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Metric-Governed Multi-Resource Resilience Planning for Western Libya Network: Coordinated Storage, Demand Response, Frequency Support, and Restoration

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Abstract:
This paper presents is an extension of a doctoral dissertation proposal a Hybrid Neural Forecasting–Resilience-Oriented Load Management (HNF − ROLM) framework for Western Libya, coupling load-forecast uncertainty with battery storage, demand response, network screening, and restoration assessment. In the reported 2023-data experiment, HNF − ROLM achieved a root mean square error of 170.91 MW, 1.86% below persistence, while persistence retained lower absolute and percentage errors. A coordinated resource package reduced illustrative N − 1 loading from 116.10% to 98.85% and equivalent losses from 147.82 to 138.20 MW. In the declared restoration scenario, equivalent energy not supplied fell from 19,676.97 to 13,886.15 MWh, the resilience index increased from 0.58375 to 0.70625, and modeled recovery shortened from eight to six hours. The minimum simulated frequency over 20 s increased from 49.018 to 49.876 Hz. These

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results quantify the framework's forecast-to-action benefits within the stated experimental and functional-equivalent assumptions.
Keywords: Power-system resilience; hybrid load forecasting; battery energy storage; demand response; service restoration.

التخطيط المرن متعدد الموارد الخاضع للمعايير لشبكة غرب ليبيا: تخزين منسّق، والاستجابة للطلب، ودعم التردد، والاستعادة

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الملخص

تقدم هذه الورقة البحثية، وهي امتداد لمقترح أطروحة دكتوراه، إطار عمل هجين للتنبؤ العصبي الهجين وإدارة الأحمال الموجّهة نحو المرونة (HNF–ROLM) لشبكة غرب ليبيا، إذ يربط عدم يقين التنبؤ بالأحمال بالتخزين بالبطاريات والاستجابة للطلب وفحص قيود الشبكة وتقييم استعادة الخدمة. في التجربة الواردة بالورقة والمستندة إلى بيانات 2023، بلغ جذر متوسط مربع الخطأ 170.91 ميجاوات، بانخفاض 1.86% مقارنة بنموذج الاستمرارية، بينما حقّق نموذج الاستمرارية أخطاء مطلقة ونسبية أقل. وخفّضت حزمة الموارد المنسّقة التحميل التوضيحي عند فقدان عنصر واحد من 116.10% إلى 98.85%، والفاقد المكافئ من 147.82 إلى 138.20 ميجاوات. وفي سيناريو الاستعادة المعلن، انخفضت الطاقة غير المورّدة المكافئة من 19,676.97 إلى 13,886.15 ميجاوات ساعة، وارتفع مؤشر المرونة من 0.58375 إلى 0.70625،

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وتقلّص زمن التعافي المحاكي من ثماني ساعات إلى ست ساعات. كما ارتفع أدنى تردد محاكى خلال 20 ثانية من 49.018 إلى 49.876 هرتز. وتُكمّم هذه النتائج فوائد الربط بين التنبؤ والإجراء ضمن افتراضات التجربة والنموذج المكافئ المعلنة.

الكلمات المفتاحية: مرونة نظم القدرة؛ التنبؤ الهجين بالأحمال؛ تخزين الطاقة بالبطاريات؛ الاستجابة للطلب؛ استعادة الخدمة.

1. Introduction

Resilience is treated here as the ability to anticipate a disturbance, withstand its initial impact, restore prioritized service, and adapt after the event; this is broader than steady-state reliability and requires explicit time-dependent service metrics [1].

Modern power systems increasingly depend on flexible demand, storage, renewable generation, and stronger grids. For Western Libya, these resources are valuable only when their uncertainty, energy limits, communications, and protection interactions are represented in the operating decision [2]. Recent distribution-resilience research demonstrates that coordinated flexible resources can outperform isolated interventions, motivating a portfolio rather than a single-device solution [3]. Two-stage resilience formulations also distinguish preparedness from post-event recovery [4]. This paper adopts that separation by pre-positioning reserve and then evaluating an explicit restoration trajectory. Frequency-constrained microgrid formation confirms that restoration sequences must respect dynamic limits and available grid-forming support, not merely reconnect the largest load block [5]. Systematic evidence on coordinated restoration highlights topology verification, communication readiness, switching feasibility, and crew actions as indispensable layers beyond an optimization result [6]. Metric-driven restoration is particularly useful for an operator because each candidate action can be evaluated by restored power, restored energy, and recovery time instead of an opaque score [7].

Grid-forming storage can strengthen black-start and restoration, but transient feasibility must be checked [8]. The present work therefore treats the frequency trace as a screening layer and does not substitute it for EMT or relay studies.

