(Large-Scale Ubiquitous Sensor-Actuator Technology)

# Phased Underwater Grid

Combining Zambia’s river energy resource with hydrokinetic technology, AI, IoT and predictive analytics for reliable, clean power nationwide.

*Full Technical, Strategic & Comparative Overview*

*Large-Scale Ubiquitous Sensor-Actuator Technology | Zambia | 2026*

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# 1. Executive Summary

LUSAT (Large-Scale Ubiquitous Sensor-Actuator Technology) proposes a scalable pathway to reliable, clean electricity for Zambia by combining the country's abundant river resources with modular hydrokinetic turbines and an advanced intelligence layer of AI, IoT and predictive analytics. The resulting "phased underwater grid" begins with local microgrids and expands into coordinated clusters that can ultimately contribute firm capacity to the national system.

Unlike traditional large-dam hydropower, hydrokinetic systems extract energy from the kinetic energy of flowing water without requiring major reservoirs. Generation continues day and night, providing a firm complement to intermittent solar. The intelligence layer monitors river flow, equipment health, load and line conditions, forecasts generation, schedules maintenance, and balances supply across sites and with solar/storage resources before shortfalls appear as outages.

This document consolidates the technical concept, grid-integration approach, stability considerations, detailed public description of the grid architecture, and comparisons with other African initiatives (including Hydrobox in Kenya and hydrokinetic efforts in Zambia) into a single reference overview.

# 2. Zambia's Energy Context & Opportunity

## Progress Made

Installed generation capacity has risen significantly since 2021 (from roughly 3,100 MW toward the mid-4,000+ MW range by 2026). Solar capacity has expanded rapidly (from under 100 MW to several hundred MW and beyond). National electricity access has improved substantially and rural access has moved from very low single digits toward the mid-30% range. New solar plants and hybrid projects continue to come online. The government maintains a target of universal access by 2030 and has articulated a longer-term generation ambition in the order of 10,000 MW.

## Remaining Challenges

Heavy historical reliance on large-dam hydro leaves the system exposed to drought. Solar is intermittent (zero at night, reduced under heavy cloud). Many remote communities still lack reliable supply. Long transmission distances increase losses and vulnerability. There remains a clear need for firm, clean capacity located closer to load centres. Last-mile electrification continues to be capital- and logistics-intensive.

Zambia's major rivers—the Zambezi, Kafue, Luangwa and others—carry continuous kinetic energy. LUSAT's approach treats this resource as the foundation of a distributed generation system that can address both rural access and national firmness needs.

# 3. Hydrokinetic Technology – Principles & Operation

Hydrokinetic systems extract energy from the kinetic energy of flowing water rather than from a large hydraulic head created by a dam or weir. Turbines sit directly in the river current.

## Key Characteristics

- **No dam required** — Minimal civil works, significantly lower environmental and social footprint than traditional hydropower.
- **Continuous output** — Generation continues day and night, in rain or under cloud, for as long as the river flows; a firm complement to solar.
- **Modular design** — Units can be deployed individually or in arrays; capacity scales by adding turbines rather than building a single large plant.
- **Self-adjusting** — Modern designs adapt to changing water levels and flow conditions, maintaining more predictable output across seasons.
- **Nearer to load** — Can be sited closer to communities, farms and industry, reducing transmission losses and improving local reliability.

## Operational Sequence of an Array

**1. Site Selection** — Identify reaches with adequate flow velocity, depth and channel stability; prefer locations nearer to load.

**2. Turbine Deployment** — Install modular horizontal-axis or floating turbines in rows or clusters.

**3. Power Conditioning** — Inverters and controllers convert variable output into stable AC; transformers step voltage up for local use or export.

**4. Storage Integration** — Batteries smooth short-term fluctuations and cover low-flow or peak-demand periods.

**5. Local Microgrid** — Serve nearby loads through a smart microgrid managed by IoT and AI.

**6. Grid Interconnection** — Where infrastructure exists, export surplus to ZESCO under appropriate agreements.

## 4. The Intelligence Layer (AI, IoT, Predictive Analytics)

The intelligence layer turns individual turbines and sites into a coordinated system. Sensors continuously stream data on river flow velocity, power output, equipment health (vibration, temperature), battery state of charge, inverter status, line conditions and local load profiles.

