PLATFORM FOR MICRO-HYDRO GENERATION IN RURAL AREAS OF ECUADOR

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ABSTRACT

Access to electricity is essential for economic development and improving the quality of life, yet many rural communities in Ecuador lack this basic need. Micro-hydro generation has the potential to provide electricity to these communities, but the process of setting up a micro-hydro generation system can be complex and difficult to manage. The present study proposes to address this issue by developing a web platform that provides all the necessary tools and resources for setting up and managing a micro-hydro generation system in rural areas. The platform uses hydraulic potential calculations based on river flow and head to select the most suitable turbine for the community conditions. This methodology has been validated, and a user-friendly graphical interface has been developed to enter the relevant information on hydraulic potential. The platform performs these calculations using Python, proposing a design for the selected turbine that ensures the best performance. One of the key features of the platform is its ability to act as a hub for information exchange between rural communities and experts, promoting a more informed and effective approach to micro-hydro generation. To illustrate the effectiveness of the platform, a case study of the rural communities of Guayllabamba has been presented. This demonstrates how the platform can obtain a suitable Francis turbine for microgeneration that can provide electricity for housing, agriculture, and improve the quality of life of the community. The results show the components that will be included in the beta version of the web platform, which will facilitate the selection of the most suitable turbine for micro-hydro generation, design implementation, and estimation of the hydraulic potential of a given area based on input parameters and satellite imagery. This effort represents a crucial step towards promoting sustainable energy solutions in rural areas and contributing to a more sustainable energy future for the country.

Keywords: renewable energy, micro hydro generation, rural areas, web platform, sustainable energy solutions.

1 INTRODUCTION

The implementation of alternative, sustainable, and environmentally friendly energy source is necessary as the world moves towards the goal of providing electricity for all [1]–[3]. In Ecuador, there are still areas far from the national interconnected electric system, making it challenging and costly to connect to the installed system [4], [5]. In such cases, integrating a micro hydroelectric power plant can be a better option to cover the electricity demand in these communities. Micro hydro generation is an attractive solution due to its being sustainable and environmentally friendly. By harnessing the power of small water turbines, communities can have access to reliable and affordable electricity [6], [7]. However, setting up a micro hydro generation system is a complex process that requires specific skills, resources, and knowledge of its technical and financial viability [8].

According to Sangal et al. [9], there is a rising demand for both electricity and clean water, and the hydropower will play a significant role in the future energy mix. The most efficient way to generate electricity in remote and undeveloped areas is through hydroelectric power plants because of possible access to these renewable energy sources.

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Adejumobi and Shobayo [10] found that the production of small hydropower (SHP) centres on the relationship between net yearly energy production and the water height (head), stream velocity (displacement), and turbine efficiency. However, the theoretical power rate output of a plant often does not align with the actual annual capacity, as shown by the author. For optimal performance, it is important to consider a range of factors such as water flow rates, head, and turbine efficiency so the platform identifies the most reliable and efficient power output.

This research examines the possibilities of micro hydro generating in Ecuador's rural areas. The high rainfall in the country derived by the geographical conditions has developed many drainage basins that possess a high technical and economically feasible potential of water resources for hydroelectric use. Ecuador has a substantial untapped hydro energy resource that can be crucial in reducing the nation's reliance on non-renewable sources for electricity generation [11]. Table 1 shows the results of the research carried out by Cando [11] about Ecuador's hydroelectric potential to satisfy rural people's electricity needs.

Table 1: Theoretical hydroelectric potential in Ecuador.

Description	**MW**
Theoretical resource	91,000
Technical availability	31,000
Economic availability	22,000

To address the challenges of establishing micro hydro generation systems in rural Ecuador, we propose an online platform that provides the necessary tools and resources for setting up and managing micro hydro generation systems in rural areas. The suggested strategy has the potential to raise the standard of living for rural people, increase access to power, promote economic development, and promote the use of open-source software in the energy sector.

This initiative focused on open-source software, the use of a web platform and CFD tools, represents a significant advancement to promote sustainable energy solutions in rural regions.

The present study aims to analyse the best hydro turbine selection for hydroelectric projects. It serves as a guide for choosing the ideal hydro turbine for the available operating circumstances and is essential in assuring the project's affordability and efficiency [9].

