WHITE PAPER

DEPARTMENT OF ENERGY & ENVIRONMENT

ENHANCING ENERGY SECURITY PLAN

Increasing electrification, distributed energy resource deployment, advanced inverter integration, battery energy storage adoption, and climate resilience requirements are rapidly transforming the operational behavior of the District of Columbia's electric distribution system. This white paper examines how high-DER grid conditions, prolonged outage risks, and evolving resilience needs are driving the modernization of distribution system operations across the District. The paper evaluates the role of advanced inverters, DERMS, community microgrids, resilience hubs, intentional islanding, and storage-integrated planning in supporting a resilient, intelligent, and equitable electric grid aligned with DCPSC Formal Cases 1050, 1130, and 1142, as well as the District's broader clean energy and energy assurance objectives.

JULY 2026

Advancing Distribution-Level Energy Security in the District of Columbia

A Strategic Framework for Grid Modernization, Distributed Energy Resources, Cybersecurity, and Resilient Electric Infrastructure

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Executive Summary

The District of Columbia is experiencing rapid transformation of its electric distribution infrastructure driven by electrification, renewable energy deployment, transportation modernization, and increasing digitalization of critical infrastructure systems. Existing Energy Security Plan (ESP) frameworks were primarily developed around centralized restoration models and conventional emergency backup assumptions. While those frameworks remain operationally important, future electric systems will require significantly greater operational coordination capability across distributed infrastructure environments.

The District's clean energy objectives, combined with increasing deployment of distributed solar generation, battery energy storage systems, and electrified infrastructure, are creating new operational conditions across distribution systems. These conditions include bidirectional power flow, telecommunications dependency, dynamic voltage management requirements, and increased reliance upon interoperable operational coordination systems.

At the same time, prolonged outage scenarios associated with severe weather events, aging infrastructure, and cyber-physical operational risks continue increasing vulnerability across urban electric systems. Continuity of healthcare services, emergency communications, transportation systems, government operations, water infrastructure, and affordable housing increasingly depends upon resilient distribution-level operational capability.

This white paper proposes establishment of a Distribution-Level Energy framework designed to support continuity of critical services during prolonged outage conditions lasting 72 hours or longer. The framework integrates advanced inverter operational functionality, battery energy storage deployment, DERMS-enabled coordination, resilience hubs, feeder segmentation capability, cybersecurity governance, operational performance validation, and resilience-oriented utility planning into a coordinated modernization strategy.

The proposed framework aligns with the District Energy Security Plan, Clean Energy DC, Climate Ready DC, Sustainable DC, DCPSC Formal Case No. 1050, Formal Case No. 1130, and Formal Case No. 1142.

The District of Columbia has the opportunity to establish a nationally significant model for urban distribution-level resilience modernization.

Disclaimer

This document is analytical decision-support material prepared to support discussion of energy security, resilience, and grid modernization in the District of Columbia. It does not represent an official DOEE policy, DCPSC order, utility requirement, or IEEE position, and should not be interpreted as establishing regulatory, engineering, or operational requirements.

Acronyms and Technical Terminology

Acronym	Definition
ADMS	Advanced Distribution Management System
AMI	Advanced Metering Infrastructure
BESS	Battery Energy Storage System
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DHS	U.S. Department of Homeland Security
DOEE	District Department of Energy & Environment
EV	Electric Vehicle
FC1050	DCPSC Formal Case No. 1050
FC1130	DCPSC Formal Case No. 1130
FC1142	DCPSC Formal Case No. 1142
GFM	Grid-Forming Inverter
GFL	Grid-Following Inverter
IEEE	Institute of Electrical and Electronics Engineers
IEEE 1547-2018	IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
IEEE 1547.3-2023	IEEE Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems
IEC 62351	International Standard for Power System Communications Security
MW	Megawatt
NERC	North American Electric Reliability Corporation
NWA	Non-Wires Alternative
PSC	Public Service Commission
PV	Photovoltaic
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TLS	Transport Layer Security
VPP	Virtual Power Plant
Volt-VAR	Voltage-Reactive Power Control Function
Volt-Watt	Voltage-Based Real Power Curtailment Function

Introduction

Electric distribution infrastructure throughout the United States is undergoing significant operational transformation. Historically, electric systems were designed around centralized generation resources delivering electricity through one-directional transmission and distribution infrastructure toward passive customer demand. Planning frameworks evolved around these architectures and assumed limited operational interaction between utility systems and customer-side infrastructure.

Modern distribution systems now operate under conditions involving distributed generation, battery storage systems, electric vehicles, intelligent building technologies, flexible loads, and digitally coordinated infrastructure management. These conditions require increased situational awareness, interoperability governance, telemetry integration, and operational coordination capability across utility and customer-connected systems.

The District of Columbia represents an important environment for resilience modernization because of its dense urban infrastructure, ambitious decarbonization objectives, environmental justice priorities, and increasing dependence upon electrified systems supporting healthcare, emergency response, transportation, telecommunications, and government continuity.

Future resilience planning therefore requires modernization beyond conventional emergency preparedness paradigms focused primarily on centralized restoