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Study and Design of Bofossou Hydroelectric Microplant in Macenta Prefecture - Guinea

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ABSTRACT: *The objective of this research is the design of the micro-hydroelectric plant at the Bofossou site in Macenta Prefecture. The power of the calculated microcentral is 35 kW. The hydraulic parameters of the plant calculated are: the net height of the chute (1.45 m); the pressure drops (1.45 m); the wet perimeter of the canal brought (2.28 m); flow velocity (1.27 m/s); the flow rate (0.762 m^3/s); the nominal diameter of the penstock (600 mm); the length of the penstock (85 m) and the volume of the loading pond (26.92 m^3). The types of turbines adapted to this plant are Francis or Banki. This study was conducted on the basis of theoretical and practical approaches. The valorization of these hydroelectric potentials of the country makes it possible to improve the electrical energy supply of the isolated areas of the existing network. This limits the misuse of firewood and charcoal, with a decrease in the release of greenhouse gases into the atmosphere.*

***KEYWORDS*:** *Sizing, Microcentral, Hydroelectric, Power*

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I. INTRODUCTION

A hydroelectric plant uses the kinetic energy of the water flow, converts it into mechanical energy by means of a turbine, and then into electrical energy by means of an alternator. The power of the plant is both proportional to the flow taken from the stream and the height of the waterfall. Hydroelectric structures are classified differently according to the height of the watercourse: high waterfall (with a drop height greater than 100 m); average fall (height between 15 to 100 m); low drop (height less than 15 m). Hydroelectric energy is one of the Renewable Energy sources because of the water cycle [1, 2].

The small hydropower is the most competitive renewable energy: it allows a flexible electricity production and close to the places of consumption, avoiding losses on the distribution network; it contributes to the low-carbon balance by not emitting greenhouse gases; it produces non-intermittent renewable electricity; it respects the ecological status of rivers through all environmental measures that allow the free movement of fish and sediments (fish passes, valve maneuvers, bypass rivers, turbines) and contributes to economic activity and development Nations by providing income to rural communities and supporting local industrial and craftactivity [3, 4].

Hydropoweris one of the oldest forms of electric power generation and with great technological maturity. Appeared in the Middle Ages, the water mills have a first phase of development from the 12th century. At the end of the 19th century, hydraulics took on a new dimension with the development of the electricity network. A multitude of small hydropower plants have been created to supply electricity to cities. From the beginning of the 20th century, the transmission of electricity gradually spreads. Hydropower plants provide energy that is not only consumed locally. To cover the growing needs of the country in electricity, large hydraulic complexes are emerging and, at the same time, large reservoirs. For example, in the middle of the 20th century, more than half of French electricity production is of hydraulicorigin [5].

Hydropower plants are made up of various structures, which allow them to functionproperly: water intake works (in dykes or more or less large dams that divert part of the current to the intake structure) [6]. The flow control is carried out either by a movable dam in the river or by a valve in the supplychannel; the supply, loading and forced-pipe structures (most often, the supply channel is in free open-air flow and connects the intake to the inlet of the plant, turbine against the elements carried by the river (trees, dead leaves, etc.) and a power generation structure (the power station, consisting of turbine connected to an alternator). There are four main turbine models depending on the characteristics of the turbine the power station: Pelton, Francis, Kaplan and Banki. The restitution works (once the turbined water is returned to the river via the restitution channel without having been modified) [7]. Figure 1 illustrates the diagram a smallhydroelectric plant.