AI models process this data to forecast generation hours and days ahead, detect anomalies, schedule predictive maintenance, optimise battery charge/discharge cycles, and shift supply between hydrokinetic and solar resources before shortfalls appear as outages. Control actions include adjusting output, coordinating multi-site arrays, generating remote reports and triggering alerts or work orders. This layer is central to LUSAT's claim of delivering not just generation hardware but a managed, reliable energy resource.

## 5. Phased Underwater Grid Architecture

The "underwater grid" is not a single underwater cable network. It is a growing collection of river-based generation nodes that are intelligently coordinated and progressively interconnected.

| Phase | Focus | Activities & Outcomes |
|---|---|---|
| Phase 1<br>Local Nodes | Pilots & Microgrids | High-impact sites (farms, clinics, schools, fishing communities). Islanded or lightly connected microgrids with storage. Prove performance, build local skills, generate operating data and bankable case studies. |
| Phase 2<br>River Clusters | Expansion & Limited Export | Add arrays on proven reaches. Interconnect nearby nodes. Hybrid solar–hydrokinetic sites. Begin limited export to nearby ZESCO lines. Shared monitoring platform. |
| Phase 3<br>National Resource | Coordinated Contribution | Link multiple basins. Full smart-grid coordination with solar and transmission. Firm contribution to national supply and last-mile access. Mature integration with ZESCO planning. |

## 6. Connection to the National Grid (ZESCO)

Two primary operating modes exist. Sites can transition from one to the other as infrastructure and agreements mature.

### Local / Microgrid Mode

Ideal for early phases and remote locations. Turbines, inverters and batteries form a self-contained smart microgrid that serves local loads directly. The system can operate fully islanded from ZESCO, with an optional weak or temporary grid link for backup. This mode builds community ownership and reduces diesel use where transmission is distant or unreliable.

### Grid-Connected / Export Mode

For later phases and sites near existing lines. Power is conditioned and stepped up to distribution or transmission voltage. Interconnection requires studies and a Grid Connection Agreement with ZESCO; larger clusters may involve a Power Purchase Agreement. The AI/IoT layer coordinates export so the contribution supports grid stability. Sites can both inject surplus and import when local generation is low.

### Typical Path to Connection

1. Site and resource assessment (flow measurements, environmental screening, proximity to loads and lines).
2. Technical design (turbine selection, electrical design, protection scheme, metering, communications).
3. Grid application to ZESCO and request for feasibility / stability studies.
4. Studies, protection coordination and signing of Grid Connection Agreement.
5. Commercial arrangements (PPA or other offtake for larger clusters; net metering where eligible for smaller sites).
6. Construction, testing, commissioning under ZESCO/ERB oversight and activation of remote monitoring.

# 7. Grid Stability Review

No public, project-specific stability studies for LUSAT deployments have been located. The assessment below draws on technology characteristics, general behaviour of hydrokinetic and inverter-based resources, and known conditions on the Zambian system.

## Potential Stability Benefits

Hydrokinetic generation is relatively firm (day and night), reducing the magnitude of net-load ramps that stress frequency control. Distributed placement closer to load can improve local voltage profiles and reduce transmission stress. The intelligence layer, if accurate and with sufficient control authority (including storage), can reduce sudden imbalances. Modular scaling allows operators to observe behaviour and refine settings before large volumes are connected.

## Risks and Open Questions

Most modern hydrokinetic systems use power-electronic converters and therefore contribute little rotational inertia and limited fault current—similar to solar and wind. Zambia's grid has already experienced reduced system inertia with rising solar penetration. Lower short-circuit contribution can affect protection performance and voltage-dip severity. Converter controls may introduce harmonics or interact with other inverter-based resources. Seasonal and spatial flow variability, and the transition from islanded microgrids to grid-connected operation, also require careful management.