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Battery placement and sizing affect frequency support and network losses; hence the proposed 120 MW/480 MWh resource is a planning candidate at the coastal load-generation interface, subject to a full siting study [9]. Degradation-aware operation is necessary because resilience reserve that is kept permanently full or cycled indiscriminately can impose avoidable lifetime cost. A 15–95% operational SOC band is consequently enforced [10].
$N-1$ analysis remains a minimum-security screen. The workflow rejects any action packet that leaves a modeled element above its emergency loading limit, even when the aggregate energy balance appears adequate [11]. PV-plus-storage coordination provides a practical route to reduce evening stress, but the technology portfolio must be checked against local irradiance, interconnection, reactive-power, and protection requirements [12]. Restoration in an active distribution network must also respect AC voltage and thermal limits [13]. This paper expresses those requirements as hard acceptance gates rather than post-processing observations. Energy-preserving load shifting avoids claiming demand reduction when consumption is only moved in time [14]. The proposed demand-response block is therefore constrained to zero net shifted energy over 24 h.

2. Objectives

The first objective is to create a traceable evidence hierarchy for a data-limited regional system. The second is to couple forecast uncertainty to an actual reserve request instead of presenting forecasting and control as unrelated modules. The third is to test a practical resource stack through voltage, loading, energy, and frequency gates. The fourth is to quantify restoration using ENS, RI, and recovery time while stating that these are counterfactual study outputs, not observed interruption statistics.

The study audits the dates in the 2023 Western-region dataset, links a hybrid load forecast to a one-sided reserve margin, and allocates battery storage, demand response, and conditional transfer headroom in a stated merit order. A standalone MATLAB companion documents the calculations and exports result tables.

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Figure 1 shows evidence-constrained forecast-to-action resilience workflow.

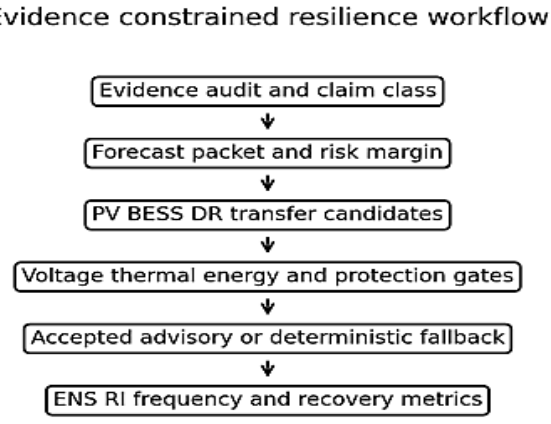

Figure 1. Proposed evidence-constrained forecast-to-action resilience workflow (developed in this study).

3. Western-Libya Data

The governed source dated Western-region records for 2023 of the 365-day calendar. It includes daily minimum, maximum, and mean load and generation plus temperature bounds [15]. Table 1 summarises the governed 2023 data anchors.

Table 1. Governed 2023 Data Anchors [15]

Quantity	Value	Evidence class
Unique dated records	251 (68.8%)	Measured file coverage
Mean of available daily means	4224.43 MW	Measured aggregation
Annual maximum load	6337 MW, 31 Jul	Measured record
Annual maximum generation	6355 MW, 26 Aug	Measured record; non-synchronous
Available August dates	1 and 12–31 Aug	Measured availability
Missing event window	2–11 Aug	Governance finding

Figure 2 shows monthly statistics computed only from available 2023 records.

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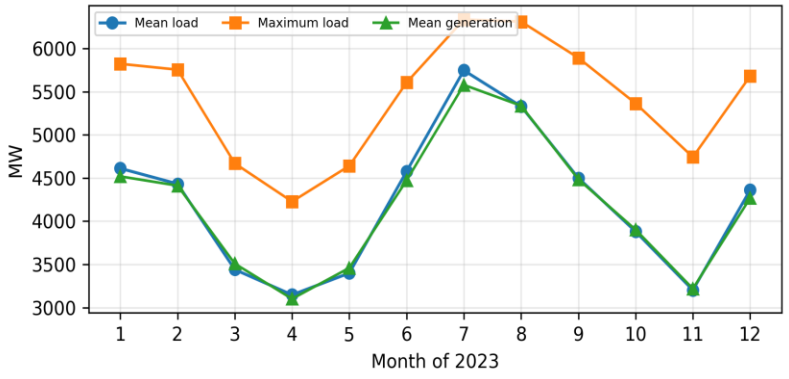

Figure 2. Monthly statistics computed only from available 2023 records (author's aggregation of the operating data in [15]).

3.1. Blackout-Anchored Evidence Boundary

A report dated 9 August 2023 quoted the GECOL spokesperson on technical tests involving a new 400 kV South Tripoli circuit and the start of power restoration [16]. The 251-record source snapshot described in this paper contains no record for that date, consistent with the disclosed 2–11 August gap. The report therefore establishes event context only; it does not supply the initiating contingency, trip sequence, frequency nadir, ENS, or restoration duration used in the modeled scenarios.