2 METHODOLOGY

2.1 Turbine selection

The specific speed approach is used for choosing the micro hydro turbine for a rural location in Ecuador. This approach is based on the power specific speed, a ratio of design parameters as shown in eqn (1):

$$Ns = \frac{N(P_t)^{0.5}}{(H_d)^{-1.25}}, \tag{1}$$

where Ns is the specific speed in rpm, N is the angular velocity of rotation, P_t is the power design of the turbine in kW and H_d is the head of water of the turbine in metres.

According to Díez [12] the following categories apply to hydraulic turbines depending on the value of Ns as seen in Table 2.

Table 2: Turbine classification according to Ns.

Turbine type	Ns
One jet Pelton	$2 \leq Ns < 30$
Multi jet Pelton	$30 \leq Ns < 60$
Slow Francis	$60 \leq Ns < 200$
Normal Francis	$Ns = 200$
Fast Francis	$200 \leq Ns < 450$
Various Impeller Francis	$450 \leq Ns < 500$
Kaplan	$500 \leq Ns < 1350$

With the use of Python, the specific speed of the turbine can be calculated by entering field variables like flow rate and water head. Python's use in this process accelerates the design stage and enables a more precise and effective choice of the right turbine. The components of the chosen turbine will then be designed using the program to achieve peak performance and efficiency.

2.2 Head of water measurement

The type of turbine to be utilized in a hydroelectric project is heavily influenced by the head, or vertical distance from the water source to the turbine. The head can be measured using a variety of techniques, such as topographic maps, surveying tools like altimeters and dumpy levels, and altimeter values obtained from satellite sources. The head and penstock length would be equivalent when the site is a vertical waterfall. The pipe length necessary to reach a particular head is known as the penstock length. In general, high head turbines are more economical and generate more power than low head units. But occasionally, a few hundred meters of pipe may be required to reach an appropriate head.

To precisely measure the head of water at the potential hydroelectric, a GPS device will compute the difference in height. The python software developed will need the value of water head that we are going to measure to decide the best kind of turbine to use at the given location.

The general methodology aims to utilize data obtained through new technologies as satellite imagery or drones imaging. By relying on these advanced technologies, the methodology used aims to successfully complete the hydroelectric project design.

2.3 Flow-rate measurement

Geological and hydrological information about the rivers is needed to obtain the necessary parameters and carry out the study. The National Institute of Meteorology and Hydrology (INAMHI) provides information about average daily levels, average daily flows, general duration curve, and an inventory of the national hydrological network [13].

According to the area and river of interest, a statistical analysis of the recorded values of daily and monthly average flows was performed. A flow range was calculated to ensure correct operation of the turbines. The limits corresponded to maximum and minimum flow values recorded during the entire period. Monthly ranges were used, due to the variability of river flow, which depends on weather conditions, along with natural and anthropic factors that may occur in the different sectors.

The environmental flow rate is important to preserve the existing ecosystem. Ni et al. [14] designed a methodology for the environmental flow, also known as T-FDC. The methodology allows the construction of flow duration curves by grouping flow data monthly from different years, in order to better represent the temporal variability of the flow of water bodies.

The basic environmental flow is the minimum discharge value that a river must maintain to guarantee the ecosystem. The average of flow percentiles is shown in eqn (2).

$$E_{min} = \frac{Q_{90}+Q_{95}}{2}, \tag{2}$$

where E_{min} is the basic environmental flow and Q_{90} and Q_{95} the flow rate at 90% and 95% of the period, respectively.

In order to guarantee an adequate ecological condition at the time of process development, the optimum environmental flow rate was determined. This flow provides a range of values obtained through eqns (3)–(5).

$$E_{opt} = \left[E_{opt.lower}, E_{opt.upper}\right], \tag{3}$$

$$E_{opt.lower} = Q_{50}, \tag{4}$$

$$E_{opt.lower} = \frac{5}{9}Q_{50} + \frac{4}{9}E_{min}, \tag{5}$$

where E_{opt} is the optimum environmental flow range, $E_{opt.lower}$ and $E_{opt.upper}$ the lower and upper limits respectively and Q_{50} the flow rate at 50% of the period of records.

