



DESIGNING A BESS ANCILLARY SERVICES FRAMEWORK FOR SENEGAL PRODUCTS REMUNERATION VALUE STACKING AND VALIDATION PROTOCOL

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ABSTRACT

Commissioning and integrating battery energy storage systems (BESS) in Senegal require a rigorous and explicit delineation of their ancillary-service functions within both operational protocols and contractual instruments. This study develops a structured framework drawing on the PATRP study for 2017 to 2035, the MCC-Dalberg assessment, national energy statistics, Senelec's 2025 report on energy flows, and Senegal's Just Energy Transition Investment Plan. The analysis encompasses frequency control, fast reserve provision, voltage regulation, smoothing and firming of variable renewable generation, and black-start capability. The technical specification sets bounds on active power, energy capacity, state of charge (SOC), and converter apparent power, and it disaggregates remuneration into availability, activation, and performance components. Illustrative computations evaluate the magnitude and sustainment of services deliverable by a 10 MW/20 MWh installation. The nameplate power equals 24.4 percent of a historical 41 MW benchmark for solar variability, 18.5 percent of a 54 MW wind benchmark, and 14.3 percent of a historical 70 MW reserve requirement. With an initial SOC of 50 percent, a minimum SOC of 10 percent, and a discharge efficiency of 95 percent, uninterrupted 10 MW delivery is theoretically maintainable for about 46 minutes. These figures neither characterize dynamic performance on the 2025 grid nor constitute measured outcomes at Walo Storage; rather, they highlight that reserve commitments must be conditioned on SOC and coordinated with other resources. The proposed pilot integrates qualification testing, telemetry, performance metrics, rules governing co-delivery and value stacking, and settlement procedures. No assumptions are introduced regarding market prices, and no unpublished performance data are used.

KEYWORDS: Battery energy storage systems; ancillary services; frequency control; operating reserves; system flexibility; Senegal; West African Power Pool; state of charge; value stacking.

Nomenclature and abbreviations

Abbreviation / unit	Definition
BESS	Battery energy storage system
BS	Black start
EMT	Electromagnetic transient
KPI	Key performance indicator
MCC	Millennium Challenge Corporation
OMVG	Organisation pour la Mise en Valeur du fleuve Gambie (Gambia River Basin Development Organization)
OMVS	Organisation pour la Mise en Valeur du fleuve Sénégal (Senegal River Basin Development Organization)
PATRP	Power Africa Transactions and Reforms Program
PV	Photovoltaic
RMS	Root mean square; used here for phasor-domain stability studies

Abbreviation / unit	Definition
RoCoF	Rate of change of frequency (Hz/s)
SIE	Système d'Information Énergétique (Energy Information System)
SOC	State of charge
MW / MWh / GWh	Megawatt / megawatt-hour / gigawatt-hour
MVAr / MVArh / MVA	Megavolt-ampere reactive / megavolt-ampere reactive hour / megavolt-ampere

Symbols

Symbol	Definition	Unit
E_B	Rated BESS energy capacity	MWh
$E_{\text{headroom,up}}$	Stored energy available above the minimum SOC	MWh
$\text{SOC}(t)$	State of charge at time t	fraction or %
$\text{SOC}_{\text{min}} / \text{SOC}_{\text{max}}$	Minimum / maximum state of charge	fraction or %
$\text{SOC}_{\text{min,safe}} / \text{SOC}_{\text{max,safe}}$	Lower / upper safe SOC limits	fraction or %
η_{dis}	Discharge efficiency	dimensionless
$R_{\uparrow}$	Upward reserve commitment	MW
T	Reserve activation duration	h
$P_{\text{BESS}} / P(t)$	BESS active power / active power at time t	MW
Q_{BESS} / Q	BESS reactive power	MVAr
$S_{B,\text{rated}} / S_{\text{rated}}$	Rated converter apparent power	MVA
S	Apparent power	MVA
$P_{\text{reserved},s}(t)$	Power reserved for service s at time t	MW
$P_{\text{available}}(t)$	Power available at time t	MW
s / t	Service index / time	index / h
Π_{service}	Net remuneration for the service	monetary unit
A	Reserved capacity	MW or MVAr
E_{act}	Activated energy	MWh or MVArh
K_{perf}	Performance index	dimensionless
C_{avail}	Availability payment coefficient	monetary unit per capacity unit*
C_{act}	Activation payment coefficient	monetary unit per energy unit
C_{perf}	Performance payment coefficient	monetary unit per index unit
C_{deg}	Degradation cost allocated to the service	monetary unit
P_{pen}	Applicable contractual penalty	monetary unit

In Equations (1) to (4), state of charge and efficiency are expressed as fractions, although reported summary values may be given in percent. When reserve capacity is stated in MW and energy in MWh, the time variable T is in hours. The availability coefficient is defined with respect to the agreed settlement interval; consequently, any time-indexed tariff must be scaled by the length of that interval. In Equation (5), all monetary terms are denominated in a single currency and referenced to an identical settlement interval.

