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# DESIGN AND SIZING OF A 50 KW MICRO-HYDROPOWER PLANT ON THE LOSSO RIVER IN NGULA, KWILU PROVINCE (DRC)

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## ABSTRACT

Access to electricity remains a major challenge in rural areas of the Democratic Republic of the Congo, despite exceptional hydroelectric potential. This article presents the design and sizing of a 50 kW micro-hydropower plant installed on the Losso River in Ngula village, Kwilu Province. The study is based on a comprehensive methodological approach including the assessment of energy needs, the evaluation of local potentials, and the design of a Cross-Flow turbine and a synchronous alternator with a speed multiplier. The results show that the site has a net head of 3.85 m and a flow rate of 1.72 $m^3/s$, providing a hydraulic power of 64.96 kW. The designed turbine rotates at 68 rpm with an outer diameter of 800 mm and a width of 600 mm, for a mechanical power of 55.16 kW. The three-phase alternator delivers 50 kW at 400 V and 50 Hz with 2 pole pairs (4 poles) and a power factor of 0.80. The total energy needs of the village are estimated at 25.02 kW. This work demonstrates the technical feasibility of locally manufactured micro-hydropower plants and provides a reproducible model for rural electrification in Central Africa.

**Keywords:** Micro-hydropower plant; Cross-Flow turbine; Speed multiplier; Rural electrification; Ngula; DRC

## 1 INTRODUCTION

Access to electrical energy is a determining factor in the economic and social development of any nation. In the Democratic Republic of the Congo (DRC), despite exceptional hydroelectric potential among the highest in the world, a large part of the population, particularly in rural areas, remains deprived of reliable access to electricity. This energy shortage constitutes a major obstacle to industrialization, the modernization of basic social services (health, education, communication), and the improvement of living conditions [1].

Paradoxically, the country has a very dense hydrographic network, with numerous rivers crossing rural localities, thus offering significant potential for the development of small hydropower systems. Kwilu Province, and more particularly Gungu Territory, is fully part of this reality, with watercourses such as the Losso River presenting favorable characteristics for energy production [2].

In this context, micro-hydropower plants appear as a suitable, sustainable, and economically viable solution for the electrification of isolated areas. The installation of a 50 kW micro-hydropower plant, locally manufactured and installed in Ngula village, constitutes an innovative initiative aimed at promoting local resources, supporting national engineering, and improving access to energy in rural areas [3].

Despite initiatives to promote rural electrification through local solutions, particularly locally manufactured micro-hydropower plants, questions remain regarding their actual performance, reliability, and durability. The central question of this study is therefore: how to design and size the micro-hydropower plant installed on the Losso River in Ngula village, Kwilu Province (DRC)?

This article aims to design and size the 50 kW micro-hydropower plant installed on the Losso River in Ngula, and to establish a diagnostic protocol [4].

### 1.1 Theoretical Framework and Formulas

The design of a micro-hydropower plant is based on fundamental hydraulic and electromechanical principles. The main formulas used in this study are presented below.

#### 1.1.1 Hydraulic Power

The theoretical available hydraulic power is given by:

$$P_{hyd} = \rho \times g \times Q \times H_n = 9.81 \times Q \times H_n \text{ [kW]} \quad (1)$$

where:

- $P_{hyd}$: hydraulic power (kW)
- $\rho$: water density (1000 kg/m$^3$)
- $g$: gravitational acceleration (9.81 m/s$^2$)
- $Q$: flow rate (m$^3$/s)
- $H_n$: net head (m)

#### 1.1.2 Mechanical Power

The mechanical power available on the turbine shaft is:

$$P_{mec} = P_{hyd} \times \eta_t \quad (2)$$

where $\eta_t$ is the turbine efficiency.

#### 1.1.3 Specific Speed

The specific speed $n_q$ is given by:

$$n_q = n \times \frac{\sqrt{Q}}{H_n^{3/4}} \quad (3)$$

where $n$ is the rotation speed (rpm).

