World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 4.326

HYDRO-TURBINE FOR ELECTRICITY GENERATION: A CASE STUDY

Alphonse Omboua*[1] and Désiré Lilonga – Boyenga[2]

Department of Doctoral Studies at the University of Brazzaville Congo.

Article Received on 19/04/2017 Article Revised on 10/05/2017 Article Accepted on 31/05/2017

***Corresponding Author**
Alphonse Omboua
Department of Doctoral Studies at the University of Brazzaville Congo.

ABSTRACT

In some parts of Africa, access to electricity is still low while the hydraulic potential of certain countries is considerable. In addition to hydroelectric dams use to supply the large urban centers, the hydro energetic can offer other applications such as water turbines which are typically adapted for rural electrification of small villages scattered Like those of African countries. This article deals with the estimation of electric power that could be obtained with a water turbine type, in the case of a river located in the northern part of Congo Brazzaville: Vouma River. For this example, we found an average power of 4 kW capacities useful for a small fishing village for instance.

KEYWORDS: Hydro turbine, rural electrification, Africa.

1.0 INTRODUCTION

A water turbine is a hydroelectric system that transforms the kinetic energy of water into electrical energy by means of a turbine placed in a stream of water (mass of water moving in a given direction) at the surface or at the depth. There are several types of hydro-turbines, due to the turbine technologies developed by the designers. Some turbines are totally submerged and others on the surface of the water.

Difficulties in supplying energy-saving rural areas and those somewhat remote from power grids are problems to be solved in developing countries. In the following, we discussed the elements of the possible dimensioning of a submerged-type hydro-turbine on a river in the

Congo: the Vouma River, not far from the village of Mbesse, in northern Congo, 500 km from Brazzaville.

We have discussed the estimation of the extractable power on this river whose surrounding terrain does not encourage the construction of hydroelectric dams.

This article deals essentially with submerged hydro turbine, which can produce more power than surface ones.

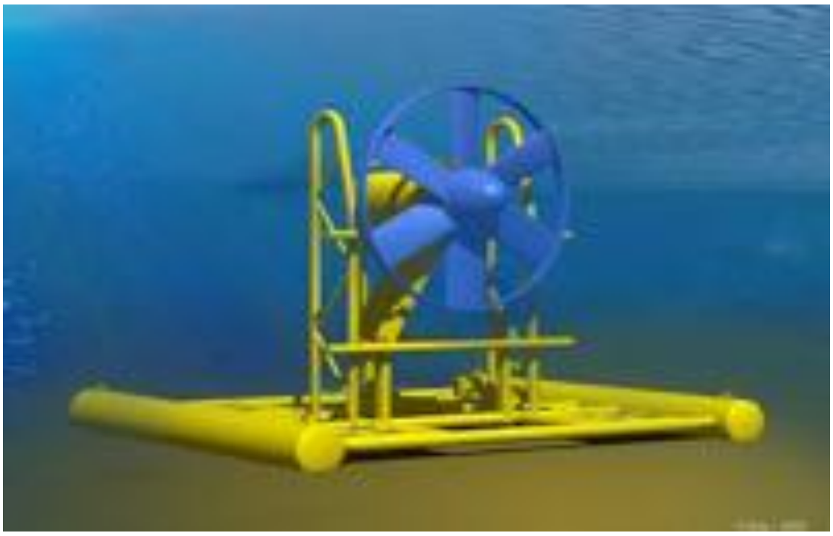

Fig.1: Example of an underwater turbine.

2. MATERIALS AND METHODS

2.1 Composition of a hydro-turbine

In general, this machine comprises the following parts:

1. A mast: it is anchored in the ground, at the bottom of the water and supports the turbine.
2. A turbine: it is the mechanical element on which there is transformation of the kinetic energy of translation of the waters into kinetic energy of rotation; The blades are fixed thereto;
3. Blades: they are fixed on the turbine and allow to capture the kinetic energy of the flow in order to drive the turbine;
4. A speed multiplier: it is a mechanical system which converts the slow speed of the turbine into a faster speed adapted to the generator;
5. A generator: it converts the kinetic energy of rotation into electrical energy;
6. A beacon: this is the part that emerges from the water, it indicates the presence of the hydro-turbine, avoiding any collision with seagoing bodies, in this case submerged hydro-turbine.

2.2 Classification

A classification of the hydro turbines can be made according to the orientation of the axis, one distinguishes: vertical-axis hydro-turbines; horizontal and transverse.

Among the vertical axes, we distinguish:

1. Darrius
2. Gorlov
3. Savonius

2.3 Operating principle of hydro-turbines

A hydro-turbine can be considered an "underwater wind turbine", it is relevant to differentiate the operation in water and in the air.

The density of water is about 800 times greater than that of air.

The usual speed for the operation of a wind turbine	air velocity between $10\,\mathrm{m.s^{-1}}$ and 20 $\mathrm{m.s^{-1}}$
The usual speed for the operation of a hydro-turbine	Water velocity between $1\,\mathrm{m.s^{-1}}$ and $5\,\mathrm{m.s^{-1}}$.

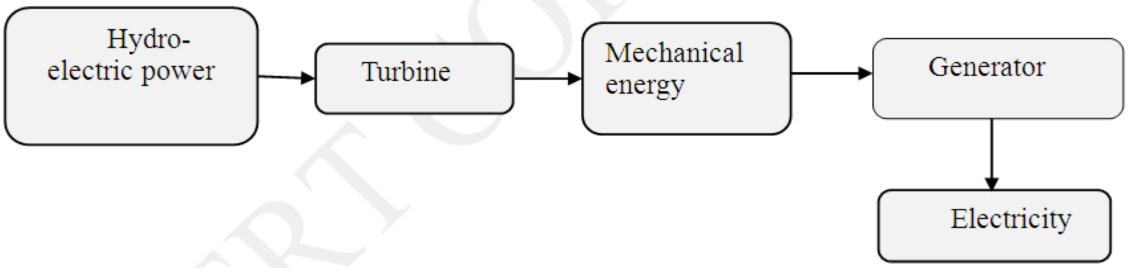

Fig 2: Principle of operation of a hydro-turbine.

The hydraulic energy of the watercourse is transformed by the turbine into kinetic energy of rotation. The kinetic energy of rotation is transmitted either directly to a variable-speed generator via a rigid coupling or to a speed multiplier which has its output shaft connected to that of the generator (alternator) which supplies the electricity.

2.4 Recoverable power

The kinetic energy of the water mass (m) that can be recovered by the turbine blades is :

$$E_c = \frac{1}{2}mv^2 \qquad (1)$$

$$\text{ET } m = \rho V \qquad (2)$$

(V) is the velocity of the water, (ρ) its density and (S) the surface swept by the rotor $S = \pi \frac{D^2}{4}$ (m^2); (D) the diameter of the surface swept by the blades , D=2R with R: The radius of a blade.

V: the volume of water; (L) the length element in the direction of flow, which give:

$$E_c = \frac{1}{2}(\rho V)v^2 \qquad (3)$$

$$\text{with } V = S * L \qquad (4)$$

Equations (3) and (4) imply:

$$E_c = \frac{1}{2}\rho S L v^2 \qquad (5)$$

The motive power of the water passing through the surface of the blades is then:

$$P_t = \frac{d}{dt}(E_c) = \frac{1}{2}\rho S v^3 \qquad (6)$$

This power increases very rapidly if the speed (v) increases.

Note that the density (ρ) of river water may vary slightly depending on the season due to suspended substances (sands, sludge, etc.).

2.5 Theory and limit of BETZ

No energy transformation system can have a 100% efficiency compared to the kinetic power of water. The recoverable power (Prec) by the turbine is a fraction of the previous total power taking into account the energy losses of the water in contact with the blades.[1] We can then introduce the hydrodynamic power coefficient Cp such that:

$$\boldsymbol{P_{rec} = \frac{1}{2} C_p \rho S v^3} \qquad (W) \qquad (7)$$

C_P is the coefficient of power of the hydrodynamics; it depends on the speed v of the water, the number of blades, their radius R, their wedge angle **β** and their speed of rotation Ω_T. The power will be written as a function of the radius R of the blades:

$$\boldsymbol{P_{rec} = \frac{1}{2} C_p \rho \pi R^2 v^3} \qquad (W) \qquad (8)$$

