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Study of the Sizing of the Small Hydroelectric Power Station of the Gueeni Site on the Kokoulo River in Pita (Republic of Guinea)

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Abstract
In the Republic of Guinea, the supply of electrical energy is still a major issue throughout the country, especially in rural areas. However, the hydroelectric energy potential of Guinea is enormous, 6000 MW, with a very dense hydrographic network (1165 rivers), which originates mainly in Fouta-Djalon. To date, only 5% of this potential has been developed and only benefits nearly 10% of the Guinean population. This study is part of this component for the improvement of electricity supply in isolated areas of the country. Its objective is to assess the hydropower potential and determine the electromechanical parameters of the Gueeni waterfall equipment on the Kokoulo River in Pita. The main results obtained are: river water flow (9.781 m^3/s), gross head (31 m), net head (28.264 m), hydraulic power (3000 kW), net power (2700 kW), the type of turbine (Kaplan), the rotational speed of the turbine (586.58 rpm), the number of poles of the generator (10), the electrical power (2160 kW), the apparent power of the transformer (2700 kVA) and valve closing time (1.1 seconds). These results represent important elements for the establishment of the small power plant at the Gueeni site.
Keywords: Small power plant, Electromechanical equipment, Hydroelectricity, Pita, Guinea

1. Introduction

In the current context of deregulation and liberalization of the electricity market, the questions and concerns about the environmental consequences of the production of electrical energy using fossil or radioactive fuels have triggered a real enthusiasm in favor of the use of renewable energies as evidenced by numerous research articles (Traore and al., 2018).
Hydroelectricity is one of the oldest techniques for producing electricity. It is a reliable and profitable technology in the long term. Hydroelectric energy exploits the potential energy of water flows (river, river, waterfall, marine currents, etc.). The kinetic energy of the water current is transformed into mechanical energy by a turbine, then into electrical energy by an alternator. Hydroelectric power stations are classified according to several hydro-energy parameters (installed power, drop height and reservoir filling time). According to the International Union of Producers and Distributors of Electric Power, hydroelectric power plants are classified according to installed power and head height (Marta Kiraga, 2021).
Depending on the power, they are classified as follows: Pico central from 1 kW to 100 kW; Micropower from 1 MW to 10 MW; Mini-power plant from 10 MW to 100 MW; Medium power plant of 100 MW to 1000 MW and Large power plant of 1000 MW and more (D. Kilama Okot, 2013).
Depending on the head height (H), there are three types of hydroelectric development, namely: high head ($H > 200$ m); medium head ($30 \text{ m} < H < 200$ m); low head ($H < 30$ m), (John G. and al., 2018 and John G., et al., 2016).
There are two important types of work for the construction of a hydroelectric dam: civil engineering works, electrical and hydraulic equipment (Mr. OUALI SALIM, and Mr. ALILI LEMNAOUER, 2012 and Report, 2010).

In 2011, hydroelectric power accounted for approximately 16.2% of global electricity production and has many advantages. It is a renewable energy, with a low operating cost and which is responsible for a low emission of greenhouse gases.
It has another advantage, that of being practically independent of the market price of fossil fuels. However, it has social and environmental drawbacks, particularly in the case of dams located in non-mountainous regions: population displacements, possible flooding of agricultural land, changes in aquatic and terrestrial ecosystems, blockage of alluvium, etc.
Hydroelectricity alone represents more than 94% of the world's electricity production based on renewable energies. It is the first renewable source of electricity production used in Guinea and, worldwide, it is the third source of electricity production (16.6% in 2014 or 3900 TWh) behind coal (40.6%) and gas (22.2%) (Doussou Lancine TRAORE and al., 2019).
Humans have used watermills powered by paddle wheels to grind wheat for over two thousand years. In the 19th century, paddle wheels were used to generate electricity, then replaced by turbines. In the 1920s, a rapid expansion of electricity was born in France, with an eightfold increase in the production of hydraulic electricity thanks to the first dams. In 1925, Grenoble organized the international exhibition of white coal. China, Canada, Brazil and the United States are the largest producers of hydroelectricity (Mohamed Nasser, 2011).
In the Republic of Guinea, the electricity system is essentially based on hydroelectric energy, which represents 58% of the total installed power, and on thermal energy. The first interconnected system, which serves the highest concentration of users and extends from Conakry to Labé, is supplied by: the Kaléta hydroelectric power station (240 MW) with maximum power, but which drops below 70 MW during the low water period; the Garafiri hydroelectric plant (75 MW) of installed capacity; the Grandes Chutes hydroelectric plant (27 MW); the Donkéa hydroelectric plant (15 MW); the Banéa hydroelectric plant (5 MW); the Kinkon hydroelectric plant (3.4 MW); the K-Énergie thermal power plant (75 MW of which 25 MW is available); the Kaloum 1 thermal power plant (24 MW); the thermal power stations of Kaloum 2 and Kipé (26 and 50 MW) and the thermal power stations of Kaloum 3 and 5 (77.2 MW). A second interconnected system is located in the center of the country. It is supplied by the Tinkisso micro hydroelectric power station (1.65 MW) and the Faranah thermal power station (1.4 MW). This system serves the cities of Dabola, Faranah and Dinguiraye, where a 160 kW micro thermal power plant is also located (Ibrahima BAYO and al., 2019 and Global Water Initiative-West Africa, 2017).
The other components of the country's electricity system are: 11 isolated centers in the west and east (Boffa, Gaoual, Télémélé, Lélouma, Kissidougou, Kouroussa, Boké, Kankan, Kérouané, Macenta and N'Nzérékoré), supplied by diesel generators developing 10.14 MW in total (only those in Kankan, Boké, Macenta and N'Nzérékoré are currently operational); 2 isolated pico-hydraulic power stations in Samankou (0.16 MW) and Loffa (0.16 MW) respectively supplying Télémélé in the west and Macenta in the south-east of the country.
Based on the standard needs of rural households and socio-collective equipment per village, the annual energy needs of rural areas of Guinea are estimated in the year 2025 at: 65,000 toe/year of electrical energy; 98,900 toe/year of cooking and heating energy, i.e. a total of 163,900 toe/year (Doussou Lanciné Traore and al., 2018).
This study thus concerns the sizing of a small hydroelectric power plant on the Kokoulo River in Gueeni - Pita in Guinea. The general objective of this study is the evaluation of the hydropower potential and the determination of the characteristics of the electromechanical equipment of the Gueeni site.