1. INTRODUCTION

Senegal's power sector is expanding at pace, underpinned by persistent demand growth, higher penetration of variable renewables, and deepening regional power exchanges. SIE 2025 records a 2024 system peak of 1,159 MW against 1,903.81 MW of installed capacity, including 267.01 MW of grid-connected solar and 159 MW of wind.^[6] Senelec's 2025 report indicates a maximum peak of 1,261 MW and 2,310.5 MW of installed capacity, and notes the commissioning of Walo Storage, the first utility-scale BESS in the country, rated 10 MW and 20 MWh.^[5] These developments sharpen an operational question: which fast-response services should the system operator

procure, and on what terms.

A BESS delivers capabilities that extend beyond simple temporal shifting of energy. Its converter can regulate active and reactive power on short timescales; sustained provision, however, is bounded by stored energy, state of charge, activation duration, round-trip efficiency, and degradation mechanisms.^[12 to 16] Converting these technical capabilities into a contractible product requires a demonstrable and measurable system need and a resource that satisfies explicit qualification criteria. It also necessitates compatibility across simultaneous commitments, since the same MW or MWh cannot be promised to multiple services if concurrent activation would exceed the asset's physical limits.

The PATRP assessment for 2017 to 2035 provides empirical benchmarks for these limits. Salient events include a 115 MW trip of Sendou generation, prospective solar variability of 41 MW, wind variability of 54 MW, and roughly 63 MW of thermal reserve potential. In a 2022 scenario replicating the Sendou outage, spinning-reserve requirements surpassed 70 MW.^[4] The present analysis employs these magnitudes to define qualification scenarios and to develop illustrative

calculations; they remain tied to the underlying case study and are not posited as current operational requirements.

1.1. Research question and contributions

The central inquiry is how to translate Senegal's technical system needs into BESS services that are contractually specified and verifiable in delivery, with particular attention to the physical feasibility of stacking multiple services within a single installation. The study advances five objectives: first, to classify services by their requirements for real power, energy, response time, service duration, reactive capability, and state-of-charge management; second, to formalize minimum constraints on real power, energy, and apparent power; third, to design remuneration structures for availability, activation, and verified performance, explicitly incorporating degradation costs and penalties; fourth, to present reproducible preliminary calculations using published data and to delimit their evidentiary scope; and fifth, to propose a pilot protocol that specifies qualification tests, telemetry, baseline construction, performance indicators, and settlement procedures.

2. Institutional framework and literature review

Senegal's 2021 Electricity Code explicitly encompasses storage.^[1] Ministerial Order No. 002168 of 5 February 2025 approves model specifications that include licensing for storage among other activities.^[2] Together, these instruments allow the incorporation of technical

and service-quality obligations into contracts, but they do not create an ancillary services market.

The MCC-Dalberg assessment identified energy shifting, renewable smoothing and firming, voltage support, frequency regulation, congestion management, operating and replacement reserves, and black start as viable storage applications in Senegal.^[3] The international literature supports the use of batteries for many of these functions and indicates that realized value depends on coordinated stacking of services, maintaining sufficient state of charge, and accounting for cycling-related costs.^[12 to 20]

Senegal's Just Energy Transition Investment Plan links higher renewable penetration with storage deployment and sets out an indicative trajectory for BESS capacity, with particular emphasis on forthcoming solar projects.^[7] As additional systems enter service, the system operator and asset owners will require agreed procedures for qualification, service prioritization, activation, and remuneration. In Equations (1) to (4), state of charge and efficiency are represented as fractions; reported values are presented in percent. When reserve capacity is specified in MW and energy in MWh, T is measured in hours. The availability coefficient is defined over the agreed settlement interval, so any time-based tariff must be multiplied by that interval. All monetary quantities in Equation (5) use a consistent currency and the same settlement interval.

