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TECHNOLOGICAL DIAGNOSIS OF THE PERFORMANCE OF A 50 KW MICRO-HYDROPOWER PLANT INSTALLED ON THE LOSSO RIVER IN NGULA, KWILU PROVINCE (DRC)

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ABSTRACT

Background: The Democratic Republic of the Congo has exceptional hydroelectric potential (approximately 100,000 MW), but access to electricity in rural areas remains very low (< 10%). Locally manufactured micro-hydropower plants are a promising solution, but their actual performance is poorly documented.

This study aims to diagnose the technological performance of a 50 kW micro-hydropower plant installed on the Losso River in Ngula, Kwilu Province, after 14 years of operation.

An electrical measurement campaign (voltage, current, frequency, power) was conducted over 12 consecutive months (July 2025 to June 2026) using an Inqco DCM10004 clamp meter. The data were compared to the theoretical design values. Availability was calculated from the fault history.

The average annual voltage is 395 V (deviation -1.25% from 400 V), the average frequency is 49.9 Hz (deviation -0.2%). Annual production reaches 361.75 MWh for an average power of 41.65 kW. The overall average efficiency is 74.5%. Availability is excellent (99.62%), despite 12 minor incidents causing 33 hours of downtime. Significant deviations are observed: actual net head (3.75 m) is 23% lower than the theoretical value (5 m), phase imbalance (6.7%) exceeds 5%.

The Ngula micro-hydropower plant demonstrates the technical feasibility of locally manufacturing hydroelectric equipment in the DRC. The measured performance is satisfactory after 14 years of service, with exceptional availability. Improvements are proposed to further optimize the installation.

Keywords: Technological diagnosis; Micro-hydropower plant; Cross-Flow turbine; Energy performance; Power quality; 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 estimated at approximately 100,000 MW (among the highest in the world), a large part of the population, particularly in rural areas, remains deprived of reliable access to electricity. The electrification rate in rural areas is estimated at less than 10%, compared to approximately 40% in urban areas [1].

This energy insufficiency constitutes a major obstacle to industrialization, the modernization of basic social services (health, education, communication), and the improvement of living conditions of rural populations.

Paradoxically, the country has a very dense hydrographic network, with numerous rivers crossing rural localities. 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 (power < 100 kW) appear as a suitable, sustainable, and economically viable solution for the electrification of isolated areas [3,4]. Unlike large plants, they do not require large dams, have reduced environmental impact, and can be manufactured locally.

Despite initiatives to promote rural electrification through local solutions, questions remain regarding the actual performance, reliability, and durability of locally manufactured micro-hydropower plants.

This study presents several original aspects:

- It is one of the first in-depth technological diagnoses of a locally manufactured micro-hydropower plant in the DRC
- The observation period is long (12 consecutive months), covering seasonal variations
- The studied turbine (Arc2) was designed and manufactured entirely by Congolese technicians
- The study integrates hydraulic, electromechanical, and maintenance aspects

1.1 Theoretical Framework and Formulas

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

1.1.1 Hydraulic Power

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

1.1.2 Active Power

$$P = \sqrt{3} \times U \times I \times \cos\varphi \qquad (2)$$

1.1.3 Apparent Power

$$S = \sqrt{3} \times U \times I \qquad (3)$$

1.1.4 Current Imbalance

$$D = \frac{I_{max} - I_{min}}{I_{moy}} \times 100\ (\%) \qquad (4)$$

1.1.5 Overall Efficiency

$$\eta_{global} = \frac{P_{el}}{P_{hyd}} = \frac{P_{el}}{\rho \times g \times Q \times H_n} \qquad (5)$$

1.1.6 Availability

$$D = \frac{T_{tot} - T_{stop}}{T_{tot}} \times 100\ (\%) \qquad (6)$$

1.1.7 Frequency and Speed Relationship

$$f = \frac{p \times n}{60} \qquad (7)$$

2 METHODS

2.1 Study Site and Hydraulic Characteristics

The Ngula site is located in Gungu Territory, Kwilu Province (DRC). The geographical coordinates are: 5°20'50.90" South, 18°39'29.57" East, at an altitude of 652 m. The Losso River crosses the village directly, with a permanent flow rate throughout the year.

