International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 10 Issue 5, Sep-Oct 2026 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Systems Energy Hybrid and Transition Energy in the Middle Urbano-Rural: Modeling, Sizing and Optimization of a Coupling Photovoltaic-Tidal to Bumba (DRC)

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ABSTRACT

The electrification of the city urbano-rural Bumba continues to face the failure of electricity supply to meet demand growth. This article summarises a study devoted to the design and modeling of a hybrid system combining a photovoltaic solar power station, a tidal river, and a storage device. The study, carried out over the period 2023-2027, is based on methods of empirical and analytical, supplemented by documentary research and interviews. The hydrological parameters considered include the flow rate, flow velocity, depth, and physical characteristics of the river Molua. The power required to be retained in the sizing of 3584,9 kW, corresponding to an apparent power of 4481,25 kVA to power factor of 0.8. An increase of 10% leads to 4929,375 kVA on the horizon 2027. The energy model combines the photovoltaic production dependent on the irradiation and the conversion of the kinetic energy of the water. The optimization is formulated around the minimisation of the cost leveled energy (LCOE) under the constraint of reliability, in particular through the indicator of LPSP. The simulation of energy management highlights the role of the storage is to absorb the excess solar and cover a portion of the deficits night. The results show the technical relevance of a hybrid architecture for the study of the electrification of Bumba, while stressing the need to strengthen measures of meteorological and hydrological local before industrial implementation.

KEYWORDS: *electrification rural, solar photovoltaic systems, tidal, system hybrid, Bumba, river Molua, LCOE, LPSP.*

How to cite this paper: Libana La Wadoa Azwa Célestin "Systems Energy Hybrid and Transition Energy in the Middle Urbano-Rural: Modeling, Sizing and Optimization of a Coupling Photovoltaic-Tidal to Bumba (DRC)" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-10 | Issue-5, October 2026, pp.1104-1110, URL: www.ijtsrd.com/papers/ijtsrd142317.pdf

IJTSRD142317

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I. INTRODUCTION

Access to a reliable electrical power is a key element for the functioning of households, social services, sales and business development of productive activities. The memory to the origin of the present article is based on the observation of a failure of the electric power in the city urbano-rural de Bumba, despite the presence of infrastructure on the electrical network. The study seeks to exploit two resources at a local level: the solar radiation and the kinetic energy of the water.

The choice of a hybrid system is based on the complementarity in time and resources. The photovoltaic production is mainly available during periods of sunshine, while the water can contribute to a diet more regularly when the conditions hydrodynamic of the site are favorable. The complete storage this architecture by transferring a portion of the energy produced during periods of surplus to times of deficit.

The memory sets as its goal the design of an electrification solution combining solar pv and tidal for the city of Bumba, with a view to the horizon 2027. The approach focuses on the electrical parameters of the request, the physical parameters of the river Molua, the sizing of the equipment and the optimization of the management of energy.

The central question is that of the ability of a system, hybrid solar photovoltaic–tidal to contribute to a power supply more stable of the city urbano-rural de Bumba, taking into account the demand estimated and local energy resources. This question involves the simultaneous evaluation of the solar resource, the

characterization of hydraulic river Molua, the sizing of generators, and the management of periods of deficit or surplus.

The main hypothesis of the dissertation considers that it is possible to generate electricity from the local energy resources in the middle of a hybrid system, solar pv and tidal. The sub-hypotheses are focused on the determination of the energy parameters which are necessary for the functioning of the system and on the identification of the physical parameters characterizing the flow of the river Molua.

The general objective is to study the production of electrical energy by the hybrid system and the adjustment of the electrical parameters of the network. The specific objectives relate to the sizing of the components of photovoltaic, the determination of the physico-technical of the water, the coupling of the two sources and the formulation of a strategy of optimization and control.

II. Material and methods

2.1. Study environment

The study concerns the city urbano-rural de Bumba, in the province of la Mongala, Democratic Republic of the Congo. The memory indicates an area of 73,33 km2 and has six districts: Lokoe, Mobutu, Lingode, Nzongo, Lokele Mongala and Lokele Molua. He also reports a field survey carried out between September 12, 2024 and on April 20, 2025.

Item	Information retained in the memory
Area of study	Cited urbano-rural de Bumba, Mongala, democratic republic of congo
Period of the study	2023-2027
Area indicated	73,33 km2
Districts	Lokoe, Mobutu, Lingode, Nzongo, Lokele Mongala, Lokele Molua
Course of the water studied	River Molua
Survey field	12/09/2024–20/04/2025

2.2. Methodological approach

The methodology combines the empirical method, the analytical method, the technical and documentary interviews. The empirical approach allows us to collect the information of the field ; the analytical approach is involved in the processing of the electrical parameters and hydraulic ; documentation supporting the review of scientific and technical ; the interviews complement the data collected from the local actors.

