

RESEARCH ARTICLE

Hydropower Plant Designs for Selected Areas in the 5th District (Rinconada) of Camarines Sur, Philippines

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ABSTRACT

Hydropower is one of the major renewable energy sources in the world. It is less expensive and environmentally friendly as it does not emit harmful gases that can affect the surroundings. The Philippines has many water resources. This indicates that it can be a very good place for hydropower development because of the huge amount of water available there. This research paper focused on developing designs for hydropower plants in selected sites in the 5th District of Camarines Sur, Philippines. Based on the initial assessment of hydropower potential for the sites, designs for hydropower plants were developed for these areas: Itbog Falls, Nalalata Falls, Tubigan Falls, and Lologon River. Likewise, hydropower plant development in the areas is mini-hydro for Tubigan Falls and micro-hydro for the rest. These designs can be used for future development and installation of hydropower plants in the mentioned areas.

KEYWORDS:

Design, Hydropower, Hydropower plant, Camarines Sur

1 | INTRODUCTION

Electricity is vital in everyday life, as it has various applications, including residential and industrial sectors [1]. The generation of electricity can be either renewable or non-renewable. Non-renewable energy harnessed from coal, oil, natural gas, and nuclear power comprises 80 percent of worldwide energy [2]. At the same time, renewable energy can be harnessed through solar, wind, and water. Hydropower is the world's leading renewable energy source for electricity generation. According to the World Energy Council [3], hydropower supplies 71% of all renewable electricity. In 2016, 1,064 GW of installed capacity was generated, which accounts for about 16.4% of the world's electricity from all sources. At the end of 2015, China, the US, Brazil, Canada, India, and Russia were leading hydropower-generating countries. Hydropower in the US already provides 6-8% of the nation's electricity, according to the US Office of Energy Efficiency and Renewable Energy [4]. One renewable energy source that can be used for run-off-river or storage hydroelectric projects is hydropower. A run-of-river (RoR) system directs water from a river or stream to the intake point, where it is then sent straight, without any or very little storage, via a penstock to the turbine located in the powerhouse. Before being sent to the hydropower house, water from the river is redirected in storage schemes to fill the water storage reservoir [5]. The main influences on hydropower generation are economic and physical. High flow rates from lakes, waterfalls, and reservoirs depend on physical variables, including dam reinforcement, variable weather, and silt-free water [6]. Meanwhile, the primary drivers of improved power generation are economic reasons, power consumption, capital investment, and the scarcity of energy sources. The economic profit of hydropower plants is further

supported by considering the costs of operating many turbines, dams, intakes, pipelines, forebays, penstocks, powerhouses, protection, regulation, control, network connections, and transmission lines [7]. River flow during dry and wet seasons can affect the potential of hydropower site development. When a river or other water source dries up and the flow falls below the required minimum amount, some hydropower plants cease [8]. Thus, this situation raises concerns about properly estimating the discharge and net head before building hydropower plants [9], [10], [11]; and penstock length must be estimated through measurement of the inclined distance from the intake to the hydropower house [12].

Various studies were conducted to examine the role of hydropower. Water potential and dams in Turkey were examined to determine its sustainability for hydropower development [13]. Hydropower potential in Pakistan is significant. Thus, regional development of hydel energy and a report on hydropower potential in Pakistan were described [14], [15], [16]. In Nigeria, hydropower resources account for about 32% of the total installed commercial electric power capacity. This is because rivers in Nigeria are distributed throughout the country, with potential sites for hydropower schemes that can serve the urban, rural, and isolated communities [17]. In Europe, an analysis of the role of small hydropower, its technology, and its current status was conducted, and the barriers to small hydropower development projects in the country were examined [18]. A comprehensive study of micro-hydropower plants and their potential in Bangladesh was conducted due to numerous rivers and canals providing off-grid power to remote areas and areas still outside the main grid network [19]. These reviews of studies highlighted important aspects of hydropower as a sustainable renewable energy source for electricity production. Likewise, the role of both large and small-scale hydropower projects should be examined with equal importance because small-scale hydropower, like run-off river projects, has a minimum impact on ecological services as compared to large dams, which are sometimes not good for the environment [15].

Natural water resources, commonly rivers and falls, are abundant in the Philippines as hydropower sources. Hydroelectric power can be harnessed from moving bodies of water. In the Philippines, there are two methods to harness power. These methods are dam storage or impoundment and run-of-river. The impoundment is much more expensive since it uses man-made dams to store water. Run-of-river is a method that relies on flowing bodies like rivers and waterfalls. The Department of Energy claims that hydropower can be implemented in almost all regions of the country [20]. According to the Department of Energy (DOE) Renewable Energy Roadmap 2017-2040 [21], the country expects to have at least 20,000 MW of renewable energy installed by 2040. As of June 2017, renewable energy plants supplied about 7,038 MW of installed capacity in the country. This equates to 32.5% of the national output of 21,621 MW, according to data published by the DOE. Adding the new facilities in 2017 (four hydropower plants) will push the hydropower contribution to the country's renewable energy percentage well over its current 51.7%. Hydropower has several types. This includes running a river, reservoir, and pumped storage. In a run of river, the electricity is generated through the flow of a river; in a reservoir, the power is generated through the release of stored water; and in a pumped storage, the stored water is recycled by pumping it back up to a higher reservoir to be released again. The classification of hydropower plants according to installed capacity varies from different countries. According to the plant installed power, hydropower plant systems are classified as large-scale hydropower plants: over 100MW capacity; medium-scale hydro plants: 15-100MW; small-hydro plants: 1-15MW; mini hydro plants: 100kW-1MW; micro-hydro plants: 5-100kW; and pico hydro plants: less than 5kW [22], [23], [24]. Also, hydropower schemes can be categorized based on the available head. High head hydropower scheme: 100m; medium head: 30m to 100m; and low head: 2m to 30m [8]. In the Philippines, according to the Department of Energy, hydropower plants are classified based on their capacities, as follows: micro-hydro (1-100kW), mini-hydro (101kW to 10MW), and large hydro (more than 10MW).

In the Renewables Readiness Assessment in the Philippines conducted by the International Renewable Energy Agency (IRENA) in 2017 [25], the assessment has identified untapped hydropower resources amounting to 13,097 MW. Of this, 11,223 MW is suitable for large hydropower in the 18 potential sites identified across the country, accounting for nearly 86% of the total potential. The rest consists of mini- and micro-hydropower schemes in 888 locations, significantly more spread out than the large hydropower sites. The 5th District in Camarines Sur comprises six municipalities and one city. These are the municipalities of Nabua, Bato, Balatan, Buhi, Baao, Bula, and the city of Iriga. The majority of these localities are rich in natural water resources such as lakes, rivers, and falls. Possible sites for potential hydropower can be found in some of these localities. Due to this, the researchers have conducted this research, which focuses on designing hydropower plants in selected areas in the localities of Camarines Sur. Measurements of initial parameters such as the flow rate of water and the head that is available were already

conducted, which served as the basis for designing the said plants. This study is deemed beneficial to the local government units, and the proposed designs can be utilized to install hydropower plants.

2 | METHODOLOGY

This research utilized the measurements of the initial parameters of the water resources that served as inputs in designing hydropower plants. This research considered several sites, including Itbog Falls, Nalalata Falls, Tubigan Falls, and Lologon River. Itbog Falls is located in Barangay Sta. Cruz, on the southeastern side of Lake Buhi. It is an almost 60-foot, identical waterfall cascading from Mount Asog. This not-so-known wonder of nature is tucked in the thriving vegetation of Buhi town. Together with Lake Buhi and Mount Asog, Itbog is one of the town's major attractions [26]. Figure 1 shows a photo of the Itbog Falls [27].



FIGURE 1 Itbog Falls

Nalalata Falls is located in Barangay Lubgan, Bula, Camarines Sur. The falls have an impressive gush of water, providing a cool mist and spray to the area. The falls have an approximate height of 60 feet. Water streams down to a pool basin that is good for swimming [28]. Figure 2 shows a photo of the Nalalata Falls [29].



FIGURE 2 Nalalata Falls

Tubigan Falls is located in Waras river in sitio Tubigan in Brgy. Sta. Maria, Iriga City. It is 15 km from the city proper. Figure 3 shows the photo of the Tubigan Falls [30].



FIGURE 3 Tubigan Falls

Lologon River is located in Barangay Monte Calvario, Buhi, Camarines Sur. Lologon is a local dialect in Buhi, which means “to be entered” in English [31]. Figure 4 shows a photo of the Lologon River.



FIGURE 4 Lologon River

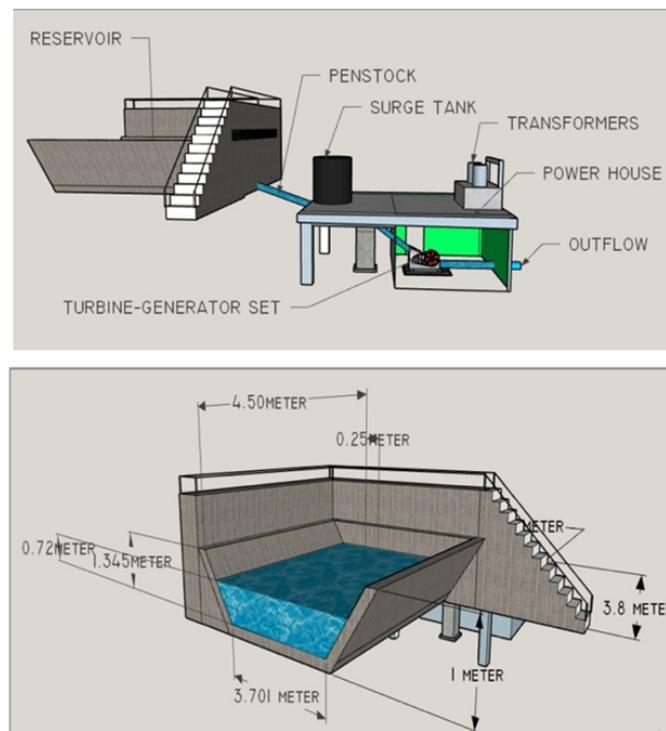
Table 1 summarizes the data on the initial assessment of potential sites for hydropower in Rinconada [32]. Based on the table, the highest computed head of water is at Itbog Falls, followed by the Nalalata Falls, Tubigan Falls, and then the Lologon River. Likewise, the location with the highest average velocity is Tubigan Falls, with the lowest at Nalalata Falls. Also, the discharge rates were highest at Itbog Falls and lowest at Lologon River. With these results, the Tubigan Falls has the highest power capacity that has 277.138kW, which can be classified as mini-hydro, followed by the Itbog Falls (73.561kW; micro-hydro), Nalalata Falls (71.932kW; micro-hydro) and Lologon River (28.593kW; micro-hydro).

TABLE 1 Summary of Assessment Results of Hydropower Potential

Location	Vertical Distance (m)	Head (m)	Average Velocity (m/s)	Discharge (m ³ /s)	Theoretical Power (kW)	Power Capacity (kW)
Itbog Falls	4.021	4.221	0.565	4.221	86.542	73.561
Nalalata Falls	4.039	3.669	0.263	3.669	84.626	71.932
Tubigan Falls	3.580	2.980	2.403	2.980	326.045	277.138
Lologon River	1.899	1.724	0.643	1.724	33.639	28.593

3 | RESULTS AND DISCUSSIONS

The researchers developed a hydropower plant design for each selected site from the initial data gathered on the head of water, discharge rate, and power capacity of the various sites and their potential to generate power. The plant's design also depended on the resources available from the site inspection conducted by the researchers. Figure 5 shows the proposed design of the plant for Itbog Falls.

**FIGURE 5** Design of Hydropower Plant for Itbog Falls

The concrete headrace is a water conveyance system that connects the intake and the forebay of a run-of-river hydropower plant [33]. It measures 5 meters, 1.3 meters in height, and a base of 3.7 meters. The water stored in the reservoir passes through the intake valve. An intake valve allows the water to be regulated. It is necessary to regulate or limit the water flow to avoid over-powered turbines and throttled intake canals [34]. After the water flows out of the intake valve, it passes through the penstock and goes directly to the turbine. Commonly, attached perpendicularly from the penstock is a surge tank. Surge tanks are applied in hydropower plants with long water conduits to reduce pressure forces during the acceleration of large water masses [35]. It reduces formed bubbles, which could lead to a damaged turbine and affect the water flow. The pressured water will strike

the turbine blades and turn these, and as a result, it will produce mechanical energy. As the turbine turns and works, the rotor inside the generator also turns and works. The generator can convert mechanical energy to electrical energy as it is used. After producing electric current, it passes through the powerhouse. The turbine and equipment required for electricity production are located in the powerhouse and are transformed into a higher voltage for more efficient long-distance transporting. The produced electricity is provided to the distribution lines for consumption. Finally, the water used is carried back to the flowing river by pipelines called tailraces.