## Zambian Grid Context & Required Steps

Available studies show measurable inertia decline as variable renewables displace synchronous hydro, with frequency response still manageable within grid-code limits under many contingencies but with tightening margins. Voltage stability and protection performance on the 132 kV network are sensitive to the location and volume of inverter-based injection. Required steps before large-scale deployment include resource-specific dynamic models, site-specific short-circuit and dynamic studies, frequency-response evaluation, protection coordination, power-quality compliance checks against the Zambian Distribution Grid Code, and clear definition of control hierarchy between local controllers, the LUSAT intelligence layer and ZESCO.

**Overall:** The concept has clear potential to improve local reliability and reduce the burden of solar intermittency. Realising system-wide stability benefits depends on grid-forming or equivalent controls, adequate fault-current contribution or mitigation, proper studies, storage integration, and close technical coordination with ZESCO and the Energy Regulation Board.

# 8. Detailed Exploration of LUSAT Grid Concept

Public materials from LUSAT (lusat.org and related statements) describe a coherent but still high-level vision. The following synthesises the available detail.

## Core Framing

LUSAT frames Zambia's rivers as a distributed generation resource. Modular hydrokinetic turbines are placed directly in the natural current. These units are coordinated by an AI + IoT + predictive-analytics layer. Over time the nodes are intended to grow from isolated microgrids into interconnected clusters and eventually into a nationally significant firm-power resource — the "phased underwater energy grid." Public phrasing includes: "Zambia's rivers carry a constant, renewable current. LUSAT is harnessing that flow with hydrokinetic turbines, AI, IoT, and predictive analytics to build a national underwater energy grid." The intelligence layer is described as monitoring solar output, river flow, load and line condition, and shifting supply from solar to hydrokinetic generation before a shortfall appears as an outage.

## Technology Stack (as described)

| Layer | Components | Stated Role |
|---|---|---|
| **Generation** | Hydrokinetic turbines (horizontal-axis or floating designs implied) | Convert river current into electricity 24/7 without dams |
| **Complementary** | Solar PV | Daytime contribution; balanced against hydrokinetic |
| **Storage** | Battery systems | Smooth short-term variability and cover low-flow or peak periods |
| **Power electronics** | Inverters, charge controllers, mounting structures | Condition and manage power |
| **Sensing & control** | IoT sensors + AI-driven monitoring, predictive analytics, remote asset management | Real-time data, forecasting, predictive maintenance, smart-grid integration |
| **R&D; themes** | Magnetic drive power systems (mentioned) | Longer-term advanced generation concepts |

### What Is Not Yet Publicly Detailed

As of the latest available information, LUSAT has not published specific turbine models, power ratings or efficiency curves; exact number or locations of deployed or near-term pilot units; quantitative capacity targets (MW) for each phase; detailed control architecture, communication protocols or latency requirements of the AI/IoT platform; results of grid-impact, short-circuit, inertia or protection studies; formal interconnection agreements or Power Purchase Agreements with ZESCO; or independent third-party validation of the predictive-analytics performance. The public narrative remains at the level of system vision, technology categories and strategic rationale rather than detailed engineering specifications or commercial track record of large operating fleets.

## 9. Comparison with Other African Projects

LUSAT is distinctive in its ambition to build a coordinated national-scale phased underwater grid. Most comparable African efforts are smaller, more localized, or focused on either pure generation hardware or conventional mini/micro-hydro.

### Closest Technology Peers in Zambia

**Achelous Energy (HKS.r)** — Floating modular hydrokinetic + solar hybrid units (50 kW class). Lake View Farm on the Kafue is targeting up to ~600 kW. Hardware-focused modular turbines for farms and mining. LUSAT places heavier emphasis on multi-site AI orchestration and a national grid vision.

**Heavy Duty Solutions – Hydro Master** — Local floating hydrokinetic design (5 kVA–1,000 kVA). Aimed at load-shedding relief for mining and agriculture. Strong local manufacturing angle. LUSAT differentiates with an explicit intelligence layer and phased national architecture.

