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Method for Evaluation of the Energy Potential and Sizing of the Works of a Hydroenergy Site for the Establishment of a Mini-Hydroelectric Power Plant. Application : Tinkisso 2 Site in Dabola in the Republic of Guinea

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ABSTRACT

The objective of this research concerns the evaluation of the energy potential and the sizing of the Tinkisso 2 hydro-energy site for the establishment of a hydroelectric power plant serving as an additional source to the existing power plant (1.65MW) for service. in electricity for the town of Dabola and its surrounding areas which currently have a need of 7MW. The methodology adopted for this study is that initiated by the Decentralized Rural Electrification Office (BERD), which consists of evaluating the potential by measuring hydrological and energy parameters using topographical tools such as: the telescope on a tripod, the GPS, graduated ruler, tape measure, float, etc. These parameters allowed us to choose the electromechanical equipment adaptable to the installation site of the hydroelectric power station and the determination of the dimensions of the loading basin.

At the end of this study, we obtained the following results:

For the evaluation of the potential: the available flow (41.81 m3/s), the reserved flow (3.35 m3/s), the equipment flow (38.26 m3/s), the gross head (45m), gross power (16.889 MW), net head (40.5m), useful power (11.628 MW);

For sizing: the diameter of the penstock (550 cm), the type of turbine is Francis, the frequency of the turbine (100 rpm), the type of generator is vertical synchronous, the number of groups (2), the efficiency coefficient of the generator (96.1%), the length of the active steel of the stator (33 cm), the power of the chosen transformer (10 MW), the weight of the transformer (23.8 tonnes), the output voltage (35 kV), the length of the charging basin (44 m), the width (27.5 m) and the height (16.5 m).

The calculated installed power was compared to that of another study which led to a difference of almost 10%.

Keywords: *Evaluation, energy potential, sizing, equipment, power plant, Guinea.*

NOMENCLATURE

BED : Decentralized Rural Electrification Office
SV : Vertical Synchronous
TD : Two-Phase Transformer
GPS : Global Positioning Satellite
F45 : Francis for a fall height of 45m

1. INTRODUCTION

Increasingly in all four corners of the world, the decentralized production of electricity from renewable sources is developing very significantly every day, thereby reducing dependence on fossil fuels. As the development of large hydropower plants has become very difficult in many industrialized countries due to the shortage of development sites and environmental restrictions on a global scale, there are many suitable sites for the development of mini-hydropower plants with a power range less than 10 MW. These constraints give mini-power plants a place of choice in the field of renewable energies since their environmental impacts are very low. Power and efficiency being fundamental elements for a company that wants to be competitive, it is therefore important to equip oneself with adequate tools to maximize them.

Hydroelectricity alone represents more than 94% of global electricity production from renewable energies [1, 2]. It is the first renewable source of electrical energy production used in Canada [3] and, throughout the world; it is the third source of electricity production (16.6% in 2014 or 3900 TWh) behind coal (40.6%) and gas (22.2%) [4]. It has another advantage, that of being practically independent of the price of fossil fuel markets. Hydroelectric power is one of the renewable energy sources due to the water cycle [5, 6, 7].

Large hydroelectric power plants (86%) are high-power hydroelectric developments above 10 MW and small hydroelectric power plants (8.3%) are those with powers less than 10 MW. This second category of developments, increasingly used for the production of electrical energy, is itself generally subdivided into small, mini and micro power stations [8]. Consequently, there is no real consensus on the terms and the boundaries between the different ranges of small hydropower are blurred.

These disparities even extend to the border between small and large hydroelectric plants, the value of which can vary from 10 MW to 30 MW. “Small-scale” mini-hydroelectric plants have an installed capacity generally less than 5 MW [9, 10]. They are essentially composed of upstream and downstream reservoirs, a balance chimney, a penstock, a hydraulic turbine, an alternator and a diffuser. In practice, small installations differ little from large ones. The difference lies mainly in the simplicity of design and operation. Small power plants are not only economical to build, but they can also operate automatically without permanent staff and with minimal monitoring and maintainability time. As a general rule, they are operated on a run-of-river basis, without a storage tank, which is the element of civil engineering that is too costly for these small installations [11].

It is obvious that the problem of electrical energy is acute in Guinea. However, its hydro-energy potential is enormous and the hydrographic network is very dense (1165 rivers). From these resources, we can develop a hydroelectric potential estimated at 6,000 MW for guaranteed energy of 19,300 GWh/year [12]. To date, despite the construction of the Kaléta (240 MW), Souapiti (450 MW) and Amaria (300 MW) hydroelectric power stations currently under construction, less than 30% of this potential has been developed and only benefits less than 25% of the population. Rural areas and towns isolated from existing electricity networks are the least served. To do this, it should be noted that Guinea has resources of more than 58MW usable for isolated sites. The establishment of new mini-hydroelectric power stations would make it possible to produce additional potential to that existing and thus improve the current service [13, 14].