The proposed design of Nalalata Falls is shown in Figure 6. This design has a concrete headrace 5 meters wide, 3 meters high, and a base of 2.51 meters that acts as the reservoir.

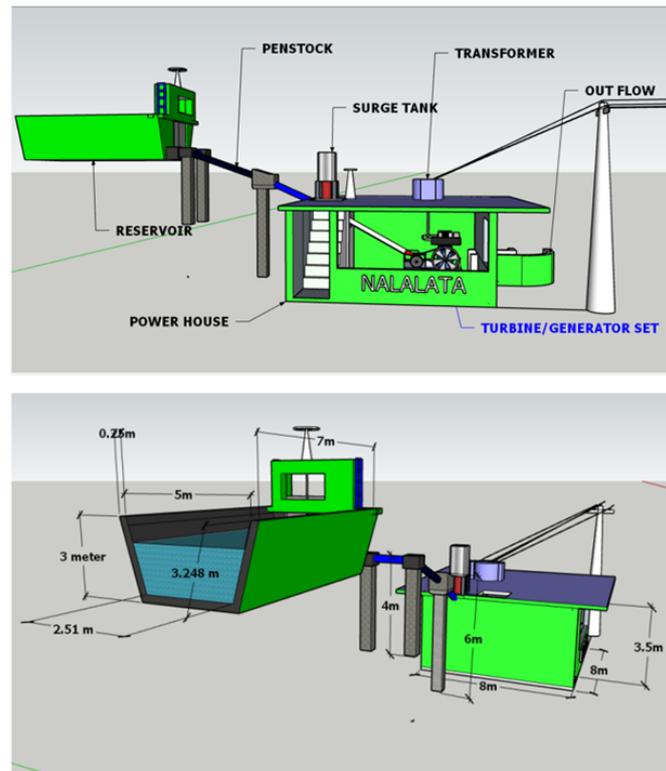


FIGURE 6 Design of Hydropower Plant for Nalalata Falls

From the headrace, there are two ways to flow the water. The first is through the penstock, and the second is through the intake valve that will control the depth of the water inside the headrace, and the water flow will come out to the river. The researchers decided to put second ways of water flow because of some emergencies that affected the amount of the water to the headrace like typhoons, El Niño or lack of water, etc. Another reason is that if the water depth is not controlled, the headrace or penstock will be ruined by pressure. Trash racks are included to prevent the debris from entering the penstock, which can damage the turbine [36]. The surge tank on top of the penstock reduces surges and bubbles in running water that can damage or increase the stress on the turbine—another intake valve for powerhouse maintenance. The pressured water strikes the turbine blades and turns the turbine, which is coupled to the generator set by a shaft. As the turbine turns, the rotor inside the generator also turns, and electric current is produced; as magnets rotate inside, the fixed coil generator produces alternating current. The transformer inside the powerhouse collects the voltage. It transforms into a higher voltage for more efficient long-distance transport and back to a lower voltage for the customers. The water that flows to the turbine will exit the outflow and go to the river.

The proposed design for the Tubigan Falls is shown in Figure 7. The concrete headrace is 6 meters wide, 1.2 meters high, and has a base of 3.6 meters. It acts as a reservoir that temporarily stores water (potential energy) from the river to supply the turbines.