Design and settlement of BESS ancillary services

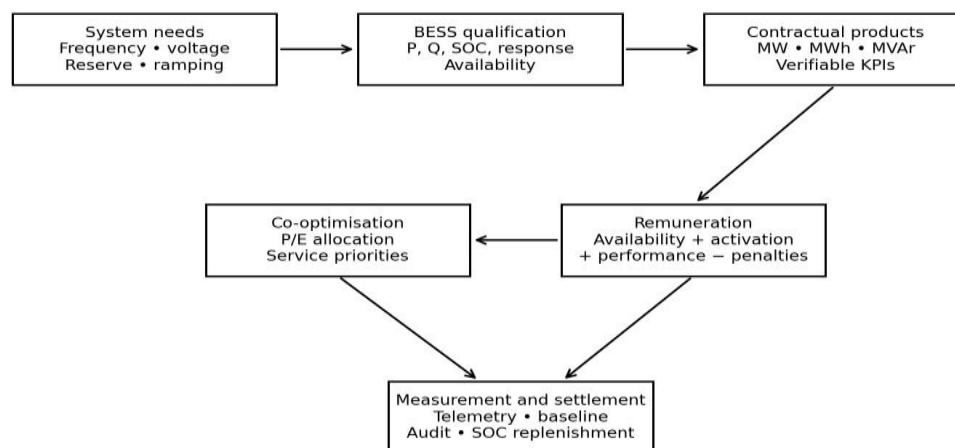


Figure 1: Proposed sequence for designing, qualifying, stacking and settling BESS ancillary services. Source: author's elaboration.

3. Data, methodological framework, and assumptions

3.1. Documentary sources and interpretive safeguards

This work synthesizes Senegalese regulatory and institutional documents^[1,7], historiographical studies addressing system stability and the integration of variable renewables^[4,8], and technical scholarship on storage technologies and system services.^[9,24] All historical time series are presented in their original

temporal resolution and extent, without resampling or aggregation. The novel outputs are restricted to deterministic feasibility assessments that evaluate whether a given service aligns with the battery's rated power and deliverable usable energy. These screening tests are not a surrogate for RMS or EMT dynamic stability analyses, for the system operator's reserve dimensioning, or for empirical validation under operational conditions.

3.2. System context indicators

Indicator	Published value	Year / source	Analytical use
System peak demand	1,159 MW	2024, SIE [6]	System scale
Installed capacity	1,903.81 MW	2024, SIE [6]	Generation fleet context
Grid-connected solar	267.01 MW	2024, SIE [6]	Exposure to variability
Grid-connected wind	159 MW	2024, SIE [6]	Exposure to variability
Maximum peak demand	1,261 MW	2025, Senelec [5]	Recent context
Installed capacity	2,310.5 MW	2025, Senelec [5]	Recent context
Walo Storage	10 MW/20 MWh	2025, Senelec [5]	Reference BESS
National demand	7,254 GWh	2025, Senelec [5]	Energy context

3.3. Selected stability benchmarks

PATRP benchmark	Value	Interpretation in this paper
Loss of Sendou	115 MW	Severe historical contingency; not a 2025 requirement
Potential solar fluctuation	41 MW	Ramping/reserve scenario
Potential wind fluctuation	54 MW	Fast-reserve scenario
Thermal reserve potential	63 MW	Historical conventional-flexibility benchmark
Reserve for Sendou loss (2022 scenario)	≈70 MW	Historical spinning-reserve requirement

4. Definition of ancillary service products

Product	Procured variable	Indicative response	Main constraint	Settlement KPI
Frequency regulation	Symmetric/asymmetric MW	Seconds–minutes	SOC, accuracy, cycling	Tracking error, availability
Fast reserve	MW	Seconds–minutes	Power headroom and energy	Response time, MW Delivered
Voltage support	MVAr / voltage range	Subsecond–seconds	Converter current	Q, voltage, availability
Renewable smoothing / firming	MW and MWh	Minutes–hours	Energy, forecasting, cycling	Ramp, energy, schedule deviation
Black start	MW/MWh + availability	Minutes	Minimum SOC, auxiliaries	Test success, delay, energy

