SOFTWARE

# Computer program for the design and evaluation of the Francis turbine in a Small Hydroelectric Power Plant

## Programa informático para el diseño y evaluación de la turbina Francis en una Pequeña Central Hidroeléctrica

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**ABSTRACT:** Hydroelectric plants are of great importance for agricultural development by providing clean energy, supporting irrigation and contributing to the stability of the electrical grid, which directly benefits the productivity and sustainability of the agricultural sector. The present study was developed at the Small Hydroelectric Power Plant "Alzamiento de Jagüecito" in the Chambas Basin with the objective of developing a computer program for the design and evaluation of the Francis turbine. The methodology used consisted of a web system in the Python programming language from which the following parameters were calculated: power, rotation speed, specific speed, net jump height, absolute entry speed, tangential speed, impeller parameters and flow parameters. the metallic spiral chamber. The results showed that the INFO_FRANCIS computer program allows determining the power of the turbine, the electrical energy produced and the load factor from the behavior of the water levels in the reservoir. This program is useful to compare the results of the program with the data obtained from the Hydraulic Use Company and the Electrical Union of the province; in addition to helping to monitor the operation of the turbine, which prevents possible problems that may arise and suggests viable corrective measures that should be applied.

**Keywords:** Turbined Flow, Hydropower, Turbine Power, Net Head.

**RESUMEN:** Las centrales hidroeléctricas presentan gran importancia para el desarrollo agropecuario al proporcionar energía limpia, apoyar el riego y contribuir a la estabilidad de la red eléctrica, lo que beneficia directamente a la productividad y sostenibilidad del sector agropecuario. El presente estudio se desarrolló en la Pequeña Central Hidroeléctrica "Alzamiento de Jagüecito" de la Cuenca Chambas con el objetivo de desarrollar un programa informático para el diseño y evaluación de la turbina Francis. La metodología utilizada consistió en sistema web en lenguaje de programación Python a partir del cual se calcularon los siguientes parámetros: potencia, velocidad de rotación, velocidad específica, altura del salto neto, velocidad absoluta de entrada, velocidad tangencial, parámetros del rodetes y parámetros de la cámara espiral metálica. Los resultados demostraron que el programa de computo INFO_FRANCIS permite determinar la potencia de la turbina, la energía eléctrica producida y el factor de carga a partir del comportamiento de los niveles de agua en el embalse. Este programa es útil para comparar los resultados del programa con los datos obtenidos de la Empresa de Aprovechamiento Hidráulico y la Unión Eléctrica de la provincia; además de contribuir a monitorear el funcionamiento de la turbina, lo que previene ante posibles problemas que se presenten y sugiere las medidas de corrección viables que deberán aplicarse.

**Palabras clave:** caudal turbinado, hidroenergía, potencia de la turbina, salto neto.

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## INTRODUCTION

Fossil fuels are currently the main source of energy to meet energy requirements; However, they are highly polluting and very expensive; For this reason, it is beneficial to implement alternative technologies such as small hydroelectric plants Morales *et al.* (2014), which are of great importance for agricultural development by providing clean energy, supporting irrigation and contributing to the stability of the network electricity, which directly benefits the productivity and sustainability of the agricultural sector (Diez y Olmeda, 2008).

Benefiting and improving the electrical service in intricate and mountainous areas is a complex task due to the necessary care that must be taken to reduce the environmental impacts that hydroelectric projects can generate to the minimum possible (Galbán *et al.*, 2023). This procedure includes the vision of an alternative model for the use of water and energy resources through hydroelectric plants, which represent the country's effort in the use of new agroecological technologies in the agricultural sector (Arias, 2009).

The global energy situation requires new challenges to solve the problems that traditional electricity generation systems have caused due to the increase in energy demand that will double by 2050 Monirul *et al.* (2021), the increase in generation costs and the need to replace the use of oil, which has promoted the use of renewable energy sources; including hydropower, which accounts for around 20% of the world's electricity (Prodanović *et al.*, 2019).

Small hydroelectric plants have a small generating capacity; However, its hydropower generation must cover the estimated demand during its useful life Moscoso & Montealegre (2013); Therefore, a hydrological and environmental study is required prior to the construction of the work (Espejo *et al.*, 2017).

The mathematical modeling of a small hydroelectric plant must consider the entire hydraulic system until reaching the generation units and must be evaluated based on the error analysis according to the model performance index. The model can be used for the distribution of load or power to be generated (Estrada *et al.*, 2013).

It is evident that the use of energy obtained from the combustion of hydrocarbons must be replaced by renewable energies; But it is a complex engineering task that requires the support of computer programs that facilitate the design of the necessary parameters of hydroelectric plants and make this process less cumbersome; For this reason, the objective of this work is to develop a computer program for the design and evaluation of the Francis turbine installed in the Small Hydroelectric Power Plant "Alzamiento de Jagüecito", which generates electric current for activities related to the production of sugar cane and its derivatives, agriculture, livestock, supply to the population and the construction materials industry.

## MATERIALS AND METHODS

The research was carried out in the Chambas River Hydrographic Basin, located on the northern slope of Cuba in the province of Ciego de Ávila; It covers the municipalities of Florencia and Chambas with an area of 384,374 km$^2$. The coordinates are included according to the North Cuba Coordinate System GCS_NAD27-CU in: Upper: 286754.723900 m; Left: 700995.360200 m; Right: 720785.727100 m; Lower: 248273.406300 m. In this basin is the Liberación de Florencia Hydraulic Complex, of Ciego de Ávila, made up of the Chambas I (Cañada Blanca) and Chambas II reservoirs; as well as the Small Hydroelectric Power Plant "Alzamiento de Jagüecito" with a generation capacity of 1.2 MW with the use of Francis type turbines.

A computer system was developed consisting of a web system in the Python programming language in accordance with Challenger *et al.* (2014) with the purpose of calculating the parameters of a Francis turbine for use in design and evaluation tasks. The computer system developed in the research was validated by specialists from the Hydraulic Use Company and the National Energy Union of the province of Ciego de Ávila. The criteria used for validation were the following: need for the software, usefulness for the company, speed, precision and user satisfaction.

The parameters of the Francis turbine that are calculated in this computer program for a Small Hydroelectric Power Plant are: power, rotation speed, specific speed, net head height, absolute inlet speed, tangential speed, impeller primitive diameter, outlet diameter of the impeller, number of impeller blades, primitive width of the impeller, impeller entry width, entry speed to the metallic spiral chamber, diameter of the first arc of the spiral and diameter of the remaining arcs of the spiral.

The power of the Small Hydroelectric Power Plant (P) in kW was calculated according to Gutiérrez *et al.* (2019) and Pérez *et al.* (2022) as a function of the turbined flow ($Q_e$) in m$^3$ s$^{-1}$, the height of the net head ($H_n$) in m and the turbine efficiency ($\eta$) as:

$$P = \frac{\rho \cdot g \cdot Q_e \cdot H_n \cdot \eta}{1000} \quad (1)$$

The rotation speed of the turbine ($N$) in rpm was estimated considering the specific speed of the turbine ($N_s$) in rpm, the height of the net head ($H_n$) in m and the power of the Small Hydroelectric Plant ($P$). The specific flow rate ($N_q$) was taken into account the turbined flow ($Q_e$). The following equations were used:

$$N_s = 3470 \cdot H_n^{-0.625} \quad (2)$$

$$N = \frac{N_s \cdot H_n^{5/4}}{\sqrt{P}} \quad (3)$$

$$N_q = \frac{N \quad \sqrt{Q_e}}{N_n^{3/4}} \quad (4)$$

The absolute inlet speed in m s$^{-1}$ ($C_o$), the tangential speed in m s$^{-1}$ ($u_1$), the impeller pitch diameter in m ($D_1$), the impeller outlet diameter in m ($D_2$), the number of impeller blades ($Z$), the impeller primitive width in m ($a_1$) and the impeller inlet width in m ($b_1$) were designed using the equations listed below:

$$C_o = 0.66\sqrt{2gH_n} \quad (5)$$

$$u_1 = 0.293 + 0.0081N_q\sqrt{2gH_n} \quad (6)$$

$$D_1 = \frac{60u_1}{\pi N} \quad (7)$$

$$D_2 = 4.375\sqrt[3]{\frac{Q_e}{N}} \quad (8)$$

$$Z = 18.87e^{-0.001N_s} \quad (9)$$

$$a_1 = (0.191 \quad ln(N_s) - 0.651)D_1 \quad (10)$$

$$b_1 = \left(0.000006 \quad N_s^2 + 0.0014N_s + 0.0085\right)D_1 \quad (11)$$

The design of the spiral chamber and the distributor was carried out based on the entry speed to the metallic spiral chamber in m ($C_{ecm}$). The spiral chamber is divided into eight 45º arcs with equal flow; Therefore, the dimensions of the spiral chamber are dependent on the diameter of the first arc of the spiral ($d_1$). The remaining diameters ($d_i$) were calculated according to equations used by Illidge *et al.* (2020).

$$C_{ecm} = 0.18 + 0.28\sqrt{2gH_n} \quad (12)$$

$$d_1 = 1.146\sqrt{\frac{Q_e}{C_{ecm}}} \quad (13)$$

The annual energy produced in kWh (EAP) was determined from the turbine power in kW ($P$), the annual operating time of the generator in hours ($T_{fa}$), the operating time of the generator in the day in hours ($T_{fd}$) and the days of the month ($d_m$). On the other hand, the load factor ($F_c$) was obtained with the equivalent time in h ($T_e$), the annual operating time of the generator in hours ($T_{fa}$), the annual energy produced (EAP) and the nominal power of the turbine in kW according to the following equations:

$$EAP = PT_{fa} \quad (14)$$

$$T_{fa} = 365 \quad T_{fd} \quad (15)$$

$$T_e = \frac{EAP}{P_{nom}} \quad (16)$$

$$F_c = \frac{T_e}{T_{fa}} \quad (17)$$

## RESULTS AND DISCUSSION

In this research, the INFO_FRANCIS software was developed in the Python v 3.7.6 programming language, which was used because it has a large number of libraries for data processing. It was decided that the application would be web-based, because this way researchers would have easy access to it from any workstation, laptop, tablet or smartphone. These workstations are responsible for showing the server's response to the client without the need to install any additional software except the browser, which comes pre-installed in most of the Operating Systems used today.

Once the application is deployed, it can be accessed using an authentication mechanism based on users and roles. Each authorized user must belong to one or more of the roles defined below. System administrator: only has access to assigning roles to users, Hydropower Administrator: has permissions to modify and create, everything related to the configuration of system parameters. You can also request reports on them, but only in reading and Specialist mode: you can request all types of reports handled by the system. It also has permissions to modify the parameters regardless of the values found.

Figure 1 shows the main interface, which appears once the system is accessed through the browser; Given the determined role, you access the interior of the application. When the user enters the program (Figure 2) he can supply the input data such as: average flow rate, gross head height, pressure pipe diameter, pressure pipe length, pipe roughness coefficient, efficiency of the turbine, nominal turbine power and operating time in the day. The program has two functions to perform: operation and cleaning the information.

The INFO_FRANCIS program quickly and accurately calculates hydraulic parameters such as ecological flow, turbine flow, minimum technical flow, flow speed, pressure pipe diameter, head losses, net head height, turbine power, speed specific speed, rotation speed, specific flow speed, absolute speed, tangential speed, parameters of the impeller and the metal spiral chamber (Figure 3).


**FIGURE 1.** Main interface of the INFO_FRANCIS program.

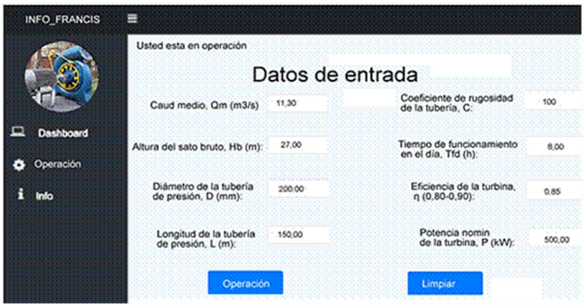


**FIGURE 2.** Data interface of the INFO_FRANCIS program.

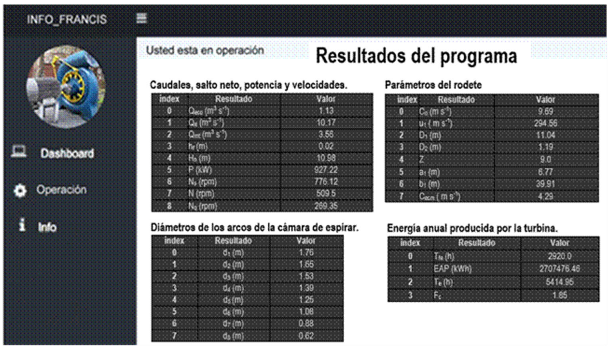


**FIGURE 3.** Results interface of the INFO_FRANCIS program.

The development of a computer program for the design and evaluation of a Francis turbine (one of the most used hydraulic turbines in hydroelectric plants) is of great importance for the evaluation of different possible damage scenarios that these turbines may suffer, the understanding of its behavior in the event of a certain breakdown, obtaining valid criteria in the process of the engineering study in a given basin, the evaluation of the environmental impact associated with the construction of a dam and the maintenance of the turbine. In this sense, Aquino *et al.* (2019) demonstrated that the use of computer programs can help improve the performance of turbine power under specific operating conditions; requiring intensive investigation of watershed parameters.

## CONCLUSIONS

- The INFO_FRANCIS computer program is a computational instrument based on the knowledge of the equations that govern the design and evaluation process of Francis hydraulic turbines installed in Small Hydroelectric Power Plants based on parameters of the hydrographic basin such as average flow, turbined flow, ecological flow, minimum technical flow, jump height; as well as the length and diameter of the pressure pipe.
- The application of the INFO_FRANCIS program allows determining the power of the turbine, the electrical energy produced and the load factor in a given period of time, based on the behavior of the water levels in the reservoir and the parameters of the installed Francis turbine; admitting to compare the results of the program with the data obtained from the Hydraulic Use Company and the Electrical Union of the province.
- The use of the computer program contributes to monitoring the operation of the Francis turbine with greater quality and systematicity, which prevents possible problems that may arise and suggests possible corrective measures that should be applied.

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