2. Materials and Methods

2.1 Materials

2.1.1 Presentation of the study area

Located in the central part of Fouta Djallon, the prefecture of Pita has an area of 2087 km^2 for a population of more than 300000 inhabitants, 92% of whom are in rural areas, 85% engaged in agriculture and 55.7% women. . The prefecture is subdivided into 11 Rural Communities. It is between 11°03′32″ North latitude, 12°23′58″ West longitude.
Of a tropical type, particularly mild at altitudes and hot in the lowlands, the climate is characterized by nocturnal cooling in all seasons, the rigor of the harmattan in December. With the alternation of two seasons (dry and rainy) of relatively equal duration. The average (minimum and maximum) annual temperatures are 14.2°C and 29.5°C respectively. The average annual precipitation is 1771.2 mm. The relief of the

prefecture consists of high plateaus whose altitude varies between 900 and 1264 m. The wooded and wooded savannah is the essential characteristic of its vegetation (Fodé CISSE and al., 2021).
The main economic activities of the prefecture are agriculture, livestock, trade and crafts. Pita Prefecture is home to the Kinkon hydroelectric dam, built by the Chinese from 1963 to 1966 on the Kokoulo River as a seasonally regulated reservoir water diversion plant (Bratislava, 1981). The waterfall on the Kokoulo River on which this study relates, is located 4 km from the village of Gueeni and 15 km from the prefecture of Pita.

2.1.2 Work equipment

During this study, we used the following materials: the level meter, a graduated ruler, a GPS, a decameter, calculation charts and rainfall data from the Pita weather station.

2.2 Method

As part of this report, we carried out a field visit on 04/24/2021. This period coincided with the low water period. Thus, during this investigation, we did:

- The topographical survey for the determination of the gross fall height;
- The choice of installation points for the structures (dam, penstock and technical room);
- Waterfall flow measurements;
- Measurements of the water flow velocity by the float method;
- Calculations of the hydro-energy parameters of the plant.

Figure 1: illustrates the diagram of a small hydroelectric plant.

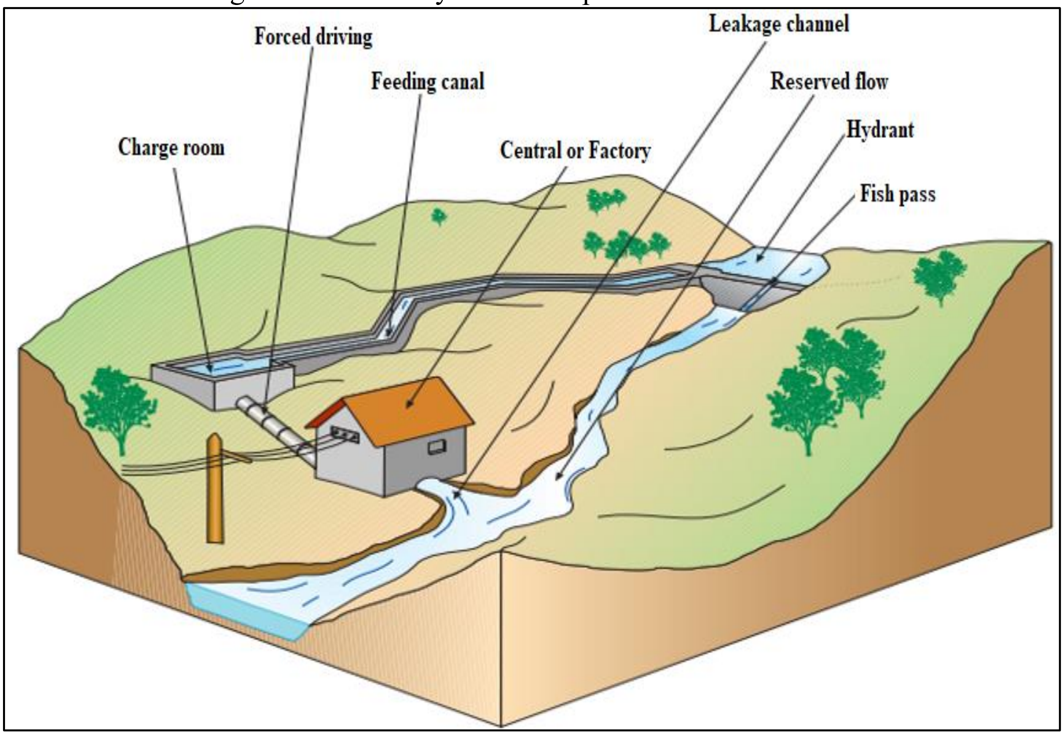

Figure 1: Diagram of a small hydroelectric power plant (ADEME, 2003).

2.2.1 Equipment Flows

The equipment flow (Qeq) is the maximum flow likely to be turbined by the plant when all the turbines are operating together at full power. It is the difference between the average available flow (Qdi) and the reserved flow (Qré) (Emmanuel Ighodalo Okhueleigbe and Ofualagba Godswill, 2017). It is determined by formula 1.

$$Q_{éq} = Q_{di} - Q_{ré} \quad (1)$$

Average throughput available

The average flow available (Qdi) is a function of the wetted section (Sm) and the average velocity (Vm) of the watercourse. It is determined by formula 2. For its calculation, a margin of error of +20% is taken into account (Joan Cecilia M., 2013).

$$Q_{di} = S_m \times V_m \quad (2)$$

Reserved flow

The reserved flow of a river is the minimum flow maintained to safeguard its physical and chemical characteristics and the life of the species that live there to guarantee their migration. The reserved flow (Qré) is the product between the reserved rate (tr = 10%) and the available flow. It is determined by formula 3.

$$Q_{re} = t_r \times Q_{di} \tag{3}$$

With :

Q_{eq}: equipment flow in (m^3/s); Q_{di}: average flow available in (m3/s); Q_{re}: reserved flow in (m3/s); Sm = lm × Pm: Wetted section in (m^2); Vm = L_m/t_m: Average speed in (m^2/s); l_m = 30 m: average width of the watercourse; P_m = 1.1 m: average depth of the watercourse; L_m = 7m: average travel distance of the float; t_m = 21 seconds: Average time taken by the float; tr = 10%: reserved water rate.

Thus, the various calculations give: $S_m = 30 \times 1.1 = 33\ m^2$; $V_m = 7/21 = 0.33$ m/s; $Q_{di} = 33 \times 0.33 = 10.89$ m_3/s. Taking into account the margin of error (+20%) and the reserved rate (10%) we have: $Q_{di} = (10.89 + 0.2) \times 0.1 = 1.109\ m^3/s$; $Q_{re} = 0.1 \times 11.09 = 1.109\ m^3/s$.

Hence the plant equipment flow rate is: $Q_{eq} = 10.89 - 1.109 = 9.781\ m^3/s$.

2.2.2 Gross drop height

There are several techniques for measuring gross head (Hb), namely: pressure gauge, barometer/altimeter, clinometer, GPS and lead string techniques. As part of this study, given the relief of the site, we used the GPS method. It consists of determining the altitude upstream of the waterfall (water intake), and the altitude downstream (technical room) then making the difference between these two altitudes upstream and downstream. It is determined by relation 4.

$$H_b = H_{am} - H_{av} \tag{4}$$

With :

H_b: Gross drop height in (m); H_{am} = 465 m: altitude upstream; H_{av} = 434 m: altitude downstream. Hence the gross drop height is: $H_b = 465 – 434 = 31$ m.

2.2.3 Civil engineering works

The main civil engineering works of the plant are: the water intake, the entrance gate and the intake channel (Alie Wube Dametew, 2016).

Hydrant

The water intake has a lateral and rectangular shape. The height of this water intake (hpr) is calculated by formula 5.

$$h_{pr} = \sqrt{S_m/2} \tag{5}$$

With :

$$S_m = \frac{Q_e}{V_{ml}}$$

$V_{ml} \leq 0.75$m/s: maximum speed limited at the water intake; Sm: wetted section at the water intake in (m^2). The length (L_{pr}) is equal to twice the height of the water intake ($L_{pr} = 2 \times h_{pr}$). We thus have:

$$S_m = \frac{9{,}781}{0{,}75} = 13\ m^2$$

$$h_{pr} = \sqrt{13/2} = 2{,}55\ \text{m}$$

$$L_{pr} = \sqrt{13/2} = 2{,}55\ \text{m}$$

$$L_{pri} = 2 \times 2{,}55 = 5{,}1\ \text{m}$$

Surface of entrance gates

Grids are tools made from parallel metal bars. They are placed at the level of the water intake upstream in order to prevent the penetration of solid particles and debris entering the development. Thus, the grids protect the turbines. They can be in several other places at the level of the layout, thus preventing debris from passing through. Their surface (Sgr) is calculated by relationship 6.

$$S_{gr} = \frac{1}{F_b} \times \frac{a+d}{d} \times \frac{Q_{éq}}{V_0} \times \frac{1}{\sin\delta} \tag{6}$$

Where: F_b = 1: form factor of the bars for steel; a = 12mm: aperture; d = 70mm: thickness of the bars; V_0 = 0.75m/s: speed of water flow; δ = 60°: slope relative to the horizontal.

So :

$$S_{gr} = 1 \times \left(\frac{12+70}{70}\right) \times \frac{9,781}{0,75} \times \frac{1}{0,86} = 17,76 \text{ m}^2$$

Geometric and hydraulic parameters of the headrace

The geometrical and hydraulic parameters of the headrace are: the fruit of the bank, the slope of the bank, the draft, the critical depth, the width of the invert, the height of freeboard, the height of the channel, the wetted section , mirror width, hydraulic depth, wetted perimeter, hydraulic radius, hydraulic diameter, channel flow velocity, center of gravity depth, pipe wall diameter and thickness pressure, the outside diameter of the pipe and the loading chamber. These geometric and hydraulic parameters are calculated as follows (Jahidul Islam Razan, 2012).

Bank slope

The bank slope is the inclination with respect to the vertical giving an angle to the slope (m), it is: m = cotg60° = 0.57.