Figure 3 shows available August records and the disclosed 2–11 August data gap.

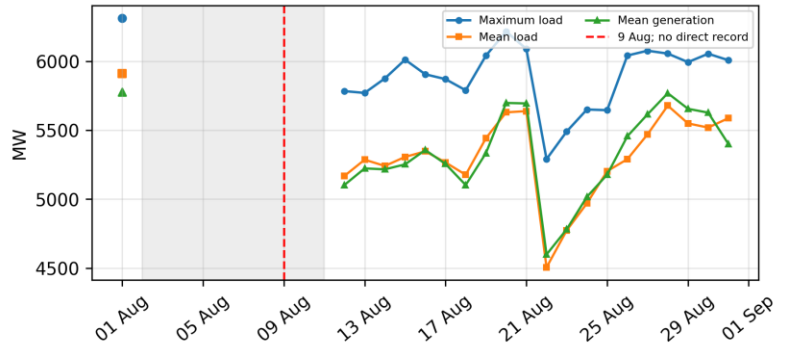

Figure 3. Available August records and the disclosed 2–11 August data gap.

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Table 2 summarizes the claim and validation ledger.

TABLE 2. CLAIM AND VALIDATION LEDGER

Claim class	Permitted interpretation	Required next validation
Measured	Directly present in supplied file	Source-owner confirmation
Reproducible experiment	Derived by documented code and split	Independent rerun
Designed screen	Functional-equivalent planning scenario	AC/EMT model calibration
Public context	Date and broad reported statement	Official event report
Deployment claim	Not made in this paper	Pilot and acceptance test

4. Forecast-to-Action Framework and Computational Procedure

4.1. Combined Hybrid Forecast

Equation (1) uses the weighted forecast-combination principle [17]. In this study, persistence, ridge − ARX, and a deterministic fixed-basis neural learner are combined; nonnegative weights summing to one are selected on validation data.

$$\hat{P}_r^{\mathrm{HNF}} = w_p \hat{P}_r^{p} + w_a \hat{P}_r^{a} + w_f \hat{P}_r^{f}, \quad w_p + w_a + w_f = 1 \quad (1)$$

Where:

- r: index of available records.
- $\hat{P}_r^{\mathrm{HNF}}$: final hybrid forecast for record r.
- $\hat{P}_r^{p}$: persistence forecast.
- $\hat{P}_r^{a}$: ridge − ARX forecast.
- $\hat{P}_r^{f}$: deterministic fixed-basis neural learner forecast.
- w_p, w_a, w_f: weights assigned to the three forecast components, and they are equal to $(0.68, 0.00, 0.32)$ respectively.

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4.2. One-Sided Reserve Margin

Following forecast-error-based reserve sizing [18], Eq. (2) defines this study's empirical one-sided margin as the 95th percentile of validation residuals clipped at zero. Only under-forecast errors contribute to upward reserve; the exact clipped-residual rule is the present implementation.

$$q_{0.95}^{+} = Q_{0.95}\left(\max\left(P_t - \hat{P}_t^{\mathrm{HNF}}, 0\right)\right) \quad (2)$$

Where:

- $q_{0.95}^{+}$: one-sided upward reserve margin (95th percentile), where it is equal to: 232.18 MW.
- $Q_{0.95}$: the 95th percentile operator.
- P_t: actual value at time/record t.
- $\hat{P}_t^{\mathrm{HNF}}$: hybrid forecast at time/record t.
- max(·, 0): positive part function, ensuring only positive residuals are considered.

4.3. Normalization and Request Allocation

Equation (3) is the study's proposed load-proportional scaling of the margin in Eq. (2), rather than a borrowed equation. It uses only the mean validation forecast, avoiding held-out-horizon look-ahead. Requests are allocated sequentially to:

1. BESS (Battery Energy Storage System)
2. DR (Demand Response)
3. Conditional transfer allowance

$$R_r = q_{0.95}^{+} \cdot \frac{\hat{y}_r}{\bar{y}_{\mathrm{val}}} \quad (3)$$

Where:

- R_{r}: flexibility/reserve request for the resource in record r, in MW. The reported range is 171.04–270.63 MW.
- q^{95+}: positive-residual margin = 232.18MW.
- $\hat{y}_r$: current forecast.
- $\bar{y}_{\mathrm{val}}$: mean validation forecast = 4043.67MW.