2.4 Turbine design

At this moment the methodology for Francis turbines is fully solved and implemented for this investigation. However, the design for Pelton turbines is still under development and will be included in the future.

For the calculation, a Python program has been created, which is based on works from the Norwegian University of Science and Technology's Laboratory of Hydraulic Energy (NTNU) [15]. This code is a useful tool for carrying out the calculations and simulations required for the design and optimization of different Francis turbine components. The code guarantees the quality and dependability of the design process by applying the know-how and research findings from NTNU.

The process in the platform begins with the entry of fundamental design information such flow rate (Q) and net head (H). Empirical data and studies derive the hydraulic design parameters for the impeller listed below:

- Exit angle of the runner (β_2)
- Peripheral velocity at the exit ($U_2 init$)
- Flow acceleration through the runner (Acc)
- Reduced peripheral velocity at the inlet ($\underline{U_1}$).

The 'exit angle of the runner' refers to the angle at which the water exits the runner or impeller of a hydraulic turbine. The 'peripheral velocity at the exit' is the speed at which the water exits the runner. The 'flow acceleration through the runner' is the increase in velocity of the water as it passes through the runner, while the 'reduced peripheral velocity at the inlet' is the decrease in the speed of the water as it enters the runner or impeller. All these parameters are important in the design and performance of hydraulic turbines, as they impact the efficiency and power output of the system; the flowchart for this process in shown in Fig. 1.

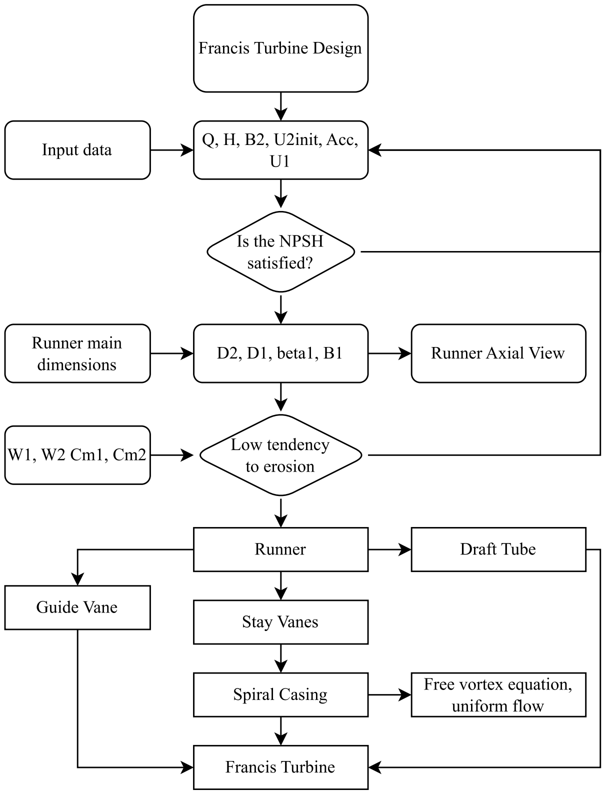


Figure 1: Francis turbine design process.

It should be emphasized that two requirements – the NPSH value and the impeller erosion tendency – must be satisfied in order for the parametric design approach to be successful. The sizing of other components can start once these values match the design standards. Eqn (6) is used to estimate the impeller erosion tendency *(E_t)*.

$$E_t = \frac{W_1^3 C_{m2} + W_2^3 C_{m1}}{C_{m1} + 2} \left[\frac{m^3}{s^3}\right]. \qquad (6)$$

Calculating the impeller's primary parameters, such as the output diameter, number of generator poles, and synchronous speed, is the first step in the procedure. To avoid impeller cavitation at the exit, the velocity triangle is finished, and the net positive suction head (NPSH) condition satisfied. The axial view, represented by streamlines, creates the 3D blade geometry for the impeller blade. After obtaining the blade shape, stress analysis is used to add the thickness.

The design of the guiding vanes comes next, which entails getting their length, input and outlet diameters, and inclination angle. The blade's hydrodynamic profile uses the Quishpe approach [16], where it is necessary to find the ideal length for preserving the spiral casing's integrity, thickness and inclination.