2.3. Energy data and receivers

The investigation of the memory door on a sample of 600 respondents. Among the receptors that have been identified include the lamps, radio sets, freezers, televisions, air conditioners, fans, irons and ironing boards. The energy sources reported include SNEL, coal, oil lamps, solar panels, generators, and fuel wood.

Receptors identified	Effective	Percentage
Lamps	240	40,0 %
Post radio	140	23.3 per cent
Freezers	40	6.6% Of
Televisions	86	14.3% Of
air Conditioners,	20	3.3% Of
Fans	14	2.3 per cent
Iron, ironing boards	60	10,0 %

The authors of the memory report several challenges: lack of data and reliable weather, inaccuracy of rainy days and sunshine, it is difficult to access certain information and availability limited data hydrological.

III. Modeling of the hybrid system

3.1. Sub-photovoltaic system

The model used in the memory connects the photovoltaic power to the effectiveness of the modules, their surface and solar irradiation incident:

$$P_{PV} = n_{PV} \times A_{PV} \times G(t)$$

where n_PV represents the performance of the pv generator, A_PV the surface of the panels, and G(t) solar irradiation at time t. This relationship is the basis for the sizing of the field of photovoltaic.

3.2. Sub-system tidal

The conversion of the kinetic energy of the water current is represented by:

$$P_HYDRO = 1/2 \times \rho \times A_h \times v3 \times C_p$$

where ρ is the mass density of the water, A_h the active area of capture, v the speed of the flow and C_p the coefficient of performance. The dependence v3 shows the importance of the measurement of the speed of the current in the sizing.

3.3. Characterization of hydraulic river Molua

The memory uses the fundamental relationship Q = V × S between the flow rate Q, the average speed V and the section wet S. The observations reported distinguish between a situation of rainy season, with a rated throughput of 9 m3/s and a speed of 4.5 m/s, and a situation of the dry season, with a flow rate of 4.5 m3/s and a speed of 3.5 m/s.

Parameter	Value reported	Unit
Flow in the season of rains	9	m3/s
Speed in the season of the rains	of 4.5	m/s
- Speed in - season dry	4,5	m3/s
Speed in season dry	3,5	m/s
Depth estimated site	14	m

The memory describes also the use of relations hydraulic such as Chezy and Manning–Strickler to relate the speed to the geometric characteristics and physical of the bed. The direct measurement and characterization over several periods remain important to reduce the uncertainty.

IV. Electrical sizing and tidal

4.1. Electricity demand

The sizing of the application retains an active power of 3584,9 kW, or approximately 3585 kW. With a power factor of φ = 0.8, and the apparent power is calculated by:

$$S = P_d / \varphi = 3584{,}9 / 0{,}8 = 4481{,}25 \text{ kVA}.$$

To take account of the increase of the demand by the year 2027, the thesis applies a markup of 10 %:

$$S_f = 4481{,}25 + 0{,}10 \times 4481{,}25 = 4929{,}375 \text{ kVA} \approx 5 \text{ MVA}.$$

This value is the reference to the apparent power in the future used in the design.

4.2. Settings mechanics of the windmill

For the wheel to be retained in the memory, the rotation speed calculated is approximately 40,94 tr/min, rounded to 41 tr/min. The rotational speed of the generator is given to 1500 rev/min. The report of the coupling wheel–generator is approximately 36,58, rounded to 36.

Parameter	Value
active Power requested	3584,9 kW
Factor of a power	of 0.8
Power apparent current	4481,25 kVA
Power apparent to the horizon 2027	4929,375 kVA ≈ 5 MVA
Speed of the wheel	40,94 tr/min ≈ 41 tr/min
Speed of the generator	1500 tr/min
Report coupling	36,58 ≈ 36

4.3. The choice of the windmill

The memory holds a tidal turbine floating house Rutten with a apparent power given to 2500 kVA for a rated voltage of 380 V and a rated current of 22.8 A. The presented calculation gives a report of 4481,25/2500 = 1,792, then rounded to a tidal turbine.

In a perspective of achieving this choice must be faced to the power actually available to the site, the overall performance, the seasonal variations, the constraints of connection and the terms and conditions of operation of the generator.