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4.4. Action Packet

Candidate actions are assembled as an ordered packet: up to 120 MW from BESS, up to 70 MW from controllable or shiftable demand, up to 100 MW from a transfer allowance subject to topology and rating validation, and only then prioritized shedding. A packet is released as an advisory only when all network and energy gates pass; otherwise, it is repaired and re-solved or replaced by a conservative rule-based fallback.

$$A = 1\{V_{\min} \geq V_{\lim},\ L_{\max} \leq 100\%,\ E_{\min} \leq E_t \leq E_{\max}\} \quad (4)$$

In Eq. (4), A is a binary network-and-energy acceptance indicator and $1\{\cdot\}$ is the indicator function. Vmin is the minimum bus voltage and Vlim its declared lower threshold (per unit); Lmax is the largest element loading (% of rating); and Et is stored battery energy, bounded by Emin and Emax (MWh). For a 480 MWh battery at 15–95% state of charge (SOC), these bounds are 72 and 456 MWh. Protection compatibility is checked separately before advisory release. Equation (4) is the study's proposed acceptance rule; an overall pass requires an explicitly specified Vlim.

4.5. Resilience Metrics

$$\mathrm{ENS} = P_{\mathrm{ref}} \int_0^T [1 - Q(t)]\ \mathrm{d}t \quad (5)$$

Equation (5) is interpreted as follows. Q(t) is normalized served load and Pref = 5909 MW is the available 1 August mean-load anchor. ENS is an equivalent counterfactual energy deficit, not a utility-reported event ENS.

$$\mathrm{RI} = \frac{1}{T} \int_0^T Q\ (t)\ \mathrm{d}t \quad (6)$$

Equation (6) is interpreted as follows. RI is the mean normalized service over the declared eight-hour restoration horizon.

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4.6. Matlab Data Input and Result Generation

The companion is invoked as results = run_Libya_Network_Revision.

Its default mode checks the reported-table arithmetic and solves an independent IEEE 33-bus load-flow benchmark. The original 251-record extraction, training configuration, and Western network model were not supplied with the manuscript; the reported scores are therefore retained rather than relabeled as a new rerun.

A separately labeled updated 2023 mode embeds the numeric transcription used by the existing reviewed-thesis companion for a consolidated 365-date archive and performs a new 60/20/20 chronological forecasting experiment. Predictors use exact-date load lags of 1 and 7 days, previous-day temperature, and calendar terms; the archive's temperature input is the midpoint of reported daily minimum and maximum temperatures. Scaling and model coefficients use training data only; hybrid weights and the 95th-percentile upward margin use validation data only. CSV/XLSX import requires Date (yyyy-MM-dd), LoadMeanMW, and Temperature Columns.

Save the file in a writable folder and run results = run_Libya_Network_Revision in MATLAB.

To use the embedded archive, run results = run_Libya_Network_Revision('updated2023'); to import data, pass the CSV/XLSX path as the first argument. Tables, figures, and an execution log are saved in a timestamped Libya_Revision folder. Published-value checks and new forecasts are labeled separately; the computational scenarios are not field measurements.

5. Results and Discussion

5.1. Forecast Accuracy and Coupled Reserve

Table 3 summarizes held-out daily forecast results.

Table 3. Held-Out Daily Forecast Results

Method	MAE MW	RMSE MW	MAPE %
Persistence	98.42	174.16	2.551
Ridge-ARX	111.37	177.12	3.016

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Method	MAE MW	RMSE MW	MAPE %
Fixed-basis FFNN	187.76	227.58	5.081
HNF – ROLM	107.17	170.91	2.787

HNF – ROLM improves RMSE by 1.86% relative to persistence but has 8.89% higher MAE and 9.24% higher MAPE. The conclusion is metric-specific: the hybrid better suppresses large squared errors on this split, whereas persistence is the preferable point baseline under absolute-error criteria.

Figure 4 shows chronological held-out forecasts against observed daily mean load.

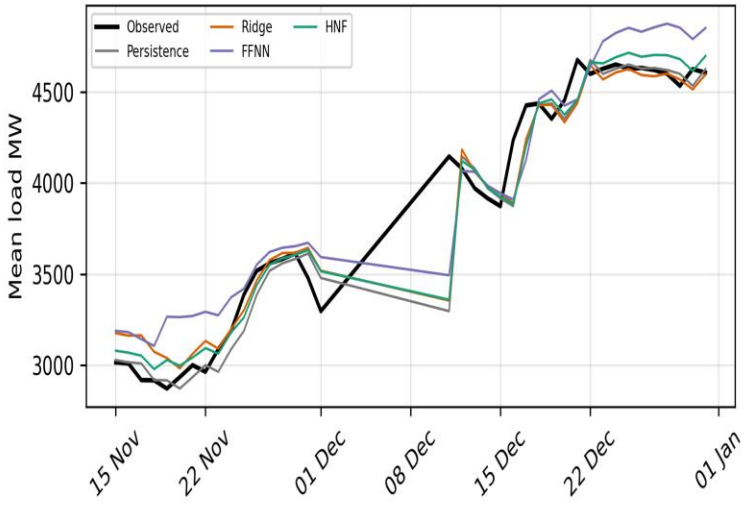

Figure 4. Chronological held-out forecasts against observed daily mean load.