The maximum power is estimated, Cp is taken to be equal to 16/27 or 0.593 (BETZ law)

This power represents 59.3% of the total power

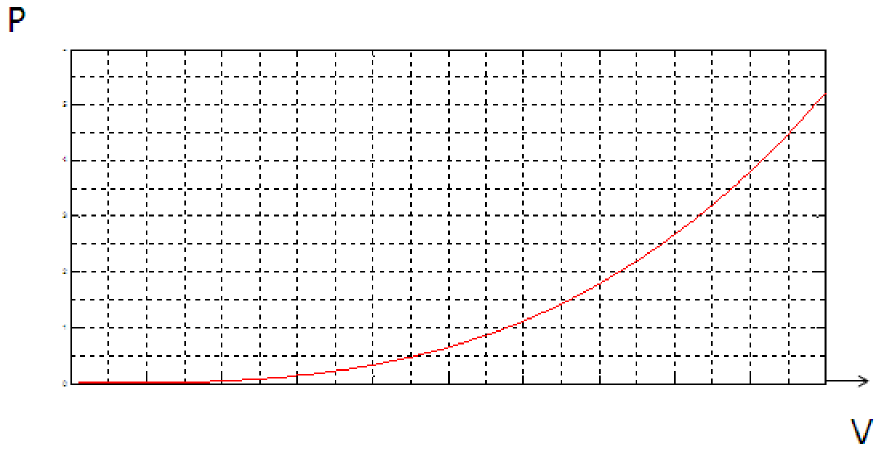

Fig. 3: Power recoverable by the turbine as a function of the speed of the flow.

This power can be amplified by coupling a gear multiplier to gears.

3. RESULTS AND DISCUSSION

3.1 Measurements on the Vouma River

The measures, which are grouped in the following tables, were carried out on the site as of March 14, 2017.

a. Measurement of float time on water

Float time measurements were obtained by timing the duration of a float over a distance of 10 m.

Table 1: Measurement of float time on the free plane of the river.

Time measurements (s)	Measures n° 1	Measures n° 2	Measures n°3	Measures n°4	Meaures n°5
Site 1	7,89	7,97	7,81	7,90	7,87
Site 2	9,05	9,10	9,06	9,00	9,08
Site 3	7,30	7,25	7,27	7,24	7,20
Site 4	8,48	8,39	8,52	8,45	8,40
Site 5	8,18	8,22	8,15	8,16	8,18

b. Density measurements of river water

Here, water is not pure because it is a flow of surface water that carries various objects and suspended substances (sands, mud, plant debris, etc.). In order to get closer to reality, a measurement of the density of the fluid is necessary.

Method

1. Pour 50 ml of water into the test tube;
2. Place on the weight scale;
3. Read the mass obtained on the reading dial.

Table 2: Mass of water obtained for a volume of 50 ml.

Mass obtained (g)	Measures n° 1	Measure s n°2	Measure s n° 3	Measures n° 4	Measures n° 5
Sample 1	48, 30	48, 80	48, 70	48,40	48,40
Sample 2	48, 80	48, 70	48, 50	48, 70	48, 60
Sample 3	48, 50	48, 80	48, 60	48, 50	48, 70
Sample 4	48, 30	48, 50	48, 60	48, 50	48, 80
Sample 5	48, 40	48, 50	48, 70	48, 60	48, 80

After several measurements, an average mass of m_0 = 48.50 g was obtained for the volume of V_0 = 50 ml; we have deduced the actual density of this cloudy water:

$$\rho_1 = \frac{m_0}{V_0} = \frac{48{,}50}{0{,}05} = 970\ g/l \quad \text{then} \quad 970\ \mathrm{kg.m^{-3}}.$$

The measurements were carried out for samples of water taken during the dry season; a first calculation of the power will be made for the value of (ρ_1). The value of $\rho_2 = 1000\ kg.m^{-3}$ will then be used for a second calculation to define the optimum power.