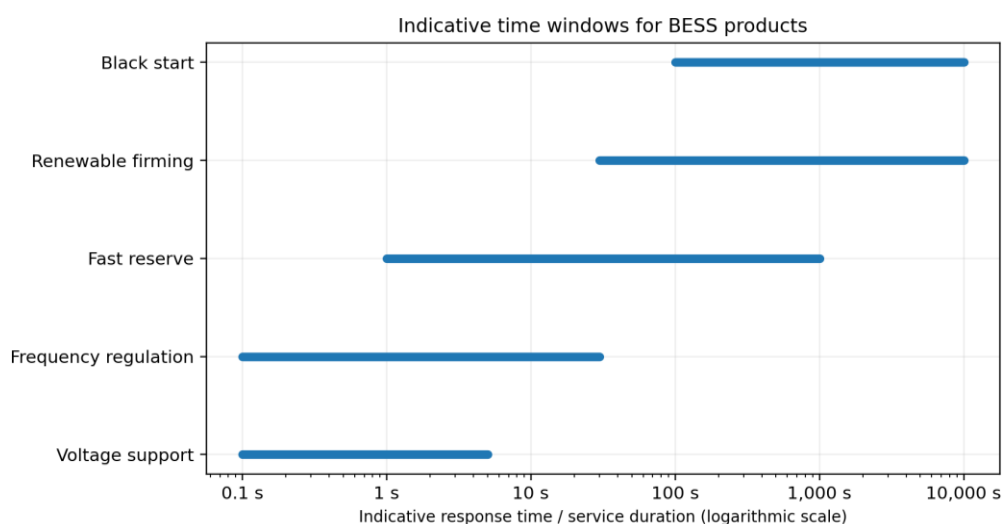


Figure 2: Indicative time windows for BESS products. The ranges are conceptual and must be specified contractually by the operator. Source: author's elaboration based on. ^[3,12,20]

5. Technical specification of power, energy, and SOC constraints

To sustain an upward reserve $R_{\uparrow}$ over a horizon T , the battery must preserve a sufficient energy margin above

its lower SOC bound. The corresponding upward energy headroom is $E_{\text{headroom, up}} = (SOC - SOC_{\text{min}}) \cdot EB(1)$. The reserve pledge is feasible only if it respects the energy sufficiency condition $R_{\uparrow} \cdot T \leq \eta_{\text{dis}} \cdot E_{\text{headroom}}$,

up (2 By symmetry, the absorptive capability for downward reserve is limited by the gap to SOC_{max} together with the charging efficiency. In all cases, active and reactive power outputs must jointly remain within the converter's apparent-power capability:

$$\sqrt{(PBESS^2 + QBESS^2)} \leq SB, \text{ rated} \quad (3)$$

When multiple services s are stacked, the following per-time-step bounds must hold:

$$\sum_s \text{Preserved}_s(t) \leq P_{\text{available}}(t); \text{SOC}_{\text{min, safe}} \leq$$

$$\text{SOC}(t) \leq \text{SOC}_{\text{max, safe}} \quad (4)$$

These constraints provide a physics-based verification of contractual offers. Even if each service is individually admissible, their concurrent activation may drive the converter into power saturation or deplete the SOC margin. Technical formulation of power energy and SOC constraints.

6. Preliminary calculation results and interpretation

6.1. Instantaneous coverage of PATRP benchmarks by 10 MW

Benchmark	Requirement / fluctuation	Coverage by 10 MW	Residual power
Solar fluctuation	41 MW	24.4%	31 MW
Wind fluctuation	54 MW	18.5%	44 MW
Sendou reserve	70 MW	14.3%	60 MW
Loss of Sendou	115 MW	8.7%	105 MW

A 10 MW BESS corresponds to roughly one quarter of the 41 MW solar benchmark, to less than one fifth of the 54 MW wind benchmark, and to about one seventh of the historical 70 MW reserve requirement. These proportions describe relative scale only; they do not proxy the system's efficacy in arresting a disturbance, and

therefore indicate that the contribution is inherently partial. Addressing the more severe historical contingencies would require coordinated operation with thermal reserves, demand response resources, and support from interconnectors.