The spiral casing's views are drawn when all interior components' dimensions have been determined. Finally, it is possible to determine the discharge tube's geometry. A Francis turbine's axial view, which depicts the general dimensions, is shown in Fig. 2 [17].

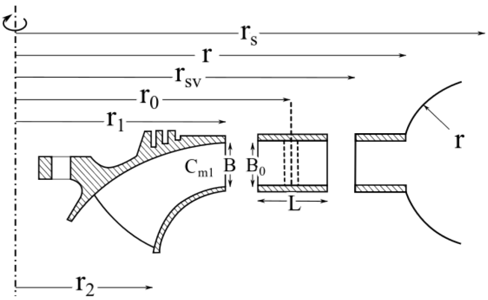


Figure 2: Axial view of a Francis turbine.

The parametric design process implemented by Ramos and López [17], which entails the calculation and suggestion of several components, including the runner, runner blades, guide vanes, predictor blades, and spiral casing. The Francis turbine must operate efficiently; thus, this design strategy seeks to maximize the geometry of these parts while ensuring their performance and integrity. The Python code may produce precise and efficient design for open-source simulations of the Francis turbine in a variety of configurations and operational settings.

2.5 Platform for microgeneration

The platform will be designed using modern web development technologies, such as HTML, CSS, and JavaScript. It will be a responsive and user-friendly interface that will allow users to access the platform from any device with an internet connection.

The platform will have a backend built with Python and the Django web framework. The backend will be responsible for processing user inputs, performing turbine design and feasibility analyses, and generating cost estimates. It will also provide users with access to a database of micro hydro projects implemented in Ecuador to serve as a reference for new projects. The backend will use OpenFOAM, a computational fluid dynamics (CFD) application, to simulate water flow and improve the accuracy of the turbine design.

The front end of the platform will consist of several web pages, including a landing page, a turbine design page, a feasibility analysis page, and a cost estimation page. The landing page will provide an overview of the platform's features and benefits and will allow users to create an account or log in if they already have one. The turbine design page will enable users to input the characteristics of their location, such as the flow rate of the river and the height of the head and generate a turbine design that best suits their needs. The feasibility analysis page will provide users with detailed information on the technical and economic viability of the project, including the estimated energy production, the required investment, and the payback period. The cost estimation page will provide a detailed breakdown of the project's expenses, including the cost of the turbine and approximate cost for the installation.

In addition to these pages, the platform will also include a resources page that will provide users with access to a wide range of information related to micro hydro generation, including manuals, instructional videos, and case studies. The resources page will also feature a discussion forum where users can ask questions and share their experiences.

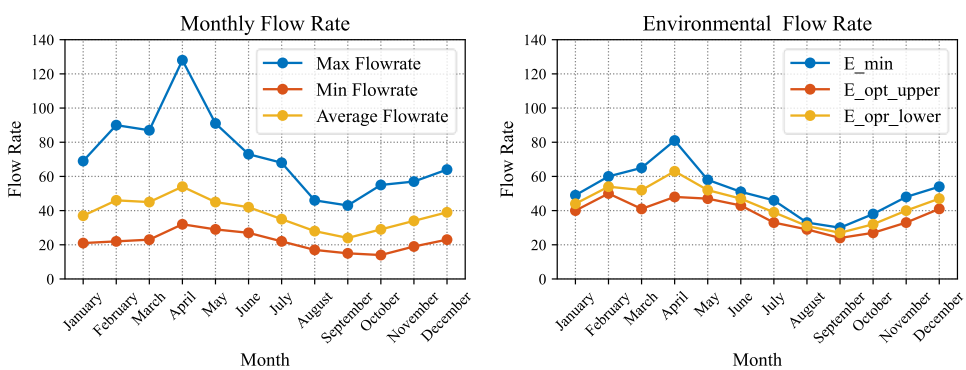
3 RESULTS

This section presents the research outcome, which includes the flow rate and water head requirements for the hydroelectric plant. The study focused on addressing the pressing need to provide electricity to communities situated near the river Guayllabamba who lack access to this service. The hydrological data corresponds to station H148 PISQUE. The parametric design methodology in Python will carry out the process for the turbine's components. Historical flow rate values were analyzed to predict the flow rate for the study, and GPS devices to calculate the head of water accurately. The platform results of this study were visualized through a platform that facilitated their interpretation and gave a thorough grasp of the design. The study provides valuable insights into the design process for small hydropower projects in similar settings.