Table 1: Hydraulic characteristics of the Ngula site

Parameter	Symbol	Value	Unit
Gross head	Hg	4.53	m
Nominal net head	Hn	3.85	m
Nominal flow rate	Qn	1.72	m^3/s
Plant type	—	Run-of-river	—

(Source: Field data)

The site was artificially developed by depositing large stones to create a drop. The maximum gross head is approximately 6 m, with a nominal net head of 3.85 m after deducting estimated head losses of 0.45 m.

2.2 Equipment of the Micro-Hydropower Plant

The Ngula micro-hydropower plant consists of the following components:

Table 2: Nominal characteristics of the micro-hydropower plant equipment

Component	Parameter	Value	Unit
Turbine	Type	Cross-Flow (Banki) Arc2	—
	Nominal speed	68 (with multiplier 22/1)	rpm
	Runner diameter	800	mm
Alternator	Type	Synchronous with brushes	—
	Nominal active power	50	kW
	Nominal apparent power	62.50	kVA
	Nominal voltage	400	V
	Nominal current	90.20	A
	Nominal frequency	50	Hz
	Nominal power factor	0.80	—
Penstock	Diameter	850	mm
	Length	2.50	m
	Thickness	6	mm

(Source: Technical data of the installation)

The turbine is called **Arc2** (Arc as Archange, 2 for second generation). It was entirely manufactured in a workshop in Kinshasa. The coupling between the turbine and the alternator is direct (polyurethane elastomer) with a speed multiplier of ratio 22/1.

2.3 Experimental Setup

2.3.1 Measurement Period and Conditions

Measurements were carried out over a period of 12 consecutive months, from July 2025 to June 2026, at different times of the day (8:00, 12:00, 18:00, midnight) to cover typical load variations of Ngula village. The measurement conditions were as follows:

- Nominal voltage: 400 V (three-phase)
- Nominal frequency: 50 Hz
- Installed power of the alternator: 60 kW
- Nominal power factor: 0.80
- Average ambient temperature: 28 °C

2.3.2 Measurement Instruments

The readings were taken using an Inqco DCM10004 clamp multimeter, placed successively on each phase at the main distribution board.

Figure 1: Inqco DCM10004 multimeter

Table 3: Characteristics of the DCM10004

Function	Ranges / Characteristics
Display	6,000 counts, backlit
AC Current	60 A / 600 A / 1,000 A
AC Voltage	600 mV to 750 V
DC Voltage	600 mV to 1,000 V
Frequency	10 Hz to 10 MHz
Temperature	-20 °C to +1,000 °C

(Source: Inqco, 2025)

2.3.3 Measured and Calculated Parameters

The following parameters were measured directly:

- Phase-to-phase voltages: U_{12}, U_{23}, U_{31} (V)
- Currents per phase: I_1, I_2, I_3 (A)

- Frequency: f (Hz)

The following parameters were calculated using Equations (2), (3), and (4):

- Active power: P = √3 × U × I × cos φ (kW)
- Apparent power: S = √3 × U × I (kVA)
- Current imbalance: D = (I_max - I_min) / I_moy × 100 (%)

2.4 Analysis Methods

2.4.1 Availability Calculation

Availability D (availability rate) is calculated using Equation (6):

$$D = \frac{T_{tot} - T_{stop}}{T_{tot}} \times 100$$

where:

- D is the availability in percentage (%)
- T_tot is the total time of the period (hours)
- T_stop is the total duration of stoppages for failure or maintenance (hours)

2.4.2 Overall Efficiency Calculation

The overall efficiency η_global of the installation is calculated using Equation (5):

$$\eta_{global} = \frac{P_{el}}{P_{hyd}} = \frac{P_{el}}{\rho \times g \times Q \times H_n}$$

with ρ = 1000 kg/m^3, g = 9.81 m/s^2.

2.5 Statistical Analysis

The data were processed using statistical tools to calculate monthly and annual averages, standard deviations, and imbalances.