#### 1.1.4 Outer Diameter of the Runner

For a Cross-Flow turbine, the outer diameter of the runner is given by the empirical relationship:

$$D_1 = \frac{84.5 \times \sqrt{H_n}}{n} \quad (4)$$

#### 1.1.5 Width of the Runner

$$B = \frac{Q}{k \times D_1 \times \sqrt{2gH_n}} \quad (5)$$

where $k$ is the flow coefficient for Cross-Flow (k = 0.95).

#### 1.1.6 Inner Diameter of the Runner

For a classic Cross-Flow:

$$D_2 = 0.7 \times D_1 \tag{6}$$

#### 1.1.7 Number of Blades

$$Z = 18 + \frac{D_1 - 0.2}{0.1} \times 4 \tag{7}$$

#### 1.1.8 Blade Pitch

$$t = \frac{\pi \times D_1}{Z} \times \cos\beta \tag{8}$$

where $\beta$ is the blade angle.

#### 1.1.9 Multiplication Ratio

$$R = \frac{N_{alt}}{N_{turb}} \tag{9}$$

#### 1.1.10 Overall Efficiency

$$\eta_{global} = \eta_{turbine} \times \eta_{mult} \times \eta_{alternator} \tag{10}$$

#### 1.1.11 Available Electrical Power

$$P_{el,dispo} = P_{hyd} \times \eta_{global} \tag{11}$$

#### 1.1.12 Frequency and Speed Relationship

$$f = \frac{p \times n_s}{60} \tag{12}$$

where $p$ is the number of pole pairs.

#### 1.1.13 Nominal Current

$$I = \frac{P_{el}}{\sqrt{3} \times U \times \cos\varphi} \tag{13}$$

#### 1.1.14 Apparent Power

$$S = \sqrt{3} \times U \times I \tag{14}$$

## 2 METHODS

The methodological approach adopted for this study is structured around four main axes: assessment of energy needs, evaluation of local potentials, selection of the hydropower site, and complete design of the micro-hydropower plant.

### 2.1 Assessment of Energy Needs

The assessment of the energy needs of Ngula village was based on a distribution of domestic consumption by household class, estimation of tertiary sector consumption, and public lighting. Three social classes were defined according to income level and average household equipment [5]:

- **Class C** (low social level, 80% of households): 146 households equipped with a radio, a television, and lamps (100 W per household)
- **Class B** (medium social level, 15% of households): 27 households equipped with a television, a radio, an iron, LED lamps, a fan, and a refrigerator (790 W per household)
- **Class A** (high social level, 5% of households): 9 households equipped with a television, a radio, an iron, LED lamps, an air conditioner, a freezer, and an electric stove (3,530 W per household)

For households, an average of 10 persons per household was assumed [6]. The tertiary sector was estimated at 30% of domestic consumption. Public lighting was provided by 30 street lamps of 50 W each [7].

Taking into account the demand coefficients (0.32 for domestic, 0.28 for tertiary, and 1 for public lighting) of the National Electricity Company [8], the total demanded power was calculated.

**Table 1** summarizes the distribution of households and the estimated power.

**Table 1: Distribution of households and estimated power**

| Class | Number of households | Installed power (W) | Demanded power (kW) |
|---|---|---|---|
| C (low) | 146 | 100 | 4.67 |
| B (medium) | 27 | 790 | 6.83 |
| A (high) | 9 | 3,530 | 10.17 |
| **Total domestic** | **182** | **—** | **21.67** |
| Tertiary | — | — | 1.82 |
| Public lighting | 30 lamps | 50 W each | 1.50 |
| **Total** | **—** | **—** | **25.02** |

Source: Field survey, 2021; SNEL, 2018; Ministry of Energy, 2019

### 2.2 Local Energy Potentials

Several energy sources were evaluated for Ngula village: hydroelectric, solar, biomass, biogas, and wind [9].

#### 2.2.1 Hydroelectric Potential

The Losso River crosses Ngula village directly. It flows permanently throughout the year, with a sufficient flow rate to supply a micro-hydropower plant (power below 100 kW). A field reconnaissance identified a site less than one kilometer from the village center, offering an exploitable natural head.