### Other African Initiatives

Kenya has seen low-cost hydrokinetic academic prototypes and the more commercial Hydrobox modular run-of-river + solar mini-grids with IoT monitoring. Nigeria is advancing small run-of-river and hybrid solar-hydro policy and pilots (e.g., Ikere Gorge ~100 MW hybrid target). South Africa has tested hydrokinetic turbines in irrigation canals. Across the continent, most advanced digital energy projects remain solar-dominant mini-grids with IoT; pure hydrokinetic arrays with AI coordination remain relatively uncommon. LUSAT's combination of pure hydrokinetic technology, explicit multi-site predictive analytics, and a dual pathway from islanded microgrids to national contribution is among the more ambitious system-level framings currently articulated in the region.

## 10. LUSAT vs Hydrobox – Side-by-Side

Hydrobox (Kenya) is one of the closest operational peers: modular water-based generation + solar hybrid + digital monitoring for rural African communities.

| Dimension | LUSAT (Zambia) | Hydrobox (Kenya) |
|---|---|---|
| **Core Technology** | In-stream hydrokinetic (current velocity; no dam/head required) | Run-of-river micro-hydro (modest head) + solar hybrid |
| **Intelligence** | Strong focus on AI + IoT + predictive multi-site analytics | IoT sensors, remote monitoring, anomaly detection, intelligent hydro-solar balancing |
| **Architecture** | Phased underwater grid: microgrids → clusters → national resource | Discrete modular mini-grids serving communities |
| **Primary Goal** | Firm capacity for communities and national energy security | Reliable 24/7 power for off-grid rural communities |
| **Maturity** | Concept / R&D; positioning; vision-oriented public materials | Operational projects; ~$9M funding for expansion; thousands of beneficiaries |
| **Grid Role** | Local start with progressive national contribution | Primarily mini-grid / off-grid focused |

**Positioning:** Hydrobox is a practical, funded mini-grid developer delivering reliable power to rural Kenyan communities today. LUSAT is a more ambitious systems play that treats hydrokinetic generation plus AI coordination as building blocks of a future national-scale distributed underwater grid in Zambia. They are complementary in many respects rather than direct competitors.

## 11. Benefits, Challenges & Path Forward

### Key Benefits

- No new large reservoirs — lower environmental and social footprint.
- Firm clean power that covers periods when solar is weak or unavailable.

- Modular and scalable — start small, expand with demand and financing.
- Local economic impact — power for irrigation, cold storage, clinics, schools and small industry.
- Improved grid resilience through distributed firm capacity.
- Smart operations via predictive maintenance and real-time balancing.

### Challenges and Mitigations

**Site selection & environmental care:** Rigorous flow studies, fish-passage and sediment assessments, community consultation.

**Financing modular arrays at scale:** Phased approach lowers capital risk; pilot data supports bankable projects; blended finance and clear offtake.

**Skills and local capacity:** Technician training programmes; remote monitoring reduces need for constant on-site specialists.

**Grid codes & interconnection:** Early engagement with ZESCO and ERB; standardised designs; clear study requirements.

**Seasonal flow variability:** Storage, hybrid solar pairing, and multi-site diversification.

**Maintenance in remote locations:** Predictive analytics, modular replaceable components, local spare-part strategies.

## 12. Summary & Conclusions

1. Zambia's rivers carry a continuous, under-utilised kinetic energy resource.
2. Hydrokinetic turbines convert that flow into electricity without dams or large reservoirs.
3. AI, IoT and predictive analytics turn individual turbines into a coordinated, maintainable system.
4. A phased approach — local microgrids → river clusters → national underwater grid — manages risk and builds capability.
5. Sites can operate islanded or connect to ZESCO, with the intelligence layer intended to ensure stable contribution.
6. The concept aligns well with the need for firm, distributed, clean capacity; realisation depends on proven hardware, a robust intelligence layer, rigorous stability and protection studies, and close coordination with ZESCO and the ERB.
7. Relative to peers such as Hydrobox, Achelous and Hydro Master, LUSAT is distinguished by its explicit national-scale systems vision rather than solely by discrete mini-grid or hardware deployment.
8. Public materials describe a coherent systems architecture but do not yet provide detailed engineering specifications, pilot performance data or formal grid studies; these remain necessary next steps.

By treating the nation's rivers as distributed power plants — intelligently managed and expanded phase by phase — LUSAT aims to turn an abundant natural resource into widespread energy security for communities across Zambia.

www.lusat.org

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