Draught

Draft (y) is the depth of free surface flow. It is calculated by relation 7.

$$y = \left[\frac{2^{2/3} \times Q_{équi}}{\lambda \times k_s \times \sqrt{I}}\right]^{3/8} \quad (7)$$

With: $\lambda = 2\sqrt{1+m^2} - m$

Where: n = 0.009: Manning's coefficient; λ: Dimensionless quantity that depends on the slope of the banks; I = 0.001 to 0.002: Longitudinal slope; Ks = 111.11: Specific coefficient for smooth concrete.

So :

$$\lambda = 2\sqrt{1 + \frac{1}{3}} - \frac{1}{\sqrt{3}} = 1,73$$

$$y = \left[\frac{2^{2/3} \times 9,781}{1,73 \times 111,11 \times \sqrt{0,002}}\right]^{3/8} = 1,25 \, m$$

Critical depth (yc)

The critical depth (yc) of a channel is the low water depth. When the water level reaches this depth, mining becomes impossible. It is equal to two thirds of the draft (yc=2/3×y). Thus: yc=2/3×1.25 = 1m.

Invert width (b)

The width of the invert (b) represents the bottom of the channel. It is obtained as follows: b = y (λ - m). Thus: b = 1.25 × (1.73 - 0.57) = 1.45 m.

Height of revenge

The height of freeboard (Hrev) is the difference in altitude between the crest of the structure and the body of water. It is equal to 3/7 of the draft (3×y/7). Thus, we have: Hrev = (3×1.25/7) = 0.54 m.

The height of freeboard is characterized by: the raising of the water level during the passage of the maximum flood; the maximum height of the waves caused by the extreme wind considered; the breaking of the waves on the surface of the upstream face; the safety supplement (waves caused by landslides, glacier ruptures, earthquakes) (Samuel Tilahun, 2021).

Channel height (Hc)

The height of the channel (Hc) is the sum between the draft and the freeboard height. We have: $H_c = H_{rev}$ +y. So : Hc = 0.54 +1.25 = 1.79.

Wetted section (Sm)

The wetted section of a channel is the portion of the channel section bounded by the walls of the channel and the free surface. It is expressed by relation 8.

$$S_m = \lambda \times y^2 \quad (8)$$

Thus, we have:

$$S_m = 1,73 \times (1,25)^2 = 2,7 \text{ m}^2$$

Mirror width (lm)

The mirror width in a free surface flow section is the contact length between water and air. It is calculated by relation 9.

$$l_m = b + 2 \times m \times y = 1,45 + 2 \times 0,57 \times 1,25 = 4,88 \text{ m} \quad (9)$$

Hydraulic depth
The hydraulic depth (ym) is the ratio between the flow area (Sm) and the width of the surface (lm) free of water. Let: ym = Sm/Im. Thus we have: ym = 2.7/4.88 =0.55 m

Wet perimeter
The wetted perimeter is the perimeter of the surface of the cross-section of a pipe through which a liquid flows, which is in contact with said liquid. It is determined by relation 10.

$$P_m = 2 \times y \times \sqrt{1+m^2} = 2 \times 1{,}25 \times \sqrt{1+(0{,}57)^2} = 2{,}88 \text{ m} \quad (10)$$

Hydraulic radius
The hydraulic radius is used in particular for free surface flows (in non-full pipes). It is the ratio between the wetted section and the wetted perimeter (Muhammadu M. M. and Usman J., 2020). (R_h = Sm/Pm). We have: R_h = 2,7/2,88 = 0,94.

Hydraulic diameter
The hydraulic diameter (Dh) is determined by relation 11.

$$D_h = \frac{4 \times S_m}{P_m} = \frac{4 \times 2{,}7}{2{,}88} = 3{,}75 \text{ m} \quad (11)$$

Flow velocity in the channel (Vc)
The channel flow velocity (Vc) is the speed of passage of a fluid along a pipeline. It is calculated by relation 12.

$$V_c = \frac{1}{n} \times \frac{y^{2/3} \times \sqrt{1}}{2^{2/3}} \quad (12)$$

With: n = 0.009 the Manning coefficient. We thus have:

$$V_c = \frac{1}{0{,}009} \times \frac{(1{,}25)^{\frac{2}{3}} \times \sqrt{0{,}002}}{2^{\frac{2}{3}}} = 3{,}71 m/s$$

Center of Gravity Depth (YG)
The center of gravity called G is the point of application of the resultant of the forces of gravity or gravity. It can be calculated by the relation (13) through the diagram of figure 2.

$$Y_G = \frac{y}{6} \times \frac{(3b + 2 \times m \times y)}{(b + m \times y)} = \frac{3 \times 1{,}45 + 2 \times 0{,}57 \times 1{,}25}{1{,}45 + 0{,}57 \times 1{,}25} = 0{,}56 \text{ m} \quad (13)$$

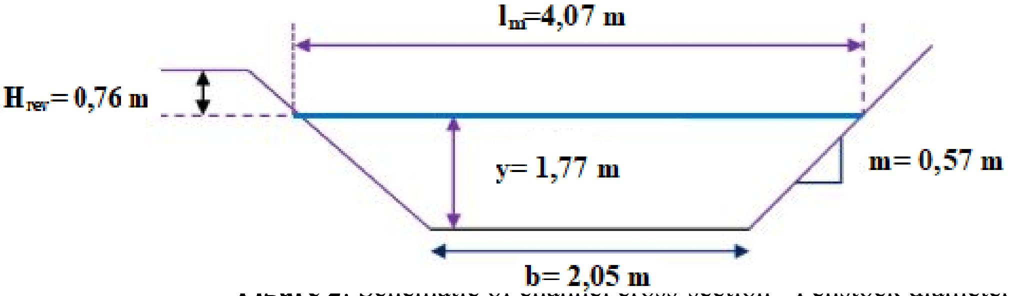

Figure 2: Schematic of channel cross section - Penstock diameter

It is determined by relation (14).