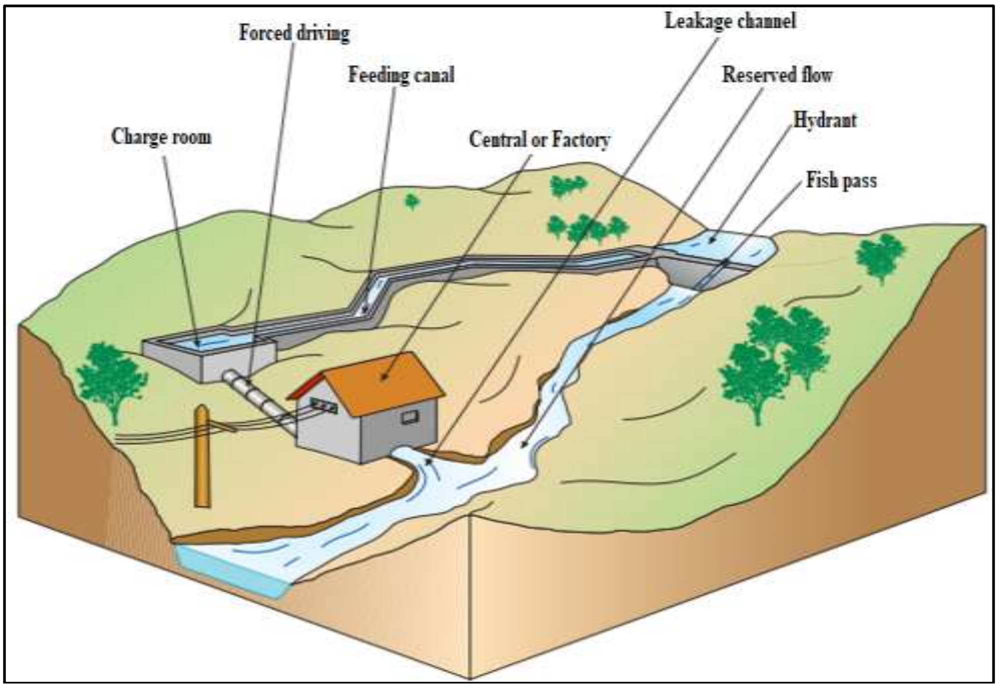

Figure 1: Diagram of a small hydropower plant

In the Republic of Guinea, the supply of electricity is still a major issue throughout the country, especially in rural areas. However, the hydropower potential of Guinea is enormous, 6000 MW, with a very dense hydrographic network, 1165 rivers, which find their origins mainly in the two mountainous regions of the country, the Fouta-Djallon and the Forest Guinea. To date, only 2% of this potential is developed and benefits only 8% of the Guinean population [8]. Guinea's electricity system is essentially based on hydroelectric power, which represents 58% of the total installed power.

The hydroelectric plants are generally classified according to the installed power, one has: Microcentrales powers lower than 100 kW; Mini power plants between 100 kW and 2 MW; Small power plants between 2 and 50 MW and Large hydropower plants for powers greater than 10 MW. For other researchers the classification is done according to the flow of equipment and the diameter of the blade, one has: Micro (flow less than 0,4 m3 / s and diameter of the blade lower than 0,3 m); Mini (flow between 0,4 to 12,8 m3 / s and diameter of the blade included (0,3 to 0,8 m) and Small (flow superior to 12,8 m3 / s and diameter of the dawn greater than 0.8 m) [9].

II. MATERIALS AND METHODS

2.1 Presentation of the study area

The prefecture of Macenta is an administrative subdivision of the Nzérékoré region, it is located in the southeast of the Republic of Guinea 700 km from the capital Conakry. Macenta liebetween latitude 8 ° 32'37 " N and longitude 9 ° 28'22 " W with an average elevation of 609 m. It covers an area of 2724 m2, with a population of 278456 inhabitants in 2014 of which almost 85% of the population live in rural areas [10].

Bofossou is one of the fourteen (14) sub-prefectures of Macenta, it is located 38 km from the urban community (Figure 2). The population of the sub-prefecture of Bofossou is 13,803 inhabitants, it is a commercial center of agricultural products, with a weekly market very frequented. It has several elementary schools, a college, a health center, health posts, a youth center and administrative buildings. There are about ten generators five video clubs, seam workshops, hairdressers, hullers, and grinding machines (rice, coffee, peanuts, cassava) and a welding shop. The site of Bofossou is located on the ZuluZia river which crosses the village with two months of low water (February and March), the waterfall is 350 meters from the center of the village. The proximity of the village site and the need for energy make this site one of the most important [11].