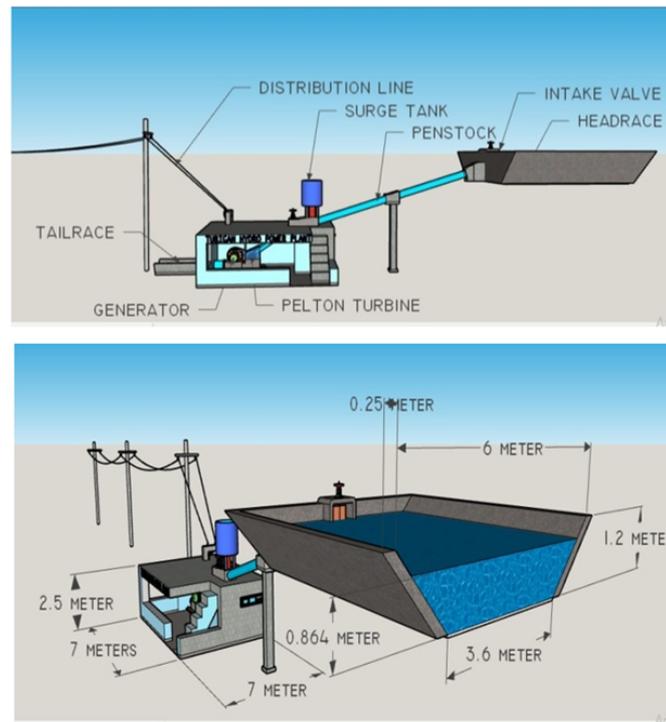


FIGURE 7 Design of Hydropower Plant for Tubigan Falls

The stored water can pass through the penstock by opening the steel intake valve. An intake valve is provided with a hoist to control the water entry. In front of the valve, trash racks are provided to prevent debris from entering the penstock, which can damage the turbine. The water flows (kinetic energy) through the 25-meter-long PVC penstock pipe, which is gravity-fed, down to the turbine. The attached surge tank on top of the penstock reduces surges and bubbles in running water that could damage or lead to increased turbine stress. The pressured water strikes the turbine blades and turns the turbine (mechanical energy), coupled to a generator set by a shaft. As the turbine turns, the rotor inside the generator also turns, and electric current is produced as magnets rotate inside the fixed coil generator to produce alternating current (electrical energy). The transformer inside the powerhouse takes the AC voltage and transforms it into higher-voltage current for more efficient long-distance transport to the grid-connection point. The electricity is converted back to lower voltage by the distribution transformer and fed into the distribution lines for consumer utilization. Finally, the used water is carried out through pipelines called tailraces and re-enters the river downstream.

For the Lologon River, the proposed design is shown in Figure 8. It has a lower head than the others, so from 1.724 m, it was adjusted to 2.5 m in design to reduce the specific speed. Kaplan turbines are generally utilized across the world for power generators [37]. These are axial flow reaction turbines generally used for low heads. It has adjustable runner blades and may or may not have adjustable guide vanes. The Kaplan type of turbine with fixed or movable blade-specific speed is the parameter based on which the turbine is selected.

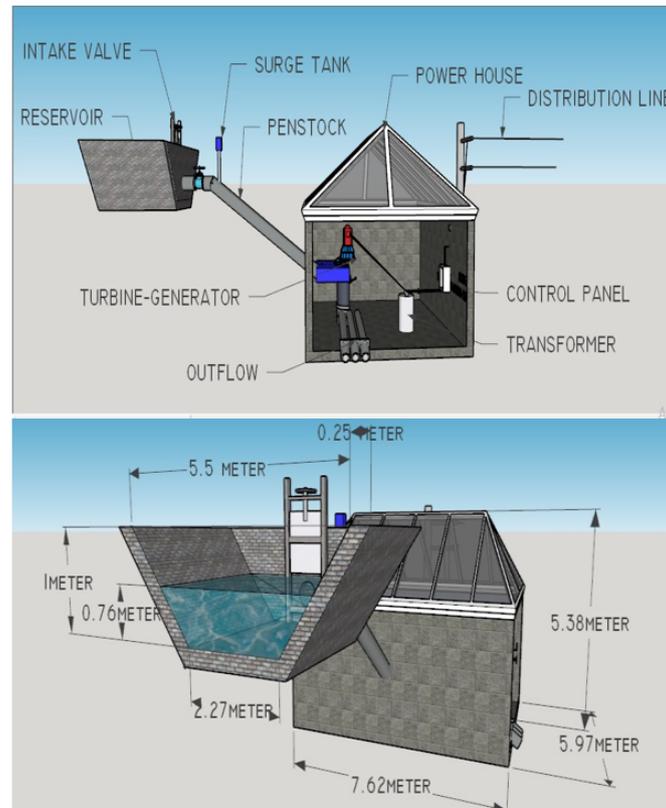


FIGURE 8 Design of Hydropower Plant for Lologon River

4 | CONCLUSIONS AND RECOMMENDATION

This study focused on designing hydropower plants in selected sites in the 5th District of Camarines Sur, Philippines. The data that were used as the basis for the design are the results of the preliminary assessment. Hydropower plant development in these areas is mini-hydro for Tubigan Falls and micro-hydro for the rest. The developed designs can be used to install hydropower plants in these areas. However, it is recommended that the assessment results be further validated by including other weather seasons since there can be variations due to limitations in conducting the preliminary assessments. Thus, more improved designs can be developed.

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