V. Architecture of the hybrid system

The proposed architecture combines a photovoltaic field, a converter, a storage battery and a generator current energy connected to the distribution network of Bumba. The block diagram of the memory involved a regulator DC/DC, converter,,, the storage battery, the hydrogénérateur, the organs of protection and the busbars of the city.

Sub-system	main Function of
Photovoltaic	Conversion of solar radiation into electrical energy
current energy	Conversion of the kinetic energy of water into electrical energy
Battery	Storage of excess and support during deficits
Converters	Adaptation and conversion of electrical quantities
Protections	Isolating switching and circuit protection
distribution Network to	deliver energy to the loads

5.1. Complementary sources

In the studied model, the pv production varies with the amount of sunlight and, therefore, presents a character in the daytime. The tidal turbine is considered as a source that may contribute to the base power as a function of the availability of the current. The storage ensures a function of the balance between production and consumption.

5.2. Strategy of energy management

The logic of management is described in the memory compared at each time step the renewable electricity production to demand. When production exceeds demand, the excess is assigned to the storage subject to the available capacity. When renewable energy production is less than demand, the battery is discharged to its minimum limit. This strategy aims to reduce the deficits of power and to stabilize the power supply.

The simulation illustrative on 24 hours uses a variable demand, a photovoltaic generation zero during the night and increasing during the day, as well as a contribution to tidal constant of 50 kW. The memory specifies that this farm is voluntarily under-sized in the simulation in order to reveal the situations of deficit.

VI. Optimization of the hybrid system

6.1. Criterion economic: LCOE

The proposed optimisation seeks to minimize the cost leveled energy (LCOE), which is defined in the memory by:

$$\mathbf{LCOE = (NCPC \times CRF) / \Sigma\ E_load(t), for\ t = 1,...,8760.}$$

NCPC is the net present value of the costs, including the initial investment, replacement of batteries, cost of operation and maintenance as well as the value of final recovery. E_load(t) represents the energy consumed at time t. The recovery factor of capital is:

$$\mathbf{CRF = i(1+i)^N / [(1+i)^N - 1].}$$

6.2. Criterion of reliability: LPSP

The LPSP (Loss of Power Supply Probability) is used to measure the probability or fraction of the demand is not being met. The principle of optimization is to find a configuration economical while maintaining the LPSP to as low a level as possible.

6.3. Decision Variables

Variable	Interpretation
N_PV	Number or size of the units, photovoltaic
N_HYDRO	Number/size of units tidal
N_BAT	Capacity or number of units of batteries
LCOE	Cost leveled energy
LPSP	Indicator of deficiency of power supply

A procedure of optimization can browse different configurations of generators and storage, and then perform a simulation schedule on 8760 hours. The memory present in this formulation as a basis for the research of a configuration that minimizes the cost while respecting the constraint of continuity of service.

VII. Results and analysis

7.1. Sizing results

Indicator	Result reported
Power requested	3584,9 kW
Power apparent	4481,25 kVA
Power apparent future	4929,375 kVA
Tidal chosen	2500 kVA
Speed wheel	≈ 41 tr/min
Speed generator	1500 tr/min
Report coupling	≈ 36

The results show that the electricity demand is a major constraint in the design. The increase of 10 % applied to the apparent power reflects the willingness to incorporate a margin of growth on the horizon 2027.

7.2. Simulation of energy management

The profile schedule presented in the memory shows a demand in the range of approximately between 100 and 250 kW in the simulation illustrative. The pv production increases during the day, while the contribution of tidal turbine is maintained at 50 kW. When the sum of the production exceeds the demand, the system charges the battery. In the evening, when the pv becomes zero, and the demand increases, the battery provides most of the energy is missing.

Period	Behavior of the system
at Night	PV null ; contribution tidal ; available storage
Morning	gradual Increase of the PV production
Day	PV high ; possibility of charging the battery
Evening	PV null ; increased demand ; discharge of the storage
Deficit	Appearance of a power which is not satisfied when the SOC reaches its limit

7.3. Economic Estimation reported

Equipment	Quantity	unit Price	Total
Tidal floating 4500 kW	1	£13 000 000	£13 000 000
Cable reinforced Cu	7000 m	£19,5/m	£136 500
Transformer 2500 kVA	1	£21 000	£21 000
Contingencies	10 %	—	£131 575
Total			£13 289 075

These costs are those reported in the memory from the sources consulted by the year 2025. They must be updated and verified by quote providers before any decision of investment.