Figure 5 shows forecast-risk reserve translated into feasible resource commitments.

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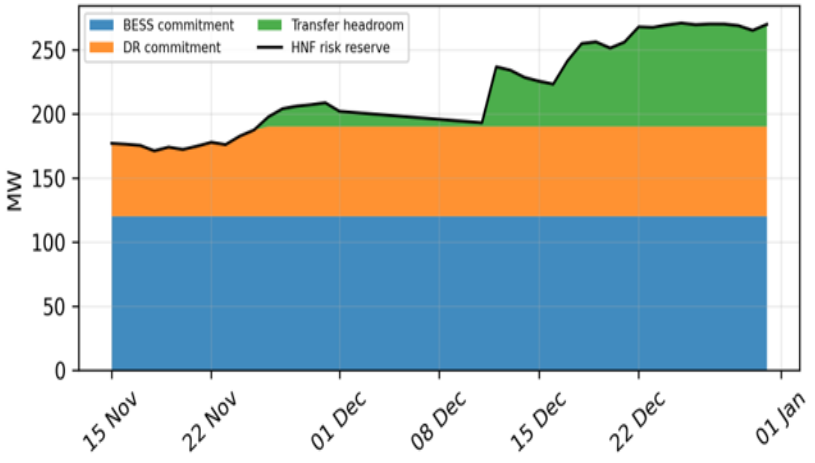

Figure 5. Forecast-risk reserve translated into feasible resource commitments.

5.2. Network and Frequency

Table 4 summarizes designed western functional-equivalent screen.

Table 4. Designed Western Functional-Equivalent Screen

Case	Vmin p.u.	Loss MW	Loading %	Decision
Peak	0.91644	147.82	102.17	Fails threshold
N − 1	0.91644	147.82	116.10	Fails threshold
Voltage sag	0.90824	175.06	111.14	Fails threshold
BESS + DR	0.91810	141.14	100.03	Fails threshold
Full stack	0.91854	138.20	98.85	Meets threshold

The full packet reduces the designed N − 1 overload by 17.25 percentage points, equivalent to 14.86% relative improvement, and lowers the equivalent loss by 9.62 MW. BESS plus DR alone remains 0.03 percentage points above the thermal gate and is therefore rejected despite its near-feasible appearance.

Figure 6 shows the maximum-loading gate for the designed Western functional-equivalent cases.

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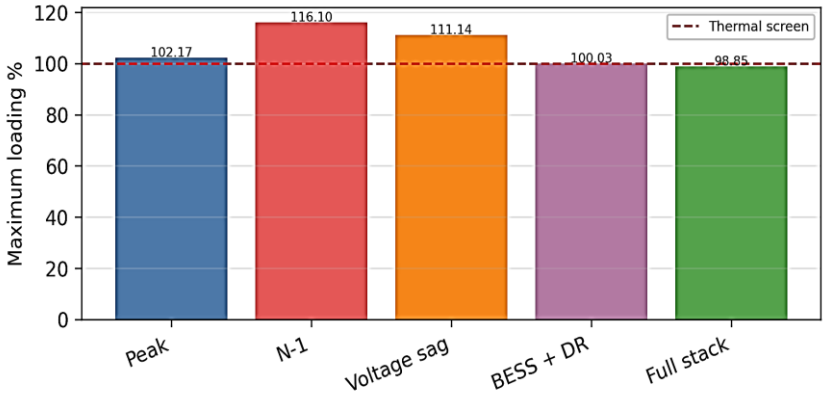

Figure 6. Maximum-loading gate for the designed Western functional-equivalent cases.

In the aggregate 20 s frequency screen, the minimum observed within the window rises from 49.018 to 49.876 Hz, an 87.40% reduction in frequency drop from nominal. The maximum initial RoCoF remains 0.15625 Hz/s in both cases because the modeled BESS response begins after 0.10 s; the study therefore does not claim inertial improvement.

Figure 7 shows aggregate frequency screening trace; minimum refers to the 0–20 s window

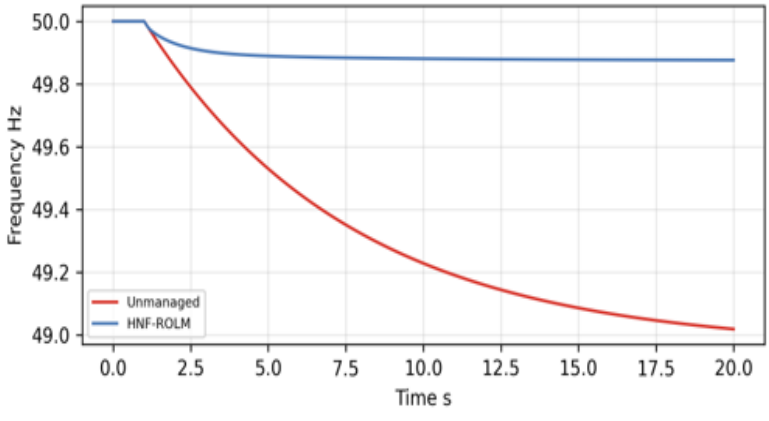

Figure 7. Aggregate frequency screening trace; minimum refers to the 0–20 s.

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5.3. Restoration Counterfactual

Table 5 summarizes restoration counterfactual.

Table 5. Restoration Counterfactual

Strategy	ENS MWh	RI	Recovery h
Baseline	19,676.97	0.58375	8
FFNN guided	16,249.75	0.65625	7
HNF – ROLM	13,886.15	0.70625	6

Relative to the declared baseline, the HNF-guided trajectory avoids 5790.82 MWh of equivalent unserved energy, reduces ENS by 29.43%, improves RI by 20.99%, and shortens recovery by 25.00%. These values are conditional on the stated service curves and Pref and must not read as historical event measurements.

Figure 8 shows declared restoration trajectories used in the counterfactual comparison.

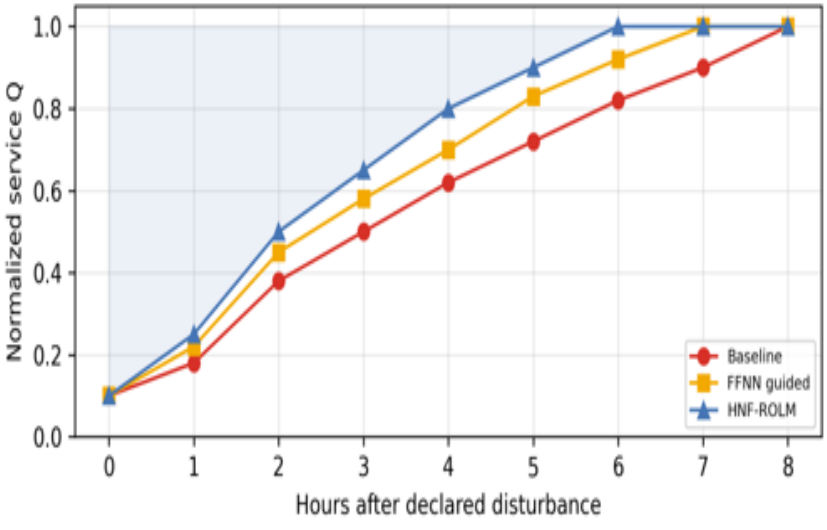

Figure 8. Declared restoration trajectories used in the counterfactual comparison.

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Figure 9 shows equivalent ENS and resilience-index comparison.

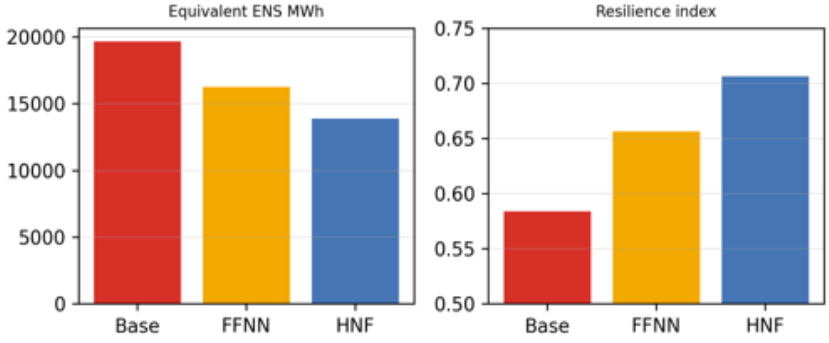

Figure 9. Equivalent ENS and resilience-index comparison

6. Practical Implementation

A pilot should be deployed in four stages. First, establish time-synchronized telemetry for 400/220/66/30 kV interfaces, generator availability, feeder demand, breaker status, frequency, voltage, and BESS SOC. Second, calibrate a state-estimation and contingency model against seasonal snapshots. Third, run HNF − ROLM in advisory shadow mode and compare every proposed packet with dispatcher actions. Fourth, permit closed-loop operation only after cyber-security, fail-safe, relay-coordination, and human-factor acceptance tests.

Table 6 summarizes operator packet by decision horizon.

