacity factor, net present value (NPV) and payback period.

Based on the above calculation results, it can be concluded that, for the highest energy generated and NPV value, the best choice is Pelton turbine. The cash flow profile is indicated in the Table 9 and Figure 6 below, the tax regime cannot be determined as it depends on the developer, and not considered tax in deriving the cash flow.

The net present value of this project is RM 1,416,030 at a discount rate of 10%. The proposed project is a high return in short term dura-

Table 7: The Progression of the NPV over the Various Design Flow

| Design Flow (m ³ /s) | NPV (RM) | Payback Period (Year) |
|---------------------------------|------------|-----------------------|
| 0.10 | -898508.83 | >35 |
| 0.20 | -250251.99 | 22.6 |
| 0.80 | 1321346.69 | 9.7 |
| 0.90 | 1389238.94 | 9.9 |
| 1.00 | 1415975.16 | 10.3 |
| 1.10 | 1416029.89 | 10.8 |
| 1.20 | 1387957.32 | 11.4 |
| 1.80 | 674801.11 | 16 |
| 1.90 | 511924.02 | 16.4 |
| 2.00 | 322883.83 | 16.9 |

tion compare to other power plant projects. The breakeven point of the return is at 10.8 years. The total energy delivered is up to 1712MWh and tariff rate RM 0.24per kWh. This hydropower plant project can be considered one of the very minimal risk projects.

Calculation of revenue as below:

$$\text{Revenue} = \text{Output Power (MWh)} \times \text{Tariff Rate (RM)} = \\ 1712\text{MWh} \times 0.24\text{kWh} = \text{RM}410, 880$$

The hydrology sensitivity study in Table 10 shows the detail of the NPV value and the payback period if there are any changes in the rainfall. If there is any decrease in the rainfall, it will affect the volume of the river level. Based on hydrology study, if the volume of rainfall decreased by 30%, the project would still be viable and profitable. In a nutshell, rainfall is playing a significant role in this project. RM200, 000 has been budgeted for the maintenance cost that incurred in the period of 20 years, for the major overhaul turbine, control and instrumental cost.

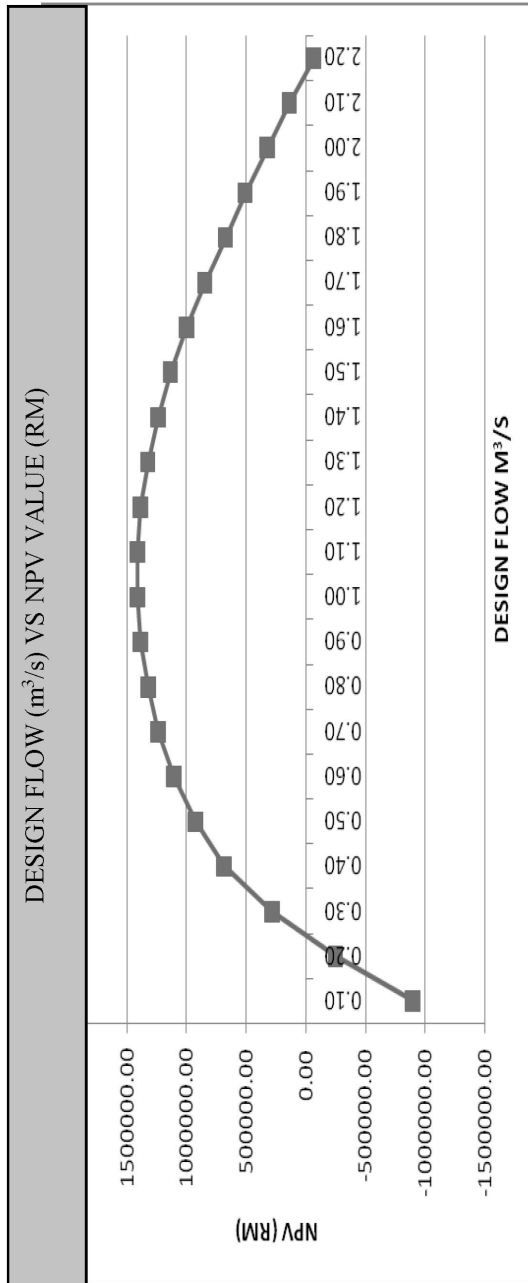


Figure 5: Design Flow (m³/s) versus and NPV Value (RM)

Table 8: Overall Calculation to Determine the Best Turbine for Mini Hydro Power Plant

| Turbine Type | Maximum Efficiency (%) | Efficiency at Design Flow (%) | Plant Capacity (kW) | Firm Capacity (kW) | Capacity Factor (%) | NPV (RM) | Payback Period (Year) |
|--------------|------------------------|-------------------------------|---------------------|--------------------|---------------------|-----------|-----------------------|
| Kaplan | 89.8% | 89.3% | 506 | 40 | 37% | 1,341,680 | 10.9 |
| Francis | 90.5% | 86.7% | 491 | 33 | 35% | 953,431 | 13.2 |
| Pelton | 87.4% | 85.4% | 484 | 82 | 40% | 1,416,030 | 10.8 |
| Turgo | 84.4% | 82.5% | 467 | 79 | 40% | 1,205,929 | 12 |

Table 9: Cash Flow Profile

| Year | Cumulative |
|-------------|-------------------|
| # | MYR |
| 5 | (608,992) |
| 6 | (546,254) |
| 7 | (466,553) |
| 8 | (369,153) |
| 9 | (253,288) |
| 10 | (118,158) |
| 11 | 37,069 |
| 15 | 876,843 |
| 20 | 3,686,064 |
| 25 | 7,590,469 |
| 30 | 12,440,149 |
| 35 | 18,452,960 |

The project costing was estimated in a very optimistic manner, so that high profit return in a short period can be achieved with the best cost effective management and procurement. Anticipating a price increase of up to 30%, it may impact project cost to increase up to RM4.5 million. The unit cost per KW of the project will increase to RM9, 300, and the project would still be viable.