VIII. Discussion

The main interest of architecture studied lies in the association of two renewable resources with profiles different time. The pv is used to valuate the solar field during the day, so that tidal may contribute to the provision of a base power when the current of the river is sufficient.

Storage is a critical interface between the variability of output and demand variations. The simulation of the memory shows in particular that the battery can be charged during periods of excess solar and then discharged during periods of deficit. However, the level of storage capacity directly influences the risk of a deficit and the overall cost of the system.

8.1. Constraints and uncertainties

The main limitation of methodological reported in the thesis is the lack of local data. The lack series reliable weather to Bumba limit the precise characterization of solar irradiation. Similarly, the measures of hydrological available are limited, so that the power tidal turbine is strongly dependent on the speed of the flow.

Another difficulty relates to the representativeness of measurements are seasonal. The reported values for the flow and speed allow a first characterization of the site, but a study of industrial establishment would require a campaign hydrometric longer, with several measurement points and for different seasons.

8.2. Consistency of sizing

The memory provides two indications of load power at different places in the document. For the present article, the value detailed in the chapter of sizing, or 3584,9 kW, is retained as a reference for calculation of the apparent power, since it is directly used in the relation $S = P/\varphi$ and in the design presented.

Similarly, the relationship of apparent power needs to be interpreted with the units correct: a apparent power expressed in kVA multiplied by a factor of power is an active power in kW. This precision is important in order to avoid a confusion of units during the publication or reproduction of the calculations.

IX. Technical Implications for the electrification of Bumba

9.1. Data Acquisition

Before the project, it is recommended to establish a local database including solar irradiation, temperature, precipitation, stream flow, the speed of the current and the seasonal variations. The data must be time-stamped and controlled to enable a simulation annual energy reliable.

9.2. Studying the connection

The coupling must integrate the characteristics of the distribution network, the voltage levels, the protections, the transformers, converters and synchronization requirements. The thesis presents a connection including a level of 0.4 kV/6.6 kV in the circuit diagram.

9.3. Storage and control

The sizing of the battery must be bound to the request by night, to the tips of consumption, pv generation, and the actual contribution of the tidal turbine. The control system must prevent overcharging and deep discharging and ensure a priority logic between direct supply, storage and renewable generation.

9.4. Maintenance and operation

The water must be accessible for inspection and maintenance, especially in an environment of inland waterways. The photovoltaic system also requires a program of cleaning, electrical inspection and performance monitoring. The availability of spare parts and local knowledge should be incorporated into the operating plan.

9.5. Complementary studies

A techno-economic study detailed should compare several configurations of PV/tidal/battery, calculate the LCOE for each, evaluate the LPSP on a typical year and perform sensitivity analyses on the cost of the batteries, the speed of the water, the irradiation, the discount rate and the growth of the demand.

X. Conclusion

This study synthesizes the approach developed in the memory of DEA dedicated to the electrification of the city urbano-rural Bumba by a hybrid system, solar pv and tidal. The approach combines the assessment of the demand for electricity, the characterization of the river Molua, the sizing of the renewable sources, storage, and energy management.

The design retains a power demand of 3584,9 kW and an apparent power of 4481,25 kVA with a power factor of 0.8. A margin of 10% growth leads to 4929,375 kVA on the horizon 2027. The memory provides a speed of wheel tidal approximately 41 tr/min and a speed of generator 1500 tr/min, with a ratio of mating neighbor of 36.

Energy modelling is based on the dependence of the photovoltaic production to irradiation, and on the cubic dependence of the power a windmill at the speed of the current. The optimization is structured around the LCOE and the LPSP, while the management strategy uses the battery to transfer energy between periods of surplus and deficit.

Ultimately, the work provides a basis for sizing and modeling for a hybrid project to Bumba. The actual implementation, however, requires a consolidation of local data, a validation of hydrological and meteorological, a detailed study of the network, a discounting of costs and a simulation annual full before making any investment decision.

XI. Recommendations

- Install or build the devices for measuring meteorological and hydrological Bumba and on the river Molua.
- Constitute a series of time of at least a year for solar irradiation, temperature, flow rate and the speed of the current.
- Refresh the costs of equipment, transport, civil engineering, hook-up and maintenance.
- Carry out a feasibility study of electric and an environmental impact study of the site tidal.
- Compare multiple battery sizes and multiple configurations of production by optimization schedule.
- To validate the performance of the system by simulating the annual and, if possible, by a prototype or an installation driver.

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International Journal of Trend in Scientific Research and Development
IJTSRD
International Journal of Trend in Scientific Research and Development
ISSN: 2456-6470