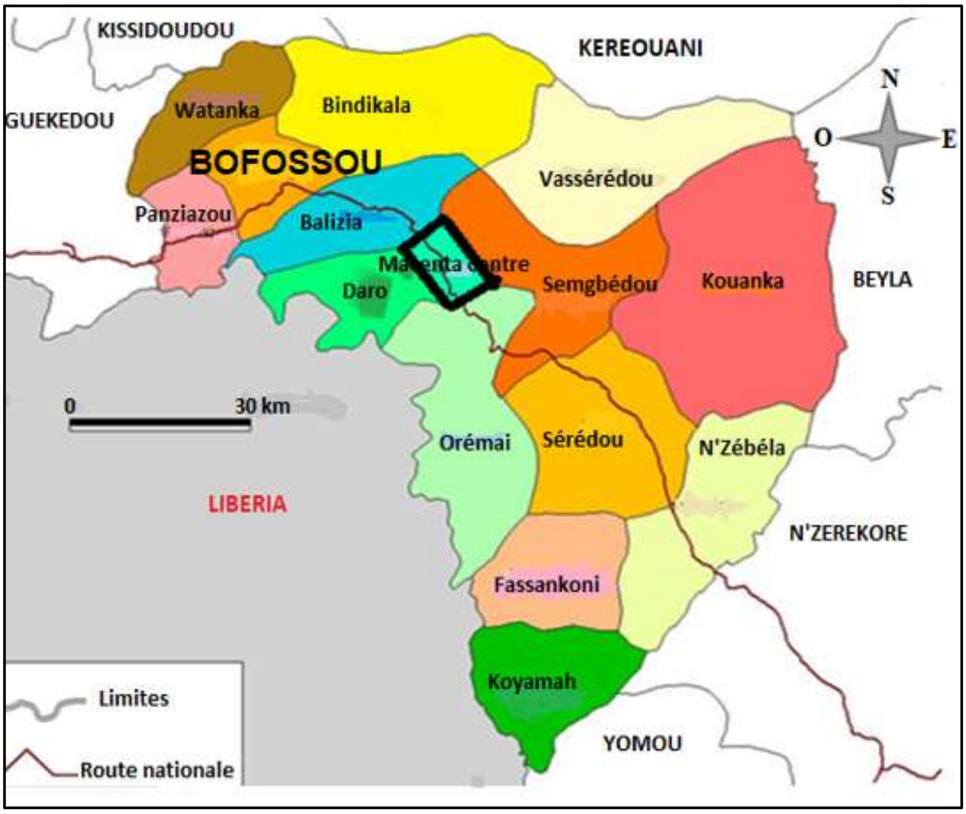

Figure 2: Map of Macenta Prefecture

2.2 Materials

As part of this research, the following equipment and materials were used: a float, a stopwatch, a graduated ruler, a decameter, two Current and Propeller currentometers, a GPS (Global Positioning System), a clisimeter, a level, a compass and a telescope on a tripod.

2.3 Method

Practical and theoreticalapproaches were used for the design of the micro-power plant at the Bofossou site. Measurements of some hydrological parameters (width, depth, flow velocity, and head of the watercourse) were made. The other parameters (pressure drop, net drop height, stream flow, pipe diameter, loading pond dimensions, and electric power) were calculated based on the measurements made. The choice of turbine is made [12, 13].

2.3.1 Choice of the location of the works

The location of the works (dam, loading basin and technical room) of the Bofossou microcentrale site are chosenbecause of the nature of the relief. The dam is laid on rocky ground with a length of (6 m). The dimensions of the loading pond (width, length, and height) are calculated according to the diameter of the penstock.

2.3.2 Gross fallheight

The measurement of gross drop height was made using the telescope mounted on a tripod and with a ruler (rim). The absolute value of the difference between the rear measurements (Mar) and the front measurements (Mav) of the wall gives the gross height (Hb) of fall, (relation 1).

$$H_b = M_{ar} - M_{av} \quad (1)$$

2.3.3 Net fall height

The net height (Hnet) is the difference between the gross height and the losses of loads, it is calculated by the relation 2.

$$H_{net} = H_b + \sum J_{ls} \qquad (2)$$

Where: $J_{ls}$is the sum of the losses of linear (J_l) and singular (J_s) loads.