Table 6 Operator Packet by Decision Horizon

Horizon	Primary update	Operator use
10 min	Telemetry residual and ramp	Fast reserve readiness
1 h	Load/weather and unit state	BESS/DR commitment
24 h	Unit, PV, energy and maintenance	Day-ahead secure schedule
1 week	Fuel, outage and weather envelope	Maintenance/reserve plan
1 month	Seasonal energy and availability	Resource adequacy review
1–15 years	Scenario demand and project pipeline	Planning, not dispatch

7. Limitations

The principal limitations are retrospective rather than forecast temperature, a short, no validated Western bus-branch model, and

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no field BESS or DR response. The Western cases are deliberately labeled functional-equivalent screens. The separate IEEE 33-bus benchmark contained in the executable companion demonstrates the numerical load-flow routine but is not a surrogate for the Libyan topology.

8. Conclusion

The paper delivers an auditable path from regional evidence to a constrained resilience advisory. HNF − ROLM achieved the lowest held-out RMSE, though persistence remained superior under MAE and MAPE. The full flexibility stack, not BESS plus DR alone, meets the declared illustrative N − 1 thermal threshold in the functional-equivalent screen; the restoration counterfactual reduced equivalent ENS by 29.43% and recovery time by 25.00%. These results meet the stated objectives as reproducible engineering evidence, while the explicit claim ledger prevents simulated values from being mistaken for field measurements. The immediate recommendation is a synchronized-data and calibrated-network pilot focused on the coastal interface before operational automation.

References

[1] M. Panteli and P. Mancarella, 'Influence of extreme weather and climate change on the resilience of power systems: Impacts and possible mitigation strategies,' Electric Power Systems Research, vol. 127, pp. 259–270, 2015, doi: 10.1016/j.epsr.2015.06.012. Authors: M. Panteli and P. Mancarella. University or institution: The University of Manchester. Year: 2015. Research field: power-system resilience. Specialty: disturbance impact and mitigation. Journal and issue: Electric Power Systems Research, vol. 127.

[2] International Energy Agency, Electricity 2026, Paris, France, 2026. Available: https://www.iea.org/reports/electricity-2026. Authors: IEA electricity-market and system analysts. Institution: International Energy Agency. Year: 2026. Research field: electricity-system outlook. Specialty: grids, flexibility, demand response, and storage. Publication: IEA annual electricity report.

[3] H. Wang, J. Ge, Y. Zhao, J. Gu, C. Li, and C. Liu, 'Resilience enhancement strategies for distribution networks considering the coordination of 5G base stations and multiple flexible resources,' Scientific Reports, vol. 16, Art. 5481, 2026, doi: 10.1038/s41598-026-35188-z. Institution: Changchun Institute of Technology and Jilin Electric Power Research Institute. Research field: distribution resilience. Specialty: coordinated flexible resources. Journal and issue: Scientific Reports, vol. 16.

[4] L. Huang, M. Wang, and L. Wang, 'Two-stage distribution system resilience improvement strategy considering coordinated scheduling of multiple types of emergency resources,' Electrical Engineering, vol. 108, Art. 348, 2026, doi: 10.1007/s00202-026-03715-w. Institution: College of Electrical and New Energy Engineering and Hubei Provincial Engineering Research Center of Intelligent Energy Technology, China Three Gorges University, Yichang, China. Research field: distribution resilience. Specialty: pre-event positioning and post-event recovery. Journal and issue: Electrical Engineering, vol. 108.

[5] S. Li, T. Yu, Y. Gong, and W. Xiao, 'Frequency-Constrained Dynamic Microgrid Formation Using Distributed Energy Resources and Soft Open Points for Resilient Distribution System,' IET Renewable Power Generation, vol. 20, no. 1, Art. e70268, 2026, doi: 10.1049/rpg2.70268. Institution: South China University of Technology. Research field: resilient distribution operation. Specialty: frequency-constrained black-start and dynamic microgrid formation. Journal and issue: IET Renewable Power Generation, vol. 20, no. 1.

[6] P. Eisenkraemer et al., 'A Systematic Review on Coordinated Restoration Strategies for Power Distribution Grids,' IEEE Access, vol. 14, pp. 30702–30725, 2026, doi: 10.1109/ACCESS.2026.3667471. Institution: affiliations are identified in the cited IEEE publisher record; no unaudited institutional expansion is inferred here. Research field: distribution-system restoration. Specialty: coordinated restoration and resilience assessment. Journal and issue: IEEE Access, vol. 14.

[7] S. Sajwan, B. K. Panigrahi, and A. K. Srivastava, 'DER-based power and energy restoration for distribution system resilience: a metric-driven approach,' Environment Systems and Decisions, vol. 46, Art. 45, 2026, doi: 10.1007/s10669-026-10112-y. Institution: Indian Institute of Technology Delhi and West Virginia University. Research field: distribution resilience. Specialty: metric-driven power and energy restoration. Journal and issue: Environment Systems and Decisions, vol. 46.