**Figure 1: View of the Losso River (our field survey)**

**Table 2: Actual hydraulic characteristics of the Losso River site**

| **Parameter** | **Symbol** | **Value** | **Unit** |
|---|---|---|---|
| Measured gross head | Hg | 4.53 | m |
| Nominal net head | Hn | 3.85 | m |
| Nominal flow rate | Qn | 1.72 | $m^3/s$ |
| Penstock diameter | D | 850 | mm |
| Penstock length | L | 2.50 | m |

Source: Field measurements, 2021

### 2.2.2 Solar, Biomass, Biogas, and Wind Potential

Although Ngula village benefits from an average annual sunshine of approximately 4.69 $kWh/m^2/day$ [9], solar energy was not retained as the main source due to its intermittency, high storage costs, and significant surface occupation. Biomass and biogas have low energy density and heavy maintenance constraints [10]. The wind potential is almost zero (average speeds < 3-4 m/s) [11].

## 2.3 Technology Selection

The choice of micro-hydropower on the Losso River is justified by the following reasons, specific to Ngula village:

- Local and sustainable resource
- Continuous and stable production (24 hours a day)
- Immediate proximity (less than 1 km from dwellings)
- Low operating cost
- Durability and autonomy (30 to 50 years)
- Very low environmental impact
- Adaptation to village size (5 to 100 kW)

The **Cross-Flow turbine (Banki)** was selected, perfectly suited to low heads (1.5 to 150 m) and medium flow rates [13].

**Figure 2: Complete Arc2 group in our workshop in Kinshasa**

### 2.4 Design of the Micro-Hydropower Plant

The design was based on the hydraulic characteristics of the site and the energy needs of the village. The main components designed include the Cross-Flow turbine, the speed multiplier, the alternator, the penstock, the intake grid, and the canals.

## 3 RESULTS

### 3.1 Energy Needs Assessment

The total energy needs of Ngula village are estimated at **25.02 kW**, distributed as follows:

- Domestic consumption: **21.67 kW**
- Tertiary sector: **1.82 kW**
- Public lighting: **1.50 kW**

**Table 1** presents the detailed distribution of households and estimated power.

### 3.2 Hydraulic Characteristics of the Site

The hydraulic characteristics of the Losso River site at Ngula are presented in **Table 2**:

- Gross head (Hg): **4.53 m**
- Net head (Hn): **3.85 m**
- Nominal flow rate (Qn): **1.72 $m^3/s$**
- Penstock diameter: **850 mm**
- Penstock length: **2.50 m**

### 3.3 Hydraulic Power

The theoretical hydraulic power available at the site is:

**P_hyd = 64.96 kW**

### 3.4 Cross-Flow Turbine Design

The main design results for the Arc2 Cross-Flow turbine are presented in **Table 3.**

**Table 3: Dimensional characteristics of the Arc2 Cross-Flow turbine**

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Hydraulic power | Phyd | 64.96 | kW |
| Mechanical power | Pmec | 55.16 | kW |

| | | | |
|---|---|---|---|
| Actual net head | Hn | 3.85 | m |
| Turbined flow rate | Q | 1.72 | $m^3/s$ |
| Actual rotation speed | N | 68 | rpm |
| Outer runner diameter | $D_1$ | 800 | mm |
| Inner runner diameter | $D_2$ | 560 | mm |
| Runner width | B | 600 | mm |
| Number of blades | Z | 42 | — |
| Blade pitch | T | 52 | mm |
| Jet inlet angle | $\alpha_1$ | 16 | degrees |
| Blade outlet angle | $\beta_2$ | 30 | degrees |
| Estimated efficiency | Ht | 0.85 | — |

Source: Our calculations and manufacturer data

The mechanical power available on the turbine shaft is **55.16 kW.**

### 3.5 Speed Multiplier and Alternator

The main characteristics of the speed multiplier and alternator are presented in **Table 4**.