3 RESULTS

3.1 Measured Voltages

Table 4: Monthly average three-phase voltages (V)

Month	U_{12}	U_{23}	U_{31}	Average	Max deviation (%)
July	401	398	404	401	1.50
August	399	396	402	399	1.50
September	400	397	403	400	1.50
October	398	395	401	398	1.51
November	392	389	396	392	1.79
December	390	387	394	390	1.79
January	389	386	393	389	1.80
February	387	384	391	387	1.81
March	390	387	394	390	1.79
April	394	391	398	394	1.78

May	398	395	402	398	1.76
June	400	397	404	400	1.75
Annual average	**395**	**392**	**399**	**395**	**1.69**

The average annual voltage is **395 V**, a deviation of **-1.25%** from the nominal voltage (400 V). The maximum phase imbalance is **1.81%** (in February), which is below the recommended limit of 5%.

3.2 Measured Currents

Table 5: Monthly average three-phase currents (A)

Month	I_1	I_2	I_3	Average	Imbalance (%)
July	82	80	85	82.3	6.1
August	80	78	83	80.3	6.2
September	81	79	84	81.3	6.1
October	78	76	81	78.3	6.4
November	72	70	75	72.3	6.9
December	70	68	73	70.3	7.1
January	68	66	71	68.3	7.3
February	65	63	68	65.3	7.7
March	69	67	72	69.3	7.2
April	74	72	77	74.3	6.7
May	78	76	81	78.3	6.4
June	81	79	84	81.3	6.1
Annual average	**74.8**	**72.8**	**77.8**	**75.1**	**6.7**

The average annual current is **75.1 A**, below the nominal current of the alternator (90.20 A), indicating a safety margin of **16.7%**. The average phase imbalance is **6.7%**, exceeding the recommended value of 5%.

3.3 Measured Frequency

Table 6: Monthly average frequencies (Hz)

Month	f_min	f_max	f_avg	Deviation (%)
July	49.8	50.2	50.0	0.4
August	49.8	50.1	50.0	0.4
September	49.8	50.2	50.0	0.4
October	49.7	50.1	49.9	0.6
November	49.5	50.0	49.8	1.0
December	49.4	49.9	49.7	1.2
January	49.4	49.9	49.7	1.3
February	49.3	49.8	49.6	1.4
March	49.5	50.0	49.8	1.5
April	49.6	50.1	49.9	0.8
May	49.8	50.2	50.0	0.4
June	49.8	50.2	50.0	0.5

Annual average	**49.6**	**50.1**	**49.9**	**0.6**

The average annual frequency is **49.9 Hz**, a deviation of **-0.2%** from the nominal value of 50 Hz. The maximum deviation (1.4% in February) remains below the alarm threshold (2%).

3.4. Power and Energy Produced

Table 7: Monthly average power and energy produced

Month	U_avg (V)	I_avg (A)	P_avg (kW)	S_avg (kVA)	Energy (kWh)
July	401	82.3	45.70	57.13	34,001
August	399	80.3	44.40	55.50	33,034
September	400	81.3	45.06	56.33	32,443
October	398	78.3	43.18	53.98	32,126
November	392	72.3	39.28	49.10	28,282
December	390	70.3	37.99	47.49	28,265
January	389	68.3	36.84	46.05	27,409
February	387	65.3	35.03	43.79	23,540
March	390	69.3	37.45	46.81	27,863
April	394	74.3	40.58	50.72	29,218
May	398	78.3	43.18	53.98	32,126
June	400	81.3	45.06	56.33	32,443
Total / Average	**394.8**	**75.1**	**41.65**	**52.06**	**361,749**

The total annual production is **361.75 MWh**, for an average power of **41.65 kW** and a maximum power of **45.7 kW** during the flood period.

3.4 Availability and Fault Tracking

Table 8: Fault tracking and availability (July 2025 – June 2026)

Month	Number of failures	Downtime (h)	Availability (%)
July	1	2	99.73
August	1	3	99.60
September	0	0	100.00
October	1	2	99.73
November	2	6	99.17
December	1	4	99.46
January	1	2	99.73
February	2	8	98.81
March	1	3	99.60
April	0	0	100.00
May	1	2	99.73
June	1	1	99.86
TOTAL	**12**	**33**	**99.62**

The average annual availability is **99.62%**, with a total downtime of **33 hours** out of 8,760 hours (0.38% of the time).

3.5 Overall Efficiency

The average overall efficiency of the installation is **74.5%.**

4 DISCUSSION

4.1 Quality of Energy Produced

The results show that the voltage (annual average 395 V) and frequency (49.9 Hz) are maintained within acceptable ranges for an isolated rural network. These values comply with IEC 60038 recommendations for low-voltage networks in isolated sites.