The linear pressure losses (Jl) are composed of height losses in the supply line and of loads in the penstock. The height loss in the supply line is equal to the observed slope multiplied by the length of the pipe (0.002 * 65 = 0.13m). The linear losses (J_l) are determined from the diagrams according to the diameter (D_{CF}) and the length of the forced pipe (L_{CF}). In the case of this search, for D_{CF} = 600 mm corresponds to a linear loss J = 7.581 m / km. Thus, this linearloss of load (J_{lCF}) throughout the length (L_{CF}) of the penstock isdetermined as follows:

$$J_{Lcf} = J \times L_{CF} = (7{,}581 \times 85)/1000 = 0{,}644 \text{ m.}$$

The singular pressure losses are calculated by the relation 3.

$$J_s = \sum K_i \times \frac{V^2}{2 \times g} \tag{3}$$

Where: V is the flow velocity in the penstock; g = 9.81m / s2 is the acceleration of gravity; $K_i$is the pressure loss coefficient, which depends on the nature and geometry of the protective grid placed between the loading pond and the penstock. The different values of Ki are: 0.37 (which depends on the section of the bars of the grid); 0.5 (which function is the spacing between the bars) and 1 (for a gridwithvoid angle).

2.3.4 Flow velocity in the intake channel

The supplychannel has an open trapezoidal shape (Figure 3). The flow velocity in this channel is determined by the Manning-Strickler formula (relation 4).

$$V = K_S . R^{\frac{2}{3}} . J^{\frac{1}{2}} \tag{4}$$

Or:

$K_S = \frac{1}{n}$: Strickler coefficient and n Manning coefficient; $R = \frac{S}{P}$: Hydraulic radius;$j = 2\text{mm/m}$: Bottom slope of the canal; $S = l \times h + \left(\frac{L-l}{2}\right).h$ .h: Wetted section of the channel; $P = l + 2 \times X$: Wet perimeter. The coefficient (K_S) is a function of the materials, it varies between 70 and 90 for smooth concrete.

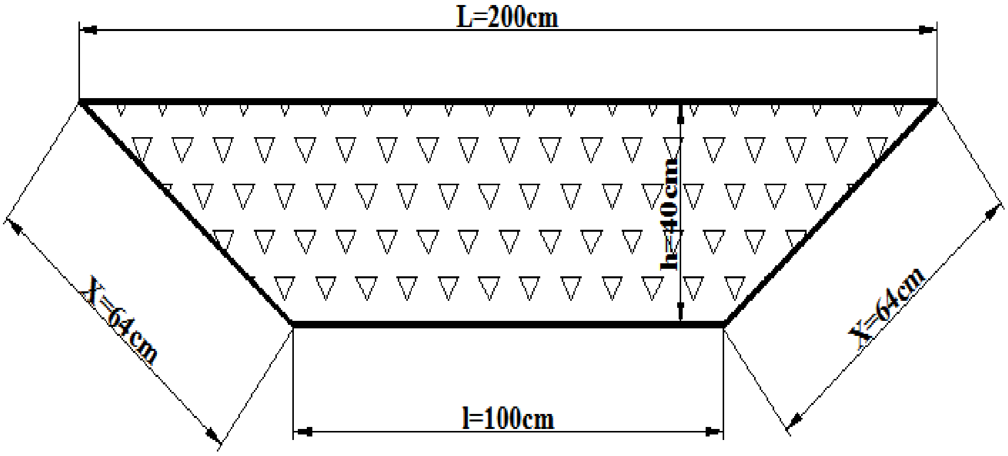

Figure 3: Form of the lead channel

2.3.5 Flow rate in the canal

The flow rate (Q) in the channel is a function of the flow velocity (V) and the wet section (S). It is calculated by the relation 5.

$$Q = V \times S \tag{5}$$

2.3.6 Nominal diameter of the penstock

The diameter of the penstock between the water intake and the micro hydro turbine is a function of the flow rate (Q) and the flow velocity (V). It is determined by relation 6.

$$D_{CF} = 2 \times \sqrt{\frac{Q}{\pi \times V}} \tag{6}$$

2.3.7 Bearing Basin Dimensions (BMC)

The dimensions of the BMC are calculated as follows: the width is equal to five (5) times the diameter of the penstock, the length is eight (8) times the diameter of the penstock and the height is three (3) times the diameter of the penstock [8]. The volume of the loading pond is calculated by the relation 7.

$$V_{BMC} = l_{BMC} \times L_{BMC} \times H_{BMC} \quad (7)$$

2.3.8 Electric power of the microcentral

The electric power of a hydroelectric power plant is proportional to the flow and the net height of the fall, taking into account the acceleration of the gravity of the waterfall ($g = 9.81 m/s^2$), the density of water ($\rho = 1000 kg/m^3$) and the overall yield (η). It is expressed by relation 8 [14, 15].

$$P_b = \eta \times g \times \rho \times Q \times H_n \quad (8)$$

Where: ($\eta = \eta_{tu} \times \eta_{ac} \times \eta_{gé} \times \eta_{tra}$) is the overall efficiency, which is the product of different machine efficiencies (turbines, couplings, generator and transformer). This yield is generally between 60 to 90%.