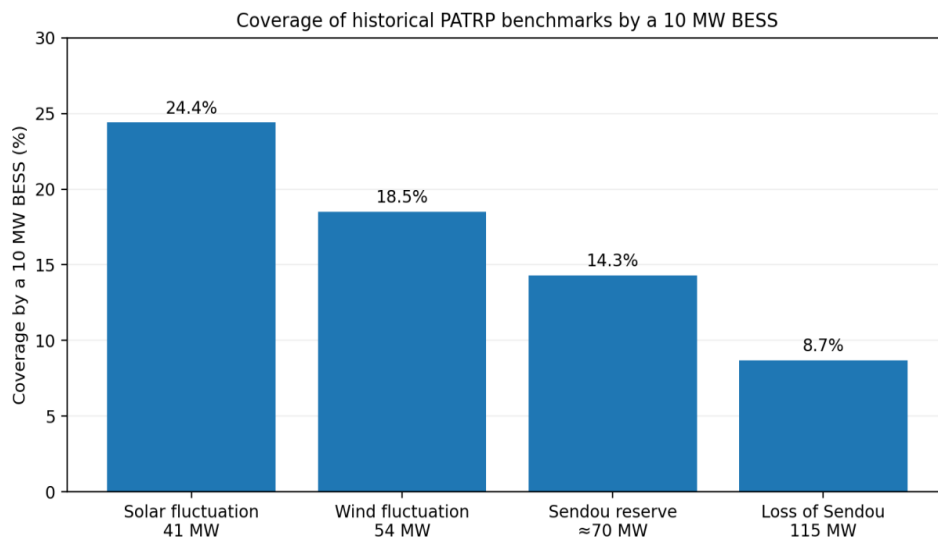


Figure 3: Instantaneous coverage of historical PATRP benchmarks by 10 MW of BESS power. Author's calculations based on.^[4,5]

6.2. Energy adequacy of a 10 MW/20 MWh BESS

Initial SOC	Theoretical energy available above 10% SOC*	Duration at 10 MW*	Operational interpretation
30%	3.8 MWh	23 min	Short-duration reserve
50%	7.6 MWh	46 min	Short-duration reserve
70%	11.4 MWh	68 min	Reserve > 1 h
80%	13.3 MWh	80 min	Reserve > 1 h
90%	15.2 MWh	91 min	Reserve > 1 h

* For the illustrative computation, take EB = 20 MWh, SOC_{min} = 10%, and η_{dis} = 95%. These parameters are provided solely for demonstration and must not be taken as indicative of any documented Wallo Storage performance.

A careful energy-balance treatment of state of charge shows that a nameplate power rating, by itself, does not suffice to characterize reserve capability. With SOC at

50%, a 20 MWh asset retains 8 MWh above the 10% lower bound. After accounting for a 95% discharge efficiency, the net deliverable energy is 7.6 MWh, which

sustains a 10 MW output for approximately 46 minutes. In comparison, a 15-minute activation at 10 MW requires 2.5 MWh at delivery, before applying any operational safety margins. It follows that a reserve agreement must

state both the duration corresponding to the reserved megawatts and the operating rules governing SOC maintenance.

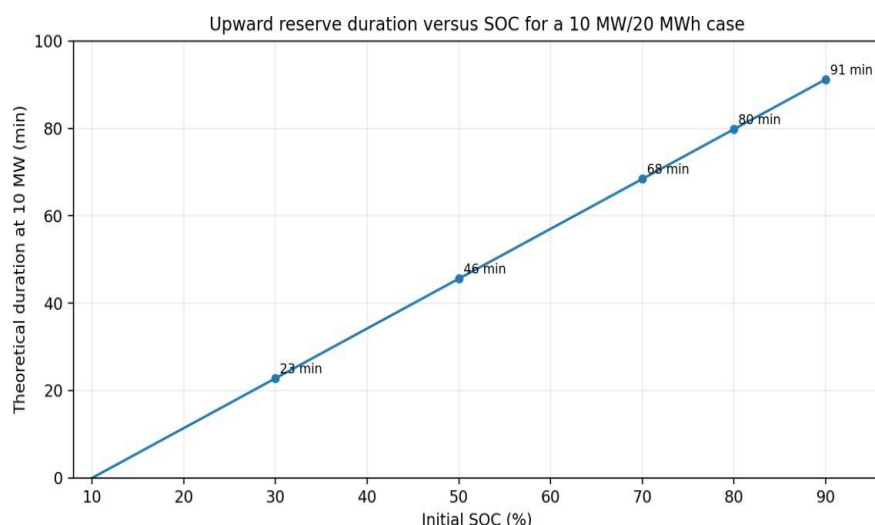


Figure 4: Sensitivity of theoretical reserve duration to initial SOC for an illustrative 10 MW/20 MWh case (SOC_{min} = 10%, η_{dis} = 95%). Source: author's calculations.

6.3. Scope of the historical stability results

PATRP documented that, during a 115 MW trip at Sendou, preventing involuntary load shedding would have required more than 70 MW of spinning reserve. In contrast, a separate incident showed that 54 MW of reserve was adequate to counterbalance a 72 MW shortfall in wind generation.^[4] These case-specific outcomes primarily reflect the exact contingency, the contemporaneous system inertia, and the reserve posture at the time. They therefore cannot be extrapolated to predict the frequency nadir associated with a 10 MW BESS operating on the 2025 system. Anticipated differences in network topology, unit commitment and dispatch, protection settings, interchange schedules, and control policies in 2025 are likely to be material relative to the historical configurations. Consequently, the screening-level calculations presented here should be interpreted independently from those earlier stability assessments.

7. Remuneration and value stacking

A remuneration architecture can explicitly price capacity maintained in reserve, energy actually delivered upon activation, and the quality of the response. A technology-agnostic representation is:

$$P_{service} = C_{avail}A + C_{act}E_{act} + C_{perf}K_{perf} - C_{deg} - P_{pen} \quad (5)$$

where A denotes the reserved capacity, E_{act} the energy delivered when activated, and K_{perf} a performance index. The final two terms capture the degradation cost allocated to the service, C_{deg}, and any applicable penalties, P_{pen}. This additive decomposition permits distinct compensation for availability and for activated energy, while transparently incorporating performance-based adjustments. Scope of the historical stability results.

Value component	Payment basis	Main risk	Proposed safeguard
Availability	Qualified MW or MVA _r	Overcommitment	Periodic testing + measured availability
Activation	Activated MWh / MVA _r h	Disputed baseline	Ex ante baseline + telemetry
Performance	Tracking / response score	Poorly calibrated metric	Public, audited formula
Degradation	Throughput / equivalent cycles	Underestimated ageing	Explicit allocation to the service
Penalty	Deviation from commitment	Double penalty	Cap and transparent rules

7.1. Compatibility matrix for value stacking

Service 1 / Service 2	Frequency	Fast reserve	Voltage	Renewable firming	Black start
Frequency	—	Conditional	Often P–Q compatible	Conditional	No during a BS commitment
Fast reserve	Conditional	—	Often P–Q compatible	Conditional	No during a BS commitment
Voltage	Often P–Q compatible	Often P–Q compatible	—	Conditional	Conditional
Renewable firming	Conditional	Conditional	Conditional	—	No during a BS commitment
Black start	No	No	Conditional	No	—

“Conditional” signifies that any contemplated concurrent activations are contingent upon prior verification of available margins in real power, energy, state of charge, and apparent power. Provision of black-start service typically necessitates a dedicated SOC reserve and precedence over all commercial commitments.

8. Measurement qualification and settlement

KPI	Operational definition	Unit	Use
Availability	Qualified time / contractual time	%	Capacity payment
Response time	Command → agreed threshold crossed	s	Qualification / performance
Tracking error	Setpoint–measurement deviation	MW or %	Performance bonus/penalty
Activated energy	$\int P(t) dt$ during activation	MWh	Activation settlement
Reactive capability	Q supplied/absorbed at a given voltage	MVar	Voltage support
Safety SOC	Margin before and after activation	%	Commitment reliability
Throughput	$\int P(t) dt$ over the period	MWh	Degradation
Success rate	Compliant activations / requested activations	%	Ongoing qualification

The qualification campaign delineates the practicable operating envelope the installation can deliver, whereas settlement calculates remuneration strictly from measured delivery.

At a minimum, the qualification protocol shall evaluate real-power capability, response to step changes, setpoint-tracking fidelity, reactive-power capacity, the ability to sustain output over the contracted interval, post-fault recovery performance, and independent verification of

state of charge. Black-start capability shall be demonstrated through a dedicated test.

For settlement, telemetry must include precise timestamps with strict time synchronisation, and the operational baseline must be defined and mutually agreed prior to activation. The procedure must also codify the treatment of missing data and the auditing mechanisms that enable independent verification of results.

9. Proposed validation protocol

Scenario	Event	Comparison	Main outputs	Decision criterion
F1	Reference PV fluctuation	Without / with BESS	Ramp, error, SOC, throughput	Ramp reduction and SOC compliance
F2	Severe generation loss	Without / with BESS	RoCoF, nadir, recovery, MW	Improved dynamics without saturation
F3	Interconnection weakening/loss	Without / with BESS	Frequency, flows, SOC	Local resilience
F4	Simultaneous P–Q request	P only / P+Q	P, Q, S, voltage	Compliance with S_{rated}
F5	Stacked services	One / multiple services	Revenue, SOC, unavailability	No double counting

Results intended for publication for F2 and F3 shall be derived either from an operator-approved analytical model or from tests conducted with comprehensive instrumentation. Each data record must include frequency, active and reactive power, voltage, state of charge, control setpoints, availability status, and alarm indicators. Time windows before and after each event are required to establish a robust and defensible operational

baseline.