[8] D. Wang, T. Ding, Y. Li, W. Jia, Y. Ding, and X. Wang, 'An Iterative Transient-Constrained MILP Model for Black-Start Restoration Leveraging Grid-Forming Energy Storage to Enhance Resilience,' IET Generation, Transmission & Distribution, vol. 20, no. 1, Art. e70419, 2026, doi: 10.1049/gtd2.70419. Institution: Xi'an Jiaotong University and State Grid Qinghai organizations. Research field: restoration. Specialty: transient-constrained black start with grid-forming storage. Journal and issue: IET Generation, Transmission & Distribution, vol. 20, no. 1.

[9] L. Ngoma, J. Munda, and Y. Hamam, 'Power System Frequency Response Enhancement Using Optimal Placement and Sizing of Battery Energy Storage Systems,' Energies, vol. 19, no. 10, Art. 2278, 2026, doi: 10.3390/en19102278. Institution: Tshwane University of Technology and ESIEE. Research field: frequency response. Specialty: BESS siting and sizing. Journal and issue: Energies, vol. 19, no. 10.

[10] X. Xue and Y. Xu, 'Data-Driven Microgrid Operation Toward Optimized Battery Energy Storage Lifetime Degradation,' IEEE Transactions on Smart Grid, vol. 17, no. 4, pp. 2682–2692, 2026, doi: 10.1109/TSG.2026.3660273. Institution: Nanyang Technological University. Research field: microgrid operation. Specialty: degradation-aware battery control. Journal and issue: IEEE Transactions on Smart Grid, vol. 17, no. 4.

Metric-Governed Multi-Resource Resilience Planning for Western Libya Network: Coordinated Storage, Demand Response, Frequency Support, and Restoration
http://www.doi.org/10.62341/istj-vol39-2-ma39

[11] W. Jin, S. Li, K. He, H. Chang, X. Zhao, X. Ling, J. Hu, and J. Zhang, 'N − 1 Security-Constrained 8760-Hour Power Flow Generation Method for New-Type Power Systems,' Energies, vol. 19, no. 13, Art. 3086, 2026, doi: 10.3390/en19133086. Institution: State Grid Central China and South China University of Technology. Research field: security assessment. Specialty: N − 1 verification and reoptimization. Journal and issue: Energies, vol. 19, no. 13.

[12] I. Pizzuti and G. Delibra, 'Integration of battery energy storage systems in renewable energy communities: Optimal configurations and strategies,' Journal of Energy Storage, vol. 153, Part B, Art. 120857, 2026, doi: 10.1016/j.est.2026.120857. Institution: Sapienza University of Rome. Research field: energy storage. Specialty: PV-BESS configuration and scheduling. Journal and issue: Journal of Energy Storage, vol. 153, Part B.

[13] J. Soni and A. Giri, 'Multi-objective thermal-constrained service restoration in active distribution networks with distributed energy resources using artificial protozoa optimization,' Discover Electronics, vol. 3, Art. 98, 2026, doi: 10.1007/s44291-026-00248-1. Institution: School of Electrical Engineering, Shri Mata Vaishno Devi University, Katra, Jammu and Kashmir, India; and Department of Electrical Engineering, Government Engineering College Bharuch, Gujarat, India. Research field: active-distribution restoration. Specialty: full-AC thermal-constrained restoration. Journal and issue: Discover Electronics, vol. 3, Art. 98.

[14] H. Ahn, J. Park, and C. Ok, 'A SMP-Based Load Shifting Optimization Model for Voluntary Demand Response in Industrial Complexes,' Electricity, vol. 7, no. 2, Art. 26, 2026, doi: 10.3390/electricity7020026. Institution: Hongik University and VGen. Research field: demand response. Specialty: energy-preserving industrial load shifting. Journal and issue: Electricity, vol. 7, no. 2.

[15] General Electricity Company of Libya (GECOL), "Western-region operating records for 2023," unpublished dataset supplied by the author, 2023. The 251-record extraction cited in this paper has no public repository identifier; its original version is required for exact experiment replication.

[16] Al-Wasat, "GECOL: Technical tests completed and work underway to restore power" [Arabic], Aug. 9, 2023. [Online]. Available: https://alwasat.ly/news/libya/407827. The report quotes the GECOL spokesperson; it is used for event context only.

[17] J. M. Bates and C. W. J. Granger, "The Combination of Forecasts," Journal of the Operational Research Society, vol. 20, no. 4, pp. 451–468, 1969, doi: 10.1057/jors.1969.103.

[18] J. Dowell, G. Hawker, K. Bell, and S. Gill, "A Review of Probabilistic Methods for Defining Reserve Requirements," in Proc. 2016 IEEE Power and Energy Society General Meeting, 2016, doi: 10.1109/PESGM.2016.7741361.