3.1 Flowrate calculation

The hydrological information for the Guayllabamba river area was gathered by utilizing the annual hydrological reports provided by the INAMHI. The specific station of interest for this study was Guayllabamba Dj Pisque, identified by its H0148 code.

A statistical analysis was performed using flow records obtained from the Guayllabamba Dj Pisque hydrological station between 2007 and 2013. Fig. 3(a) shows the minimum, mean, and maximum monthly flow values during this time, with higher flows recorded in the winter (December to May) than the summer (June to November). The highest and lowest flow values were observed in April (128 m^3/s) and October (14 m^3/s), respectively, while the average flow exhibited a consistent seasonal trend throughout the study period.



(a) (b)

Figure 3: (a) Monthly flow; and (b) Environmental flow rate obtained from hydrological station H148.

The environmental flow ensures the ecological integrity of the Guayllabamba river. Fig. 3(b) presents the basic and optimal environmental flows for each month, based on the data collected between 2007 and 2013. The group of monthly flow data from different years represent the temporal variability of the river flow. This approach enabled the identification of the basic flow required to maintain the river's ecological functions, as well as the optimal flow required to support the maximum ecological potential of the river.

It is recommended to maintain a river flow value within the range of the optimal environmental flow, while using the flow value corresponding to E_{min} as the maximum threshold. For instance, in April, when the highest flow value was observed, the minimum discharge value required to maintain the river's ecological functions is 81 m^3/s, but it is suggested to maintain the river flow between 48–63 m^3/s. A similar approach was used to determine the recommended flow value for each month throughout the year.

3.2 Turbine selection

In this investigation, we compare the operational characteristics of ten hydroelectric projects. In order to achieve this, we will compile data on the specific type of turbine that each project actually has installed, as well as data on their flow rate and head of water. The gathered data will then be arranged and presented for comparison and study. Table 3 shows the gathered information.

Table 3: Hydroelectrical projects current installed in Ecuador.

Hydroelectric project	**Head (H_d) (m)**	**Flow rate (Q_m) (m^3/s)**	**Turbine type**
Coca Codo Sinclair Hydroelectric Plant	620	287	Pelton
Sopladora Hydroelectric Plant	361	150	Francis
Hydroelectric Power Plant 'Minas San Francisco'	474	48	Pelton
'Quijos' Hydroelectric Project	64	13	Francis
'Toachi Pilatón' Hydroelectric Project	60	41	Francis
'Mazar Dudas' Project	300	3	Pelton
'Delsitanisagua' Hydroelectric Project	495	47	Pelton
'Manduriacu' Hydroelectric Plant	31	169	Kaplan
'Three Gorges' Chinese Hydroelectric Plant	181	116,000	Francis

The created Python application will take the data from the ten hydroelectrical projects as input to compare the results and demonstrate the precision of the calculation. In order to classify the turbine and determine its specific speed, the program will utilize the real turbine type, flow rate, and head of water. This will ensure that the turbine is appropriate for the hydrogeneration conditions in the area. The results of this comparison will provide information about the accuracy and effectiveness of our computation process. When determining whether our methodology was successful, the compared information is shown in Table 4.

These results were crucial in demonstrating the program's effectiveness in offering trustworthy design options for micro-hydro projects in Ecuador.

The selection of the appropriate turbine for a hydroelectric project is important for its efficiency and performance. In our case study, we utilized a head of water of 201.1 m and an

Table 4: Comparison of Installed turbine types, and the predicted by the developed python program.

Hydroelectric project	Specific speed	Turbine type recommended	Does it match?
Coca Codo Sinclair Hydroelectric Plant	59	Pelton	Yes
Sopladora Hydroelectric Plant	85	Francis	Yes
Hydroelectric Power Plant ‘Minas San Francisco’	59	Pelton	Yes
‘Quijos’ Hydroelectric Project	207	Francis	Yes
‘Toachi Pilatón’ Hydroelectric Project	257	Francis	Yes
‘Mazar Dudas’ Project	59	Pelton	Yes
‘Delsitanisagua’ Hydroelectric Project	52	Pelton	Yes
‘Manduriacu’ Hydroelectric Plant	176	Francis	No
‘Three Gorges’ Chinese Hydroelectric Plant	134	Francis	Yes

ecological flow rate of 63 m^3/s as inputs to our developed Python code for turbine selection. The program recommended using a Slow Francis turbine based on the specific speed value of 110, which corresponds to the category of the turbine according to Table 2.