CONCLUSION

The mini hydro project in Tioman is a viable and it is an alternative energy to replace the existing fossil fuel generation on the island. The hydro plant is designed at 40% capacity factor, even though the CF is on the low side for typical mini hydro plants. The plant will be supportive to cover for the expensive diesel generating units that are running now. Diesel generator may support during the unavailability of water and can run as redundant to meet the customer power demand in the island.

The hydro plant is free from carbon emission. The energy generated can reduce fossil fuel carbon emission by 1.712 Million kWh, which is equivalent to $1.712 \times 0.614 = 1$ million kg of CO₂. The cost per kW of the

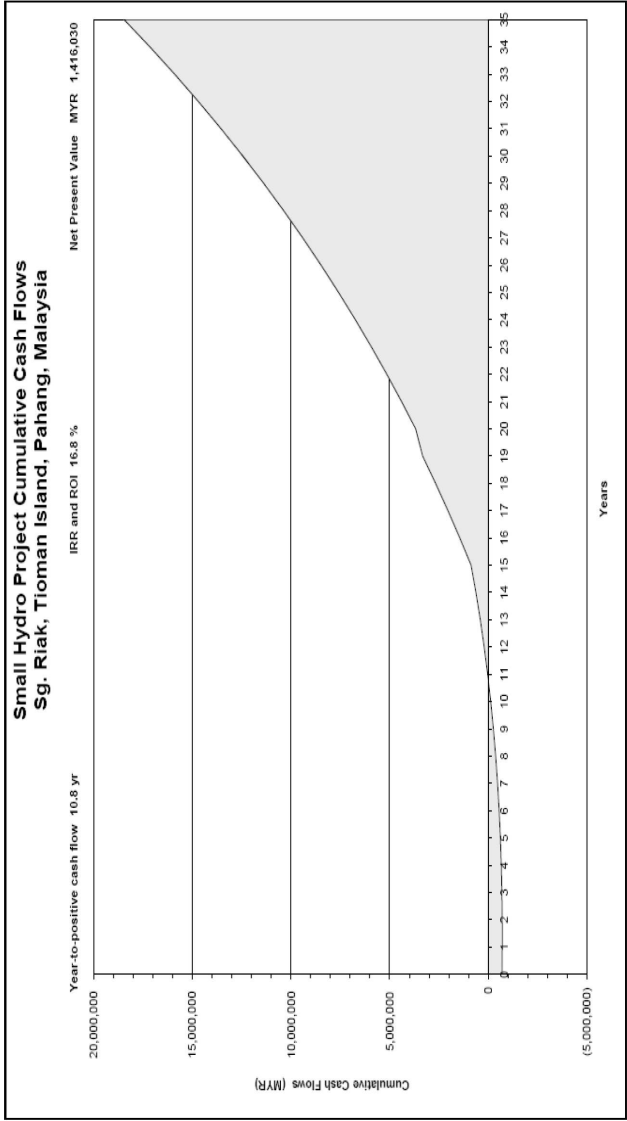


Figure 6: Cash Flow Analysis Graph

Table 10: Hydrology Sensitivity Study

| Hydrology Sensitivity (%) | NPV | Payback Period (Year) |
|---------------------------|-----------|-----------------------|
| Less 5% | 1,178,010 | 12.2 |
| Less 10% | 876,533 | 14.3 |
| Less 15% | 652,932 | 15.4 |
| Less 20% | 391,911 | 16.2 |
| Less 25% | 101,166 | 17.3 |
| Less 30% | -211,114 | 18.6 |

project is RM7, 150, which is twice about the cost of coal and thrice from combined cycle gas turbine (CCGT). Both options are not accessible in Tioman Island as it is much cheaper than other RE options. Solar energy can be obtained RM 16,000 per kW in Tioman Island.

Based on the financial analysis report, the RM3.5 million net present values can obtain and required minimum payback period of 10.8 years. The assumptions are as below:

- a. Energy sold at RM0.24,
- b. Discount rate 10%
- c. Interest rate 7%
- d. Equity 20%
- e. 80% debt term of 15 years (the shorter debt term is used to make financing attractive due to the uncertainty in RE business, risk associated with the predictability of hydro inflow)

The tariff used is only RM0.24, which is the lowest RE tariff [5]; there is potential for the tariff to be adjusted higher which will bring better profit for the project. If the project is to be developed by TNB the Tioman island sole supplier, economic analysis on the energy cost of Tioman at RM0.70 (cost of diesel generation) the project payback period is 3.9 years and the NPV is RM10.5 million. TNB can develop the project as the risk on the hydrology is minimized due to the attractiveness of the economic study as the current energy cost is very high in the island. The hydrology sensitivity study indicates the project is still viable up to 30% less water than forecasted with positive NPV and payback period is within plant life. With the introduction of Feed-In-Tariff (FIT), many

companies are competing in search for mini hydro potential sites and anticipated that Malaysia may see many new mini hydro plants commissioned in the future. The major challenges remain the finding of the sites, establishing reliable hydrology data the distance to the nearest grid connection.

Nomenclature

Z: Selection specified head

Φv : Flow rate

D: Turbine diameter

Ω : rotational speed of the turbine

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The desktop study was conducted using The RETScreen Clean Energy Project Analysis Software, it is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia.

The software, provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training. The software can be downloaded at <http://www.etscreen.net/ang/home.php>.

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