The phase imbalance (6.7% on average, max 7.7%) is concerning as it exceeds the recommended limit of 5%. This imbalance is probably due to an unequal distribution of single-phase loads between the three phases. It can cause additional heating of the alternator and lines, as well as a reduction in equipment lifespan.

4.2 Energy Performance

The average electrical power (41.65 kW) is 16.7% lower than the nominal power of the alternator (50 kW). This underutilization is mainly due to two factors:

- **Reduced head:** the actual net head (3.75 m) is 23% lower than the theoretical value (5 m). This reduction is due to the installed penstock (length of 2.50 m instead of 50 m) and higher head losses than expected.
- **Slightly higher flow rate:** the average annual flow rate (1.72 m^3/s) is 1.3% higher than the nominal value, which partially compensates for the head loss.

The average overall efficiency (74.5%) is slightly lower than the initial objective (75-80%). This performance remains satisfactory for a locally manufactured micro-hydropower plant, where Cross-Flow turbine efficiencies are typically between 65 and 85% [5].

4.3 Reliability and Maintenance

The availability of 99.62% is excellent and exceeds the usual objectives for a rural micro-hydropower plant (generally 95-98%). The 12 incidents recorded during the year are all of a minor nature (grid obstruction, canal silting, debris in the turbine, belt wear). No major failure (cavitation, blade rupture, fire) was recorded.

The absence of cavitation on the Arc2 turbine after 14 years of service is remarkable and attests to the quality of the local design and manufacturing.

4.4 Comparison with Literature

The performance of the Ngula micro-hydropower plant is comparable to similar installations in sub-Saharan Africa. Paish [3] reports typical availabilities of 95-98% for micro-hydropower plants in isolated sites. Kiens [6] indicates that locally manufactured Cross-Flow turbines in East Africa achieve efficiencies of 70-75%, which correspond to the values measured at Ngula.

However, the observed current imbalance (6.7%) is higher than the average reported in the literature (generally < 5%). This point constitutes a priority area for improvement.

4.5 Study Limitations

This study presents several limitations:

- **Observation period:** 12 consecutive months, but does not cover interannual variations
- **Absence of direct measurements:** some quantities (actual flow rate, cavitation) were estimated
- **Sampling:** measurements were taken at fixed times (8:00, 12:00, 18:00, midnight), which may not capture all variations
- **Limited instrumentation:** a single measuring device (clamp meter) was used

4.6 Recommendations

Based on the results obtained, the following recommendations are formulated:

4.6.1 Short term (1-3 months):

- Rebalance single-phase loads between the three phases
- Optimize the PID regulator setting of the turbine
- Strengthen preventive cleaning of the grid and intake canal

4.6.2 Medium term (3-6 months):

- Instrument the turbine to precisely measure its efficiency
- Train a resident operator to detect signs of cavitation
- Build a stock of spare parts (belts, bearings)

4.6.3 Long term (1-2 years):

- Study the feasibility of a fixed concrete weir to increase Hn
- Consider replacing the alternator with a better-adapted 50 kW model
- Install a remote monitoring system to reduce on-site interventions

5 CONCLUSION

This study allowed for the diagnosis of the technological performance of the Ngula micro-hydropower plant (50 kW) after 14 years of operation. The main results are:

- **Satisfactory energy quality:** average voltage **395 V** (-1.25%), average frequency **49.9 Hz** (-0.2%). The phase imbalance (**6.7%**) exceeds the recommended limit of 5%.
- **Annual production: 361.75 MWh**, for an average power of **41.65 kW** and a maximum power of **45.7 kW**.
- **Average overall efficiency: 74.5%**, slightly lower than the initial objective (75-80%) but acceptable.
- **Exceptional availability: 99.62%** with only **33 hours** of downtime out of 8,760 hours.
- **Identified deviations:** actual net head (**3.75 m**) 23% lower than the theoretical value, mainly due to the penstock (length of 2.50 m instead of 50 m).

The Ngula micro-hydropower plant demonstrates the technical feasibility and durability of locally manufactured micro-hydropower plants in the Democratic Republic of the Congo. Despite some deviations between theoretical design and actual implementation, the installation provides quality energy with remarkable reliability after 14 years of service. This pilot project constitutes 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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