2.3.9 Choice of turbine type

The choice of turbine is a function of its specific speed (n_s). This specific speed is related to the following parameters: the net drop height (H_{net}), the mechanical power (P_{mt}) and the rotational speed (n) of the turbine. The specific speed of a turbine is the speed at which a geometrically similar turbine would spin which provides mechanical power of a Steam Horse (1CV = 0.736 kW) under a falling set. It is determined by the relation 9 [16, 17].

$$n_s = n \times P_{mt}^{\frac{1}{2}} \times H_{net}^{-\frac{5}{4}} \quad (9)$$

Taking into account the parameters of the Bofossou microcentral site, the calculation of the specific speed (n_s) gives the relation (10).

$$n_s = 0.30 \times n (10)$$

Some standardized values of the rotation speed (n) of the turbines are: 450 rpm; 500 rpm and 600 rpm. Applying the relation (10), these values respectively correspond to the following specific speeds: 135 rpm; 150 rpm and 180 rpm. Table 1 gives the classification of turbine types according to their specific speeds

Table 1: Classification of turbine types according to their specific speeds

n_S (trs/min)	**10**	**33**	**70**	**80**	**150**	**300**	**500**	**1000**	**1300**
Pelton (P)	1 Jet		Multi jet		Non	Non	Non	Non	Non
Francis (F)	Non	Non	F	F	**F**	F	F	Non	Non
Banki (B)	Non	B	B	B	**B**	Non	Non	Non	Non
Kaplan (K)	Non	Non	Non	Non	Non	K	K	K	Limite

From Table 1, it can be seen that the types of Francis or Banki turbines are suitable for the Bofossou micro-power plant.

III. RESULTS AND DISCUSSIONS

3.1 Results

The results obtained during this study are shown in Table 2.

Table 2. Hydropower characteristics of the Kalako waterfall

Designation	**Symbol**	**Value**	**Unit**
RearMeasurements	Mar	4.201	m
Measuresbefore	Mav	18.103	m
Gross fallheight	H_b	13.902	m
Loadlosses	J_{ls}	1.45	m
Net height of fall	H_{ent}	12,452	m
Wetperimeter of the canal	P	2.28	m
Wet section	S	0.6	m^2
Slope of the canal	j	2.0	mm/m
Coefficient	KS	70.0	-
Flow velocity	V	1.27	m/s
Flow rate	Q	0.762	m^3/s
Nominal diameter of the penstock	D_{CF}	0.600	m
Length of the penstock	L_{CF}	85	m
Load Basin Width	l_{BMC}	3	m
Load Basin Length	L_{BMC}	4.8	m
Loading Pond Height	H_{BMC}	1.8	m
Charge Basin Volume	V_{BMC}	25.92	m^3
Overall performance	η	60	%
Electric power	P	35 kW	kW
Turbine type	F ou B	Francis ou Banki	-

3.2. Discussions

The hydroelectric power of the micro hydropower plant at the Bofossou site is 35 kW. This power is an average value of the plant, it was determined at a less rainy time of the year (October, September and December). This power lies in the range of micro hydroelectric power plants. The development of this potential would improve the electricity needs of the locality.

IV. CONCLUSION

The lack of hydrological and meteorological data from Guinea is a handicap for a comprehensive study of the country's various hydropower sites. However, in a perspective of valorization of the numerous sites available on the whole territory, preliminary studies of dimensioning and evaluation of the environmental impacts remain an unavoidable necessity. It is in this sense that the results we have achieved are of paramount importance for the sustainable development of Guinea.

This study was conducted on the basis of theoretical and practical approaches. Such an evaluation campaign and the development of these hydroelectric potentials of all waterfalls available in the country allows most of the Guinean population to have a guaranteed electricity consumption. This limits the misuse of firewood and charcoal, with a decrease in the release of greenhouse gases into the atmosphere.

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