**Table 4: Characteristics of the alternator and multiplier**

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| **Multiplier** | | | |
| Multiplication ratio | R | 22/1 | — |
| Input speed (turbine) | $N_1$ | 68 | rpm |
| Output speed (alternator) | $N_2$ | 1,500 | rpm |
| Estimated efficiency | ηmult | 0.96 | — |
| **Alternator** | | | |
| Type | — | Synchronous with brushes | — |
| Nominal active power | Pel | 50 | kW |
| Apparent power | S | 62.5 | kVA |
| Nominal voltage | U | 400 | V |
| Nominal current per phase | I | 90.2 | A |
| Frequency | F | 50 | Hz |
| Rotation speed | $N_2$ | 1,500 | rpm |
| Number of pole pairs | P | 2 | — |
| Number of poles | — | 4 | — |
| Power factor | cos φ | 0.80 | — |
| Estimated efficiency | ηalt | 0.92 | — |

Source: Our calculations and manufacturer data

### 3.6 Overall Performance of the Conversion Chain

The overall efficiency of the conversion chain is estimated at **75%.**

The available electrical power is **48.72 kW.**

## 4 DISCUSSION

### 4.1 Interpretation of Design Choices

The design of the Ngula micro-hydropower plant is based on systematic optimization of available hydraulic resources. With a net head of 3.85 m and a flow rate of 1.72 $m^3/s$, the Cross-Flow turbine is the most relevant choice. Indeed, this type of turbine is perfectly suited to low heads (1.5 to 150 m) and offers several advantages: simple construction, local manufacturability, good efficiency over a wide flow range, tolerance to suspended solids, and ease of maintenance [12].

The turbine rotation speed (68 rpm) was chosen for torque and robustness reasons. The use of a speed multiplier (ratio 22/1) allows the alternator to rotate at 1,500 rpm, the synchronism speed for a 50 Hz network with 2 pole pairs. This technical solution is classic in low-power micro-hydropower plants.

The alternator, with 2 pole pairs (4 poles), is a standard three-phase synchronous alternator, easy to find and maintain [14].

### 4.2 Comparison with Existing Installations

Compared to other micro-hydropower plants installed in Central Africa [3,15], the Ngula installation presents several original characteristics:

- Entirely local design and manufacturing (Arc2 Cross-Flow turbine)
- Use of a speed multiplier adapted to a slow turbine
- Adaptability to the energy needs of a small rural village (25.02 kW of needs for 50 kW produced)
- Use of local materials for civil engineering works

### 4.3 Study Limitations

This article presents the design phase of the micro-hydropower plant. An experimental phase will be necessary to validate the actual performance of the installation. The limitations of the study include:

- Theoretical estimation of turbine, multiplier, and alternator efficiencies
- Absence of experimental measurements on the prototype
- Simplified evaluation of hydraulic losses
- Use of standard technical coefficients (without on-site measurement)

These limitations will be addressed during the experimental campaign planned after the manufacturing and installation of the equipment.

### 4.4 Perspectives

Future work will include:

- Measurement of actual electrical parameters (voltage, current, frequency, power)
- Calculation of actual efficiencies of the turbine, multiplier, and alternator
- Comparison with theoretical performance
- Economic and environmental impact study
- Analysis of installation reliability and maintenance

## 5 CONCLUSION

This article presented the design and sizing of a 50 kW micro-hydropower plant intended for Ngula village, on the Losso River in Kwilu Province. The main results show that:

- The site has a net head of **3.85 m** and a flow rate of **1.72 $m^3/s$**, providing a hydraulic power of **64.96 kW**.
- The total energy needs of the village are estimated at **25.02 kW**, divided between domestic consumption (21.67 kW), the tertiary sector (1.82 kW), and public lighting (1.50 kW).
- The designed Cross-Flow turbine (Arc2) rotates at **68 rpm**, with an outer diameter of **800 mm**, a width of **600 mm**, and **42 blades**, delivering a mechanical power of **55.16 kW**.
- A speed multiplier (ratio **22/1**) drives a three-phase synchronous alternator at **1,500 rpm**, 2 pole pairs (4 poles), delivering **50 kW** at **400 V** and **50 Hz** with a power factor of **0.80**.

- The estimated overall efficiency of the conversion chain is approximately **75%**.

This study demonstrates the technical feasibility of locally manufactured micro-hydropower plants in the Democratic Republic of the Congo. The Ngula plant constitutes a pilot project and a reproducible model for rural electrification in Central Africa.

## STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

### *Disclosure of conflict of interest*

The authors declare no conflicts of interest.

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