10. DISCUSSION

Separating instantaneous deliverable power from the duration over which it can be sustained has direct consequences for reserve procurement. A 10 MW response can materially stabilize the system in the first seconds or minutes of a disturbance while remaining

insufficient to cover the full contingency. Its persistence depends on active state-of-charge management; any contract that secures capacity without specifying replenishment provisions risks non-delivery at dispatch. Cross-border transactions add further constraints. Although the OMVS and OMVG interconnections contribute to system balancing, reserves obtained via these ties cannot fully replace domestic reserves when the credible contingency is the loss of the interconnection itself.^[4]

These considerations intensify as the system grows. Senelec forecasts a 2025 peak demand of 1,261 MW against 2,310.5 MW of installed capacity^[5], and the Investment Plan foresees additional BESS deployments alongside new renewable capacity.^[7] Piloting the framework on a single installation would generate the empirical evidence needed to generalize the approach to resources dispersed across multiple grid nodes.

Remuneration must be aligned with the operator's operational needs. Paying solely for activated energy risks undervaluing readiness and response speed, while pure capacity payments without performance verification invite compensation for non-delivery. Unbundling availability, activation, and performance, in line with several international precedents, clarifies measurement and simplifies compliance assessment.^[17–21] The specific design must conform to Senegalese regulation and rely on measurements that can be obtained with high reliability.

10.1. Implications for designing a Senegalese pilot

- Prioritize services with unambiguous measurement and verification, notably fast reserves, frequency regulation, and voltage support;
- Specify for each service a minimum sustainment duration, a conservative state-of-charge threshold, and explicit replenishment rules;
- Apply a uniform, technology-neutral qualification process to comparable resources;
- Remunerate availability and activated energy separately, with adjustments indexed to verified performance;
- Include test scenarios covering interconnection loss and concurrent active and reactive power requests;
- Register all commitments to preclude double counting of MW and MWh;
- Recalibrate reserve requirements using the operator's time-series measurements.

10.2. Limitations

The data currently available do not support deriving capacity or activation prices, nor the sizing of an ancillary-services market. They also do not allow credible estimation of the 2025 grid's frequency nadir, RoCoF, or the annual economic value attributable to Walo Storage. Producing such estimates would require operator time-series data, a validated dynamic model, detailed battery cost information, and pertinent

contractual terms. The efficiency and state-of-charge parameters used herein are illustrative. Subsequent work should employ load and renewable-generation time series to co-simulate generation, the network, and the BESS, followed by on-site qualification tests.

11. CONCLUSION

Rising demand, expanding renewable generation, the first BESS commissioning, and planned investments collectively provide a solid foundation for piloting battery-based ancillary services in Senegal.^[5–7] This study proposes measurable products with explicit limits on power, energy, state of charge, and apparent power, and outlines a remuneration structure in which availability, activation, and performance constitute distinct obligations.

Relative to the historical benchmarks examined, a 10 MW BESS offers a partial contribution, with the achievable sustainment time determined by its initial state of charge. Procurement must therefore integrate energy management and coordination with complementary flexibility resources. An instrumented pilot should validate the proposed qualification criteria, telemetry requirements, commitment tracking, and settlement rules, accompanied by publication of the resulting performance indicators. Such evidence is necessary before these preliminary calculations can support a rigorous operational and economic appraisal.

REFERENCES

1. République du Sénégal. Loi n°2021-31 du 9 juillet 2021 portant Code de l'électricité. Journal officiel, 2021.
2. Ministère de l'Énergie, du Pétrole et des Mines. Arrêté n°002168 du 05 février 2025 portant approbation de modèles de cahiers des charges associés aux licences de production, d'autoproduction ou de vente de surplus et de stockage d'énergie électrique.
3. MCC Senegal / Dalberg. Storage & Ancillary Services Market Assessment: Approach & Methodology Overview, 2019.
4. Power Africa Transactions and Reforms Program (PATRP) / Tetra Tech ES. Rapport de fonctionnement et de stabilité du réseau 2017–2035. 2017.
5. Senelec. Rapport Annuel Mouvements d'Énergie – Année 2025. Direction Exploitation du Système et des Achats, Dakar, 2026.
6. Ministère de l'Énergie, du Pétrole et des Mines, DPSE. Rapport du Système d'Information Énergétique du Sénégal 2025 – bilan énergétique 2024. Dakar, 2025.
7. ENERCAP / Ministère de l'Énergie, du Pétrole et des Mines. Plan d'Investissement de la Transition énergétique juste du Sénégal – Livrable L4. Version, 2025.
8. Tractebel Engineering / Senelec. Étude stratégique pour l'intégration des énergies renouvelables dans le