$$D = 2{,}83 \left(\frac{n^2 \times Q_{equi}^2 \times l_c}{H_b}\right)^{0{,}1875} \quad (14)$$

Where: n- Manning coefficient (see appendix); LC- length of pipes (33m); Hb- Gross drop height (31m); Qequ- Equipment flow.

$$= 2{,}83 \left(\frac{(0{,}012)^2 \times (9{,}781)^2 \times 33}{31}\right)^{0{,}1875} = 1{,}28 \text{ m}$$

Wall thickness

$$e = \frac{P_h \times D}{26_f \times K_f} + e_s \quad (15)$$

Where: e - pipe wall thickness (m); P_h - hydrostatic pressure at sea level (N/m^2); σ_f - admissible stress ($140 N/mm^2$); K_f - for stabilized welds (0.9); e_s - thickness beg to take corrosion into account (0.001m).

$$P_h = \rho \times g \times H_b + P_0 = 1000 \text{ x } 9{,}81 \text{ x}31+1013= 0{,}31 N/mm^2:$$

$$e = \frac{0{,}31\times1{,}28}{2\times140\times0{,}9} + 0{,}001 = 0{,}00257m = 2{,}57 \text{ mm}$$

Outer pipe diameter

The external diameter of a pipe varies according to the thickness of the material that composes it. It is determined by relation (16).

$$Da = D+ e = 1.28 + 0.00257 = 1.3m \tag{16}$$

Loading room

It is a small pond that supplies water to the penstock at all times. The pressure chamber must guarantee a satisfactory hydraulic transition between the headrace and the penstocks. It is used to create a "decompression" zone during a sudden closing of a valve in the plant. It is sized according to the diameter of the penstock.

The width is equal to 5 times the diameter of the penstock : $l = 5\times D = 5\times1.28 = 6.4m$

The length is equal to 8 times the diameter of the penstock : $L = 8\times D = 8 \times 1.28 = 10.24m$

The height is equal to 3 times the diameter of the penstock : $H = 3\times D = 3 \times 1.28 = 3.84m$

2.2.4 Evaluation of pressure drops

Head losses or pressure losses represent the reduction in gross head as it flows through pipes. They are expressed in pascals or column meters of the liquid. These head losses depend on the flow velocity, the diameter, the length of the pipes and the Reynolds number (David Tsuanyo et al., 2023).

Singular head losses

It is determined by relation (17).

$$\Delta H_s = K_s \frac{V_0^2}{2g} \tag{17}$$

With: K_s - coefficient which depends on the type of material; V_0- speed of water flow in the material; g - gravitational constant (9.81N/kg).

Linear pressure drops

It is determined by relation (18).

$$\Delta H_g = K_l \left(\frac{a}{d}\right)^{4/3} \times \left(\frac{V_0^2}{2g}\right) \times \sin\beta \tag{18}$$

Pressure losses induced in the grids

The pressure drop in the grilles is due to the friction of the air flow during its passage through the blades of the grilles. It is determined by relation (19).

$$\Delta H_g = K_l \left(\frac{a}{d}\right)^{4/3} \times \left(\frac{V_0^2}{2g}\right) \times \sin\beta \tag{19}$$

Where: K_r - kirchner's coefficient (0.2); a - thickness of the bars; d - spacing between bars; β - inclination of the grid with respect to the horizontal; V_0 - speed at gate re-entry (0.75m/s).

$$\Delta H_g = 0{,}2 \left(\frac{12}{70}\right)^{4/3} \times \left(\frac{0{,}75^2}{2\times9{,}81}\right) \times \sin 60° = 0{,}00046 \text{ mcl}$$

Head loss when the penstock retracts

$$\Delta h_c = k_c \times \frac{V_a^2}{2g} \tag{20}$$

With: V_a - flow velocity in the penstock ($V_a = 4\ Q_{eq}/3.14xD2= 9.73m/s$); k_C – head loss coefficient (0.04).

$$\Delta h_c = 0{,}04 \times \frac{(9{,}73)^2}{2 \times 9{,}81} = 0{,}193 \text{ mcl}$$

Pressure drop at the valves

$$\Delta h_v = k_v \times \frac{V_c^2}{2g} \tag{21}$$

With: k_v - pressure drop coefficient of the spherical valves (0.04); V_c - water velocity in the penstock; D - internal diameter of penstock (m).

So : $\Delta h_v = 0.04 \times (9.73)^2/(2\times 9.81) = 0.193$ mcl

Pressure losses in the penstock

They are determined by relation (22).

$$\Delta h_c = 10{,}33 \times \frac{n^2 \times Q_{équi}^2 \times l_c}{D^{5,33}} \quad (22)$$

Where: Δh_l - linear pressure drop in the pipe (m); n - manning's coefficient; Q_{eq} - equipment flow (m^3/s); l_c - length of pipe (33m); D - pipe diameter (m).

$$\Delta h_v = 0{,}04 \times \frac{(9{,}73)^2}{2 \times 9{,}81} = 0{,}193 \text{ mcl}$$

Elbow head losses

At the level of the penstock, two (2) elbows are considered:

- *First elbow*

It is closer to the grid whose water flow velocity at the inlet is equal to that in the bend. It is determined by relation (23).

$$\Delta h_{cd1} = K_1 \frac{V_a^2}{2g} \quad (2.23)$$

K_1 - pressure loss coefficient in the elbow (0.085).

$$\Delta h_{cd1} = 0{,}085 \times \frac{(9{,}73)^2}{2 \times 9{,}81} = 0{,}41 \text{ mcl}$$

- *Second elbow*

It is located at the outlet of the penstock to the turbine. It is determined by relation (24).

$$\Delta h_{cd2} = K_2 \frac{V_c^2}{2g} \quad (24)$$

With: K_2 - head loss coefficient in the elbow (0.14).

$$\Delta h_{cd2} = 0{,}14 \times \frac{(9{,}73)^2}{2\times 9{,}81} = 0{,}68 \text{ mcl}$$

The total head losses are thus calculated using the formula (25).

$$\Sigma\Delta h = \Delta h_g + \Delta h_c + \Delta h_c + \Delta h_v + \Sigma\Delta h_{cd1} + \Sigma\Delta h_{cd2} \quad (25)$$

$$\Sigma\Delta h = 0{,}00046 + 0{,}193 + 1{,}26 + 0{,}193 + 0{,}41 + 0{,}68 = 2{,}736 \text{ mcl}$$

2.2.5 Net drop height

It is the difference between the gross drop height and the total sum of the head losses.

$$H_n = H_b - \Sigma\Delta h = 31 - 2{,}736 = 28{,}264 \text{ m} \quad (26)$$

2.2.6 Hydraulic power or raw power

Hydraulic power is the power supplied to the turbine by the water that feeds it.

$$P_h = \rho \times g \times Q_{eq} \times H_b \quad (27)$$

Where: P_h - hydraulic power in W; Q_{eq} - average flow in m^3/s; H_b - gross drop height in m; g - gravitational acceleration in N/kg.

So : $P_h = 1000 \times 9.81 \times 9.781 \times 31 = 3$MW

2.2.7 Net power

It is calculated by relation (28).

$$P_{net} = \rho \times g \times Q_{equi} \times H_n \quad (28)$$

$$P_{net} = 1000 \times 9{,}81 \times 9{,}781 \times 28{,}264 = 2{,}7 \text{ MW}$$

2.2.8 Sizing of electromechanical equipment

a) ***Choice of turbine***

The choice of the type of turbine depends mainly on the flow rate of the equipment, the net head or the specific speed of rotation (Figure 3) (Elbatran, A. H. and al., 2015).

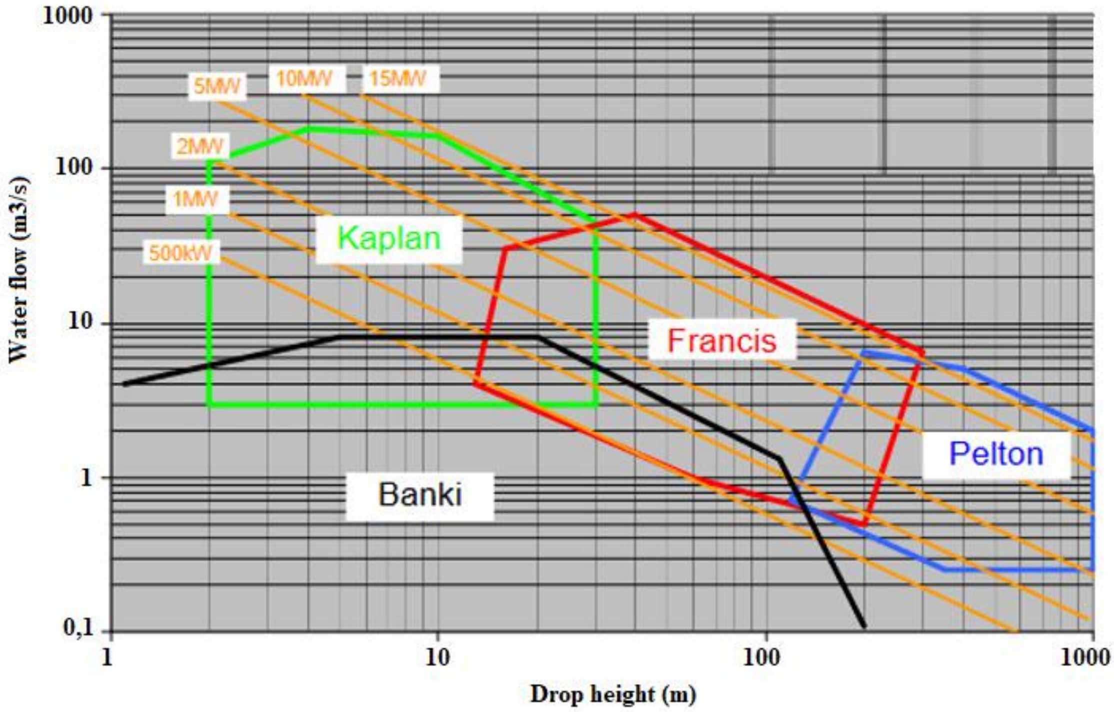

Figure 3 : Turbine type selection chart

After the screening our choice falls on the **Kaplan turbine**.

b) ***Characteristic of the Kaplan turbine***

Specific speed (n_{sp}) : It is calculated by relation (29).

$$n_{sp} = \frac{2,294}{H_n^{0,486}} = \frac{2,294}{(28,264)^{0,486}} = 47 \text{ tr/mn} \quad (29)$$

Rotation speed (n) : It is calculated by relation (30).

$$n = \frac{n_{sp} \times E^{3/4}}{\sqrt{Q_{équi}}} = \frac{27 \times (9,81 \times 28,264)^{3/4}}{\sqrt{9,781}} = 586,58 \text{ tr/mn} \quad (30)$$

Where: E - specific energy (gH_n); H_n - net drop height.

Wheel outer diameter : It is determined by relation (31).

$$D_{ex} = 84,5 \times (0,79 + 1,602 \times n_{sp}) \times \frac{\sqrt{H_n}}{60 \times n} \quad (31)$$

$$D_{ex} = 84,5 \times (0,79 + 1,602 \times 0,78) \times \frac{\sqrt{28,264}}{60 \times 9,78} = 1,56 \text{ m}$$

Wheel internal diameter : It is determined by relation (32).

$$D_{in} = (0,25 + \frac{0,0951}{n_{sp}}) \times D_{ex} \quad (32)$$

$$D_{in} = \left(0,25 + \frac{0,0951}{0,72}\right) \times 1,56 = 0,6 \text{ m}$$

Cavitation coefficient

Cavitation is a phenomenon of phase change where water in the liquid state changes to the vapor state by the decrease in pressure without heat input in the fluid flows. It is determined by relation (33).

$$\sigma = 1,5241 \times n_{sp}^{1,46} + \frac{V^2}{2 \times g \times H_n} \quad (33)$$

With: $V = \sqrt{2gH_n}$

$$\sigma = 1,5241 \times (0,78)^{1,46} + \frac{(23,55)^2}{2 \times 9,81 \times 28,264} = 2,1$$

Suction height : It is determined by relation (34).

$$H_{as} = \frac{P_{at} - P_v}{\rho \times g} + \frac{V^2}{2 \times g} - \sigma \times H_n \quad (34)$$

Where: V - velocity of the water jet in the turbine; P_v- Vapor pressure; Z - altitude upstream of the fall; P_0 - hydrostatic pressure (N/mm2); P_{atm} - atmospheric pressure (atm).

$$P_{atm} = P_0 \left(1 - \frac{0{,}0065 \times Z}{288{,}15}\right)^{5{,}255} = 0{,}31 \times \left(1 - \frac{0{,}0065 \times 465}{288{,}15}\right)^{5{,}255} = 0{,}29 \text{ atm}$$

Thus: $H_{as} = \frac{0{,}29-1}{1000\times 9{,}81} + \frac{(23{,}55)^2}{2\times 9{,}81} - 2{,}1 \times 28{,}264 = -31{,}1 \text{ m}$

As this value is negative, it will be necessary to install the turbine wheel below the restitution level.

Turbine efficiency : It is determined by relation (35).

$$\eta_{turb} = \frac{P_n}{P_h} = \frac{2{,}7}{3} = 90\% \quad (35)$$

Mechanical power : It is calculated by relation (2.35) (Okonkwo G.N and Ezeonu S.O, 2012).

$$P_{méc} = Q_{équi} \times H_n \times \rho \times g \times \eta_{turb} \quad (36)$$

$$P_{méc} = 1000 \times 9{,}81 \times 9{,}781 \times 28{,}264 \times 0{,}9 = 2{,}4 \text{ MW}$$

2.2.9 Choice of Generator

The transformation of mechanical energy into electrical energy is ensured by a converter which makes it possible to obtain alternating current electrical energy from mechanical energy. As part of our project, the turbine is directly adapted to the alternator without the intermediary of a speed multiplier, so the speed of the turbine is equal to that of the alternator.

The number of pairs of poles is calculated by relation (37).

$$p = \frac{60f}{n_s} = \frac{60\times 50}{583{,}58} = 5 \quad (37)$$

Where: n_s - generator rotation speed; P: number of generator pole pairs; f - generator frequency (50Hz). Therefore we have a generator of 10 poles or 5 pairs of poles.

2.2.10 Electrical power

It is calculated by relation (2.37) (Anaza S. O., et al., 2017).

$$P_{él} = \eta_g \times P_{méc} = 0{,}9 \times 2{,}4 = 2{,}16 \text{ MW} \quad (38)$$

2.2.11 Choice of transformer

The choice of transformer depends on its apparent power, the voltage of the transmission lines and the electrical energy produced by the plant. It is calculated by relation (39) (Jean Ouèrè Toupouvogui et al., 2023).

$$P_{app} = \frac{P_{él}}{cos\varphi} = \frac{2{,}16}{0{,}8} = 2{,}7\text{MVA} \quad (39)$$

With: cosφ= 0.8

The number of generator is calculated by the relation (40).

$$Z_G = \frac{P_h}{P_{él}} = \frac{3}{2{,}16} = 1.38 \quad (40)$$

Where: Z_G - Number of generator; P_h- Hydraulic power.

For the implementation of this project we need 02 generators of the same capacity.

2.2.12 Securing the control unit

Pressure wave velocity : This speed depends on the elasticity of the water and the material of the penstock. It is determined by relation (41).

$$C = \sqrt{\left(\frac{K}{\rho(1+\frac{K\times D}{E\times e})}\right)} \quad (41)$$

Where: C - wave speed in m/s; K - modulus of water compressibility (2.1 × 109 N/m^2); E- modulus of elasticity of penstock material (2.1×1011 N/m^2); D - diameter of penstock (m); e- penstock wall thickness (mm); ρ - density of water.

$$C = \sqrt{\left(\frac{2{,}1\times 10^9}{1000\left(1 + \frac{2{,}1\times 10^9 \times 1{,}28}{2{,}1\times 10^{11}\times 0{,}00257}\right)}\right)} = 592{,}55 m/s$$

Critical time **:** This is the time taken by the pressure wave to reach the valve. It is determined by relation (42).

$$T_c = \frac{2L}{C} = \frac{2\times 33}{592{,}55} = 0{,}11 \text{ s} \quad (42)$$

Where: T_c - critical time (s); L - length of penstock (m); C - speed of the pressure wave (m/s).

Valve closing time : For security reasons, this time is ten (10) times greater than the critical time (43).

$$t = 10 \times T_c = 10\ 0{,}11 = 1{,}1s \quad (43)$$

Transient pressure : If the transient regimes depend directly on the sudden variation of the flow velocity in the pipe. These speed variations are at the origin of pressure variations (also called water hammer) which can be positive or negative. The overpressure is determined by formula (44) (Guillermo Romero and al., 2020).

$$\Delta_p = P_o\left[\frac{N}{2} \pm \sqrt{\left(\frac{N^2}{4} + N\right)}\right] \quad (44)$$

With: Δ_p - Transient overpressure in meters of water column; P_o - Hydrostatic pressure at sea level; N - coefficient that depends on the valve closing time and the water velocity in the penstock calculated by relation (45) (R Autrique1 and E Roda, 2013).

$$N = \left(\frac{L_c \times V_c}{g \times P_o \times t}\right)^2 = \left(\frac{33\times 14{,}51}{9{,}81\times 0{,}001013\times 1{,}5}\right)^2 = 0{,}001031 \quad (2.45)$$

With: L_c - penstock length (m); V_c - water velocity in the penstock (m/s); T - valve closing time (s); g - acceleration of gravity (m/s^2).

$$\Delta_p = 0{,}001013 \times \left[\frac{0{,}001031}{2} \pm \sqrt{\frac{(0{,}001031)^2}{4}} + 0{,}001031\right] = 2{,}13.10^{-6}\text{N/mm}^2$$

The pressure that the penstock can withstand is the sum of the hydrostatic pressure due to the gross head and the overpressure (47).

$$P_t = P_o + \Delta_p = 0{,}001013 + 2{,}13.10 - 6 = 10{,}2.10^{-4} \quad (47)$$

3. Results and Discussion

3.1 Results

The results obtained during this study are shown in Table 1.

Table 1 : Hydroenergetic characteristics of the Gueeni site on the Kokoulo River in Pita

Designation	Symbole	Valeur	Unité
Equipment Flows	Q_{ep}	9,781	m^3/s
Average throughput available	Q_{di}	10,89	m^3/s
Reserved flow	Q_{re}	1,109	m^3/s
Gross fall height	H_b	31	m
Water intake height	h_{pr}	2,55	m
Maximum speed at water intake	V_{ml}	≤ 0,75m/s	m/s
Wet section at water intake	S_m	13	m^2
Surface of entrance gates	S_{gr}	17,76	m^2
Bank slope	m	0,57	-
Draught	y	1,25	m
Critical Depth	y_c	0,83	m^3/s
Invert width	b	1,45	m
Height of revenge	H_{rev}	0,54	m
Channel height	H_c	1,79	m
wWet section	S_m	2,7	m^2
Mirror width in flow section	L_m	4,88	m
Hydraulic depth	y_m	0,55	m
Wet perimeter	P_m	2,88	m
Hydraulic radius	R_h	0,94.	m
Hydraulic diameter	D_h	3,75	M
Flow velocity in the channel	V_c	3,71	m/s

Center of Gravity Depth	Y_G	0,56	M
Penstock Diameter	D_{CF}	1,22	M
Penstock Wall Thickness	e_{CF}	0,00257	M
External diameter of a penstock	Dex_{CF}	1,3	M
Weighting chamber width	l_{cmc}	6,4	M
Weight bearing chamber length	L_{cmc}	10,24	M
Weight chamber height	H_{cmc}	3,84	M
Linear pressure drops	Δh	2,736	Mcl
Net fall height	H_n	28,264	M
Hydraulic power	P_h	3000	kW
Net power	P_n	2700	kW
Turbine type	-	Kaplan	-
Turbine specific speed	n_{sp}	47	tr/m
Turbine rotation speed	N	586,58	tr/m
Wheel outer diameter	D_{ex}	1,56	M
Wheel internal diameter	D_{in}	0,6	M
Cavitation coefficient	Σ	2,1	-
Suction height	Ha	-31,1	M
Turbine efficiency	η_{tur}	90	%
Mechanical power	P_m	24000	kW
Number of generator poles	n_{pg}	10	-
Electric power	P_{el}	2160	kW
Transformer Apparent Power	P_{ap}	2700	kVA
Pressure wave velocity	C	592,55	m/s
Critical time	T_C	0,11	S
Valve closing time	T	1,1	S
Transient pressure	Δp	$10{,}2.10^{-4}$	N/mm^2

3.2 Discussion

The Gueeni Waterfall on the Kokoulo River in Pita is one of the important sites of small hydropower plants in Guinea. The main hydraulic parameters and the main hydro-energetic characteristics of the site are: equipment flow rates (9.781 m^3/s), gross head (31 m), net head (28.264 m m), hydraulic power (3000 kW), power power (2700 kW), turbine type (Kaplan), turbine rotation speed (586.58 rpm), number of generator poles (10), electrical power (2160 kW), transformer apparent power (2700 kVA) and valve closing time (1.1 s). The hydro-energetic parameters determined are average values, they were evaluated during the dry season of the year (February, March and April 2022).

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5. Conclusion

This study is a continuation of our research work in the field of the development of renewable energy resources in Guinea. It made it possible to assess the hydropower potential of the Gueeni waterfall on the Kokoulo River in Pita. Similarly, the electromechanical equipment of the plant has been sized.

The realization of this project of small hydroelectric power stations would improve the supply of electricity in the country and especially in isolated rural areas, which makes it possible to reduce the excessive use of firewood and charcoal.

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