The recommended turbine is suitable for the Guayllabamba rural communities, located near the river with hydrological station H184. These communities have agricultural activities, residential areas, and other activities. The use of the Slow Francis turbine will provide reliable and efficient power generation for the local community, while also minimizing any negative environmental impacts.

3.3 Turbine design

Based on the design considerations described above, a prototype of a Francis turbine was proposed using Python code. Specifically, the ecological flow rate of 63 m^3/s and a head of water of 201.1 m were used as input parameters for the turbine selection process. The Python code calculated a specific speed value of 110, indicating that a Slow Francis turbine was the most appropriate choice for the proposed site. Using the specific speed value, along with the eqns (1)–(3) for power, speed, and flow rate, respectively, a design for the turbine was generated. The resulting blueprint is intended to provide a basis for the construction of a working prototype of the Slow Francis turbine that can be tested at the proposed hydroelectric site.

Fig. 4 shows the blade arrangement of the proposed Francis turbine design and displays the arrangement of the surface nodes of the turbine blade, viewed from a top axial-radial perspective. The turbine has an enclosed casing and is equipped with blades that are fixed and adjustable. The blades are arranged in a radial manner around the turbine shaft, with the adjustable blades located at the inlet of the turbine. The fixed blades are located downstream of the adjustable blades, extending towards the outlet of the turbine. The arrangement takes into account the proposed parametric design. This design ensures maximum utilization of the existing hydropower resource in the case study.

Fig. 5, on the other hand, displays the arrangement of points in a frontal view on an axial plane. As seen from the figure, the python program suggests a runner with a radius of 2.5 m and a height of 1.4 m, indicating a relatively large Francis turbine for microgeneration

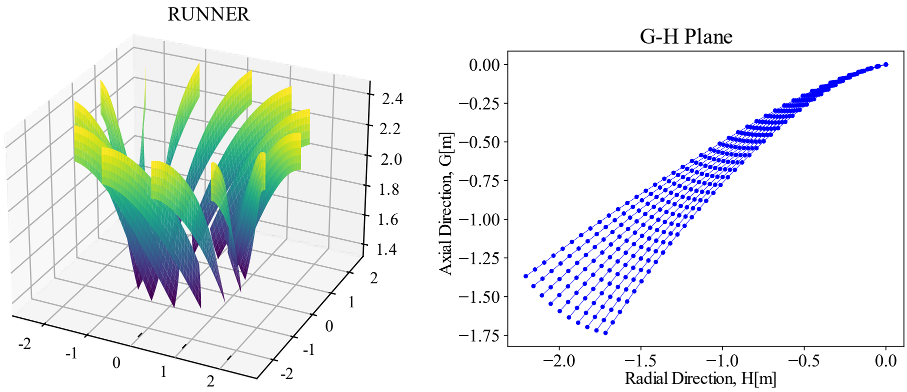


Figure 4: Design of a blade arrangement proposed by the developed Python code and runner blade radial view.

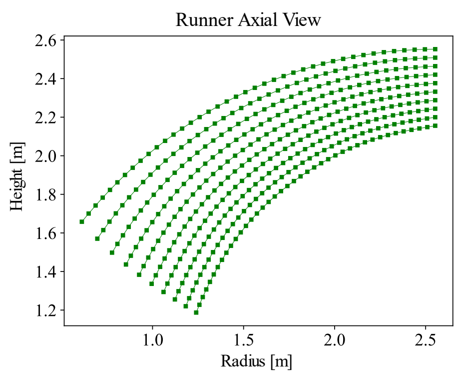


Figure 5: Runner blade axial view.

purposes. Nevertheless, these dimensions guarantee an appropriate use of existing water resources throughout the year.