- mix énergétique et définition d'un planning et d'une stratégie d'implantation. Rapport final provisoire, 2015.
9. UEMOA / IFDD. Atlas de l'énergie dans l'espace UEMOA. Rapport, 2020.
 10. UEMOA / IFDD. Chiffres clés sur l'énergie au Sénégal et dans l'espace UEMOA. Rapport, 2019.
 11. International Energy Agency. Clean Energy Transitions in the Sahel: Mobilising Resources, Maximising Potential and Accelerating the Role of Energy for Development. Paris: IEA, 2021.
 12. Zakeri B, Syri S. Electrical energy storage systems: A comparative life cycle cost analysis. *Renewable and Sustainable Energy Reviews*, 2015; 42: 569–596. doi:10.1016/j.rser.2014.10.011.
 13. Luo X, Wang J, Dooner M, Clarke J. Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Applied Energy*, 2015; 137: 511–536. doi:10.1016/j.apenergy.2014.09.081.
 14. Dunn B, Kamath H, Tarascon JM. Electrical energy storage for the grid: a battery of choices. *Science*, 2011; 334(6058): 928–935. doi:10.1126/science.1212741.
 15. Divya KC, Østergaard J. Battery energy storage technology for power systems—An overview. *Electric Power Systems Research*, 2009; 79(4): 511–520. doi:10.1016/j.epsr.2008.09.017.
 16. Oudalov A, Chartouni D, Ohler C. Optimizing a battery energy storage system for primary frequency control. *IEEE Transactions on Power Systems*, 2007; 22(3): 1259–1266. doi:10.1109/TPWRS.2007.901459.
 17. Federal Energy Regulatory Commission. Order No. 755: Frequency Regulation Compensation in the Organized Wholesale Power Markets. Washington, DC, 2011.
 18. Federal Energy Regulatory Commission. Order No. 841: Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators. Washington, DC, 2018.
 19. Denholm P, Ela E, Kirby B, Milligan M. The Role of Energy Storage with Renewable Electricity Generation. NREL/TP-6A2-47187. National Renewable Energy Laboratory, 2010.
 20. Denholm P, Nunemaker J, Gagnon P, Cole W. The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States. NREL/TP-6A20-74184. National Renewable Energy Laboratory, 2019.
 21. International Renewable Energy Agency. Electricity Storage and Renewables: Costs and Markets to 2030. Abu Dhabi: IRENA, 2017.
 22. International Energy Agency. Batteries and Secure Energy Transitions. Paris: IEA, 2024.
 23. Mongird K, Viswanathan V, Balducci P, et al. An Evaluation of Energy Storage Cost and Performance Characteristics. *Energies*, 2020; 13(13): 3307. doi:10.3390/en13133307.
 24. Hesse HC, Schimpe M, Kucevic D, Jossen A. Lithium-ion battery storage for the grid—A review of stationary battery storage system design tailored for applications in modern power grids. *Energies*, 2017; 10(12): 2107. doi:10.3390/en10122107.
 25. Stroe DI, Knap V, Swierczynski M, Stroe AI, Teodorescu R. Operation of a grid-connected lithium-ion battery energy storage system for primary frequency regulation: A battery lifetime perspective. *IEEE Transactions on Industry Applications*, 2017; 53(1): 430–438.
 26. Xu B, Oudalov A, Ulbig A, Andersson G, Kirschen DS. Modeling of lithium-ion battery degradation for cell life assessment. *IEEE Transactions on Smart Grid.*, 2018; 9(2): 1131–1140.
 27. European Network of Transmission System Operators for Electricity (ENTSO-E). Network Code on Load-Frequency Control and Reserves / System Operation framework. Brussels.
 28. North American Electric Reliability Corporation (NERC). BAL-003 Frequency Response and Frequency Bias Setting. Atlanta, GA.