The waters of this river contain a great deal of impurities (sludges, organic products, etc.), residues of various natures flowing into the river, which has a notable influence on the density of this water.

c. Estimation of a cross-section of the river

From the measurements carried out, the trapezoid method led to the following figure:

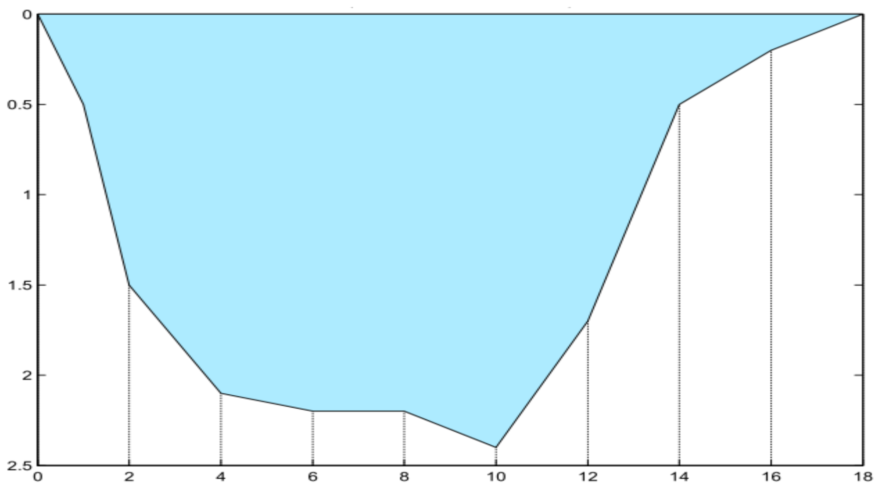

Fig. 4: Depth profile.

- ✓ The width of each subinterval $h = \frac{b-a}{n}$

$a = 2$; $b = 18$ and $n = 8$ so h= 2 (9)

- ✓ Calculation of the area of each subinterval

$$A_i = \frac{h}{2}[f(x_{i-1}) + f(x_i)] \quad (10)$$

Portion I : to $[2 - 18]$

At $x_0 = 2 \rightarrow f(x_0) = 1,50$;

At $x_1 = 4 \rightarrow f(x_1) = 2,10$;

$A_1 = \frac{h}{2}[f(x_0) + f(x_1)]$, $A_1 = 3,60\ m^2$

At $x_2 = 6 \rightarrow f(x_2) = 2,\ 20$;

$A_2 = \frac{h}{2}[f(x_1) + f(x_2)]$, $A_2 = 4,30\ m^2$

At $x_3 = 8 \rightarrow f(x_3) = 2,20$

$$A_3 = \frac{h}{2}[f(x_2) + f(x_3)], \quad A_3 = 4,40\ m^2$$

At $x_4 = 10 \rightarrow f(x_4) = 2,40$;

$$A_4 = 4,60\ m^2$$

$$A_4 = \frac{h}{2}[f(x_3) + f(x_4)] \ , \ , \ ,$$

At $x_5 = 12 \rightarrow f(x_5) = 1,70$;

$A_5 = \frac{h}{2}[f(x_4) + f(x_5)$

$A_5 = 4,10\ m^2$

$A_6 = \frac{h}{2}[f(x_5) + f(x_6)]$

At $x_6 = 14 \rightarrow f(x_6) = 0,50$;

$A_6 = 2,20\ m^2$

$A_7 = \frac{h}{2}[f(x_6) + f(x_7)]$

At $x_7 = 16 \rightarrow f(x_7) = 0,20$;

$A_7 = 0,70\ m^2$

$$A_8 = \frac{h}{2}[f(x_7) + f(x_8)]$$

At $x_8 = 18 \rightarrow f(x_8) = 0$;

$$A_8 = 0,20\ m^2$$

$$S_1 = \sum_{i=1}^{8} A_i = 24,10\ m^2 \qquad (11)$$

Portion II : to $[\mathbf{0} - \mathbf{2}]$

We find $S_2 = 1,25\ m^2$.

$$S = S_1 + S_2 = 25,35\ m^2 \qquad (12)$$

At the point of measurement, the cross section of the river is $\boldsymbol{S \cong 25,35\ m^2}$

3.2 Determination of physical quantities

a. The speed

The results are shown in the table below:

Table 3: Mean values of the speed obtained.