In addition, the blade's surface nodes have been optimized to ensure that the turbine operates at its highest efficiency while minimizing erosion damage and other negative effects. Erosion can cause significant damage to the turbine blades, reducing their efficiency and increasing maintenance requirements. The proposed blade design aims to minimize erosion by optimizing the blade's shape and thickness distribution, ensuring that the pressure distribution across the blade surface is as uniform as possible. The resulting blade shape provides a balance between maximizing power output and minimizing the risk of erosion, ensuring the turbine's long-term operation and profitability.

Fig. 6 illustrates the main dimensions of the spiral casing through which the water flow will enter for the turbine operation. The recommended design from the Python program suggests a spiral casing with a diameter of 9 m and an inlet of 2.25 m in diameter. The blue line indicates the limit of the spiral casing, while the pink line shows the location of the guide

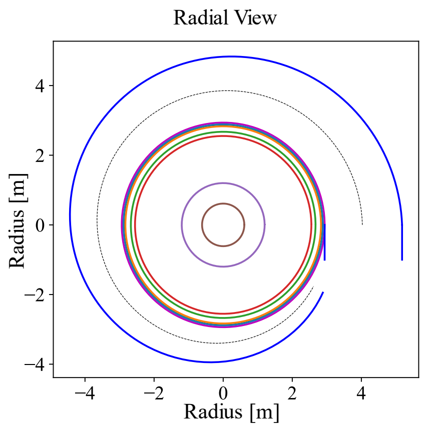


Figure 6: Spiral casing radial view.

vanes, the green line represents the position of the fixed blades or stay vanes, and the red line indicates the location of the runner.

Fig. 7 provides a comprehensive illustration of the frontal view of the spiral casing, a crucial component of hydraulic turbines used for generating hydroelectric power. The spiral casing is designed to provide a smooth and efficient flow of water to the turbine's impeller, which in turn converts the kinetic energy of the water into mechanical energy to power the generator. To ensure a uniform inflow throughout the impeller domain, the diameter of the inlet is reduced from 2.25 m to 1.75 m, as shown in the figure. This reduction in diameter helps to avoid any turbulence or irregularities in the flow, which can result in inefficient power generation and damage to the turbine.

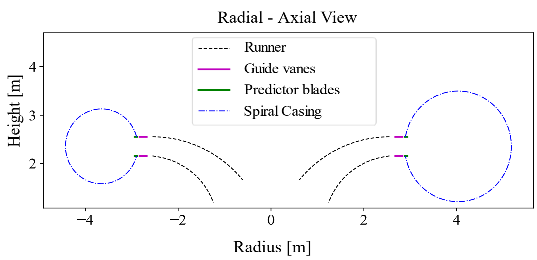


Figure 7: Spiral casing and runner radial axial view.

Additionally, the figure also illustrates the placement of the guide vanes and runner blades in the spiral casing. The guide vanes are used to direct the water flow onto the runner blades, which are attached to the impeller. The runner blades then use the kinetic energy of the water to rotate the impeller, which drives the generator to produce electricity. The figure also shows the location where the impeller will be installed in the turbine. The precise placement of the impeller is critical to ensure that it operates efficiently and produces maximum power output. Therefore, the design of the spiral casing and the positioning of the impeller and blades are critical factors in optimizing the performance of the hydraulic turbine.

4 CONCLUSION

Micro hydro generation is a viable solution for providing electricity to rural areas that are not connected to the national electric system in Ecuador. The country has a significant untapped hydro energy resource, making it a potential source of electricity generation. However, the selection of the appropriate hydro turbine for the available operating conditions is critical in ensuring the project's affordability and efficiency. The production of small hydropower is dependent on the relationship between the net yearly energy production and the water height, stream velocity, and turbine efficiency. There is a need to consider the real-world effects of SHP production when assessing theoretical outputs, and a thorough approach to turbine selection is necessary. The proposed solution to address the challenges of establishing micro hydro generation systems in rural Ecuador leverages the benefits of open-source software to streamline the process and ensure their long-term success in meeting the electricity needs of rural communities. The planned web platform for micro hydro generation in rural Ecuador will offer several benefits, including the ability to accurately select the type of turbine suitable for the location's conditions and perform feasibility analyses to identify the technical and economic viability of micro hydro generation systems in specific locations.

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