It is with this in mind that we were interested in carrying out this work on: Method of evaluating the energy potential and sizing of the structures of a hydro-energy site for the establishment of a hydroelectric power station. Application: Tinkisso 2 site in Dabola in the Republic of Guinea.

2. MATERIALS AND METHOD

2.1. MATERIALS

2.1.1. PRESENTATION OF THE STUDY AREA

The Prefecture of Dabola is one of the eight (8) Prefectures of Upper Guinea. It is located 430 km from the capital Conakry. It is between 11°30' and 11°35' West longitude and 10°20' and 11°00' North latitude. It covers an area of 6,350 km2 with a total population of 150,658 inhabitants (according to the population census of April 2014) or an average density of 24 inhabitants/km2. The Tinkisso 2 site on the Tinkisso river is located upstream of the Tinkisso micropower plant (1650 kW), in the urban commune of Dabola. It is limited to the north by the sub-prefecture of Banko, to the south by the Tinkisso micro hydroelectric power plant, to the east by the village of Souarela and to the west by the town of Dabola.

2.1.2. TOOLS

To carry out this research, we used certain materials and equipment to collect the data essential for evaluating the energy potential of a hydro-energy site. This equipment is as follows: the tripod telescope, the GPS, the float, the tape measure, the milestones, the calculator, the graduated ruler, etc. the data measured from this equipment is recorded in the table below:

Table 1: Data measured on site

N°	Parameters	Symbols	Values
1	Channel section	S	25,34m^2
2	Average depth	Prmoy	0,724m
3	Average flow speed	Vmoy	1,65m/s
4	Channel width	lcanal	35m
5	Upstream coast	Alt(A)	566m
6	Downstream coast	Alt(B)	521m
7	Channel length supplied	Lcan,ame	45m
8	Penstock length	Lcond,for	70m
9	Leakage channel length	Lcanf	95m

2.2. METHOD

The methodology adopted to achieve the objectives of this research is that initiated by the Decentralized Rural Electrification Office (BERD) which consists of evaluating the energy potential by the method of spot measurements and determining the equipment necessary for the proper operation of the power plant projected via sizing.

2.2.1. EVALUATION OF ENERGY POTENTIAL

a) ESTIMATED FLOW

The average flow rate is the product of the average water flow speed and the channel section. It is expressed by the following relationship :

$$Q_{moy} = V_m \times S_{can} \qquad (1)$$

Or :

V_m : average water flow velocity (m/s), obtained from site studies;

S_{can} : section of the dam channel to be installed (m^2).

$$S_{can} = l_{can} \times P_{r_{moy}} \qquad (2)$$

With :

Lcan : channel width (m), the value of which can be found in the site data table ;

Prmoy : average channel depth (m), the value of which can be found in the site data table.

The average flow obtained is considered as the flow available for this period.

b) DETERMINATION OF THE RESERVE FLOW

The reserve flow varies between 7 to 10% of the average flow. For this study, we take a reserve rate of 8.5% as an average (tr=8.5%). Thus :

$$Q_{rés} = t_r \times Q_{disp} \qquad (3)$$

c) ESTIMATION OF EQUIPMENT THROUGHPUT

This is the maximum flow rate likely to be turbined by the power plant when all the turbines are operating at full speed. It is determined by the relationship:

$$Q_{éq} = Q_{disp} - Q_{rés} \quad (4)$$

d) ESTIMATED GROSS FALL HEIGHT (Hb)

The gross head is the difference between the level of the upstream coast and the downstream level of the dam. It is expressed by the relationship:

$$H_b = \nabla^{Amont} - \nabla^{Aval} \quad (5)$$

The upstream and downstream coastline values can be found in Table 1 of the site data.

e) ESTIMATION OF GROSS SITE POWER

The gross power of a site is determined based on the gross head and equipment flow rate. It is expressed by the following relation [15]:

$$P_b = \rho g Q_{éq} H_b \qquad \text{[en W]} \quad (6)$$

Or :

ρ : density of water (kg.m^{-3}) ;
g : gravity acceleration (m.s^{-2}) ;
Qéq : equipment flow (m^3/s) ;
Hb : gross head (m).

f) EVALUATION OF THE NET FALL HEIGHT

The net head is the difference between the gross head and the sum of the system pressure losses. It is expressed by the relationship:

$$H_n = H_b - \sum Pertes\ de\ charges \quad (7)$$

As part of a preliminary study for the installation of a hydroelectric power station, the pressure losses to be considered represent approximately 10% to 15% of the gross head. For this study, we consider 10% of the gross head as system pressure losses.

g) EVALUATION OF USEFUL ELECTRIC POWER

The useful electrical power (Putile) of a hydroelectric power station is equal to the product of the hydraulic power and the efficiency of the energy system. It is expressed through the relationship :

$$P_{utile} = 9{,}81 \times Q_{éq} \times H_n \times \eta_{sys} \quad (8)$$

With :

$$\eta_{sys} = \eta_{tur} \times \eta_{gén}$$

Or :

η_{tur} : hydraulic turbine efficiency (85%) ;
$\eta_{gén}$: generator efficiency (90%).

h) DETERMINATION OF THE TYPE OF DEVELOPMENT

The type of hydroelectric development is determined by the filling time of a dam. Depending on the filling time, we have three types of hydroelectric developments [16]. This filling time is determined by relation (9).

$$T = \frac{V_{util}}{Q_{moy} \times 3600} \qquad \text{(in hours)} \quad (9)$$

Or :

Vutil : volume of the useful section of the dam in m^3, taken equal to 76.9 hm^3 for our site ;

Qmoy : average flow entering the lake in m^3/h, taken equal to 41.81 m^3/s.

For a useful volume of 76.9 hm3 and an average flow of 41.81 m3/s, the filling time for this dam is more than 400 hours. In this case, we have a reserve type layout.

2.2.1. SIZING OF THE PROJECTED HYDROELECTRIC POWER PLANT

a) DETERMINATION OF THE DIAMETER OF THE FORCED PIPE

The diameter of the penstock which connects the water intake to the turbines of the hydroelectric power station is determined by the following relationship:

$$D_{nom} = 2\sqrt{\frac{Q_{éq}}{\pi V_m}} \quad (10)$$

Or :
Qéq : equipment flow (m^3/s) ;
Vm : average flow velocity (m/s).
The value of the nominal diameter obtained is not standard, let us choose the closest standard value, which corresponds to 5.50 m from the methodical guide for projection of hydroelectric power stations.

b) CHOICE OF TYPE AND NUMBER OF TURBINE

The type and brand of turbines are chosen according to the nomenclature of standardized turbines according to the power, the calculated head (net head) or from the head according to tables 11 and 12 of the guide [17].
For this specific case, we considered the net head as a parameter to choose the type of turbine (Hn=40.5 m).
According to the power plant projection guide, this height is in the range of 30-49 m, which corresponds to a Francis turbine type F45, the characteristics of which are recorded in table 2.

Table 2 : Turbine characteristics

N°	Parameters	Symbols	Values
1	Optimum frequency	n'_{Iopt}	78 trs/mn
2	Calculated frequency	n'_{Ical}	78 trs/mn
3	Reduced flow	Q'_I	(1,4 à 1,37) m^3/s
4	Large wheel diameter	D_1	8,5 m
5	Cavitation coefficient	б	(0,27 à 0,23)
6	Dispenser Height	Bo	0,35 m

c) CHOICE OF TRANSFORMER TYPE

Transformers are chosen according to the power of a group, taking into account that most often the number of transformers is equal to the number of groups. For the choice of transformers, the apparent power is calculated. This power is expressed by the relation [17]:

$$P_{tr} = \frac{P_{grpe}}{Cos\varphi} \quad (11)$$

Or :
P_{grpe} : power of the group which is equal to the useful power divided by two, which gives 5.814 MW;
$Cos\varphi$: power factor, taken equal to 0.8.
By choosing the closest standard value taking into account that transformers can work with an overload of 10% to 15% of the rated power. Thus, the choice fell on a 10 MW transformer through the guide catalog, whose characteristic is: TD10000/35 with a total weight of 23.8 tons.
Or :
TD : two-phase transformer ;
10000 : transformer rated power ;
35 : voltage in kV.

d) DIMENSIONS OF THE LOADING BASIN

The dimensions of the loading basin are essentially composed of: width, length and height. These dimensions are determined as follows:

- **Width of the loading basin**
  The width of the loading basin is equal to five (5) times the diameter of the penstock.
- **Length of the loading basin**
  The length of the loading basin is equal to eight (8) times the diameter of the penstock.
- **Height of loading basin**
  The height of the loading basin is equal to three (3) times the diameter of the penstock.

3. RESULTS AND DISCUSSION

The results obtained from the evaluation of the energy potential and the sizing of the equipment at the Tinkisso 2 site in Dabola in the Republic of Guinea are recorded in tables 3 and 4.

Table 3 : Results of the potential assessment

N°	Paramters	Values	Unity
1	Available flow	41,81	m^3/s
	Reserve flow	3,55	m^3/s
2	Equipment flow	38,26	m^3/s
3	Gross fall height	45	m
	Gross power	16,889	MW
4	Net fall height	40,5	m
5	Net power or Useful power	11,628	MW

Table 3 describes the results of the assessment of the energy potential of the site. The results in this table are obtained from data from spot measurements that we carried out on April 18, 2022 in the company of guides from the Tinkisso power station. In this table, the average flow or available flow during this period is 41.81 m^3/s. This flow allowed us to calculate the reserve flow and the equipment flow which are respectively 3.55 m^3/s and 38.26 m^3/s. The gross fall height determined from GPS coordinate measurements is 45 m, which resulted in a net fall height of 40.5 m. As for the gross power, it is 16.889 MW, which led us to determine the net power taking into account the hydraulic pressure losses, which allowed us to have 11.628 MW and a filling time of the dam which is equal to 511 hours. This filling time made it possible to choose a reserve type layout.

Table 4 : Results of the sizing of the power plant to be planned

N°	Paramters	Values	Unity
1	Nominal diameter of the penstock	550	cm
2	Turbine frequency	100	trs/mn
3	Turbine types: F45	-	-
4	Generator type: SV650/82 - 60	-	-
5	Number of groups	2	-
6	Generator efficiency coefficient	96,1	%
7	Stator active steel length	33	cm
8	Corrected internal diameter of the stator	8,5	m
9	Step-up transformer power	10	MW
10	Transformer weight	23,8	tonnes
11	Line voltage	35	kV
12	Length of loading basin	44	m
13	Loading basin width	27,5	m
14	Height of loading basin	16,5	m

Table 4 illustrates the results of the sizing of the civil engineering work and the choice of electromechanical equipment for the power plant to be planned. From the results of the evaluation of the hydro-energetic potential, we made the dimensioning of the plant which consisted of determining the diameter of the penstock, which is 550 cm, the choice of the type of turbine which is of the type Francis, with a frequency of 100 rpm. The chosen generator is of the umbrella type, vertically arranged, for an efficiency coefficient of 96.1%, whose length of the active stator steel is equal to 33 cm, with a corrected internal diameter equal to 8.5 m. To minimize losses during the transport of the energy produced, we chose a voltage step-up transformer, whose power is 10 MW, weight 23.3 tonnes for a line voltage of 35 kV. The dimensions of the loading basin which will be used to transport water to the plant via the penstocks are as follows: the width, length and height are respectively 27.5 m, 44 m and 16.5 mr.

4. CONCLUSION

The aim pursued within the framework of this research was to evaluate the hydro-energetic potential of the Tinkisso 2 site, to carry out the sizing with a view to choosing the electromechanical equipment and to determine the dimensions of the elements of the civil engineering work for the establishment of a hydroelectric power station. The construction of this power plant is of capital importance for a town like Dabola and its surroundings in the Republic of Guinea which have a current deficit of 7000kW according to investigations with those responsible for the Tinkisso 1 power plant. It is in this sense that The results obtained during this study require valorization.

- Among these results we can cite:
- Mastery of the method for evaluating the energy potential of a hydro-energy site;
- Determining the parameters of the Tinkisso 2 fall;
- The filling time of the dam which is equal to 511 hours made it possible to define the type of development required for the site, which is a water reserve development;
- Mastery of the site sizing method which made it possible to determine: the net head of fall equal to 40.5 m, the diameter of the penstock which is equal to 550 cm, the useful power of the power plant equal to 11.628 MW, the turbine type chosen is Francis, the alternator type is umbrella type, the efficiency coefficient of the alternator is equal to 96.1%, etc. ;
- Comparing our results to the results of the TAF team revealed a difference of 10%;
- The drawings of the Francis turbine wheel and the umbrella type alternator were drawn up using Autocad software;
- Proposals for the use of the electrical energy produced (4 MW added to the existing power plant for the city, the oil mill of Dabola and Bissikrima, 4.628 MW for the prefecture of Faranah and 3 MW for Dinguiraye);

As part of a prospective study, we would like to set up a calculation study for the installation of an electrical network to supply the aforementioned cities and the assessment of the environmental impact of the dam.

Declaration by Authors

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