Point	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
Average speed $(\mathrm{m.s^{-1}})$	2,20	2,60	2,30	2,19	1,96

The mean experimental velocity is then $\mathbf{v_0} = 2,25\ m.s^{-1}$, which is the average of the values found in previous experiments where $2\ m.s^{-1}$ was obtained in the dry season and $2,5\ m.s^{-1}$ during the rainy season. We can therefore retain the mean value of the velocity at the surface of the water at the value of $v_0 = 2,25\ m.s^{-1}$.

However, three laws describe the decrease in speed with depth. The first and most frequent is that of the (1/7) which is given by the formula below (13):

$$\boldsymbol{v = v_0 \left(\frac{z}{d}\right)^{1/7}} \qquad (13)$$

The second law, less used is translated by the same formula substituting the exponent (1/7) by (1/10).[1,2,3]

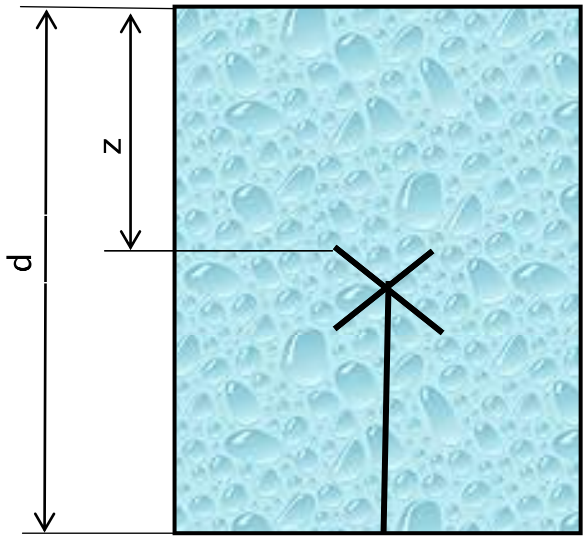

Fig. 5: A representation of the system.

The mean depth of the Vouma River is estimated to be d = 2.5m and the depth below the free surface will be adopted at Z = 0.50m when positioning the tidal turbines. It should be noted that the value of Z can fluctuate as a function of the periods of flood or low water. In the case of the Vouma, this fluctuation is not too great because of its steep piezometric slope. The knowledge of the average value of the velocity at the surface of the water $v_0 = 2,25\ m.s^{-1}$ makes it possible to find the speed of the water at the location of the turbine:

$$v = 2,25 * \left(\frac{0,50}{2,50}\right)^{1/7} = 1,78 \cong 1,80\ m.s^{-1}$$

b. Hydrodynamic flow or load

Knowing the cross section S of the river and the speed v at this point, the flow rate is calculated by the following relation:

$$Q = S * v \qquad (14)$$

The flow of water is $Q = S * v = 25,35 * 2,25 = 57,0375 \rightarrow Q = 57\ m^3.s^{-1}$

3.3 Recoverable power from turbine

The average depth of the river imposes a constraint on the turbine; we considered for height of the pole H = d- Z = 2.0 m and R = 1.0 m

The blades of the horizontal-axis hydro-turbine describe a swept surface of πR^2.

Considering the maximum value of Cp = 16/27 = 0.59, We find the recoverable power as here detailed:

Density of water	Speed of water	Recoverable power (kW)
970 $kg.m^{-3}$.	$1,80\ m.s^{-1}$	5,240
1000 $kg.m^{-3}$.	$1,80\ m.s^{-1}$	5,402

It can be seen that the power changes very little with the density.

Taking the turbine output at 0.8, the electric power finally available is estimated at 4kW.

4. CONCLUSION

The hydro- turbines have many advantages: they are modular, adaptable to each type of river with fairly short turnaround times. Relatively cheaper than hydroelectric dams, this technique is of great interest to developing countries still in search of the availability of electric power. A grouping of tidal turbines may be necessary when more loads are required. Unlike hydroelectric dams, tidal turbines have a lower impact on the environment

5. REFERENCES

1. http://www.wind-power-program.com/betz.htm.
2. http://www.sciencedirect.com/science/article/pii/S0196890406002196.
3. http://ieeexplore.ieee.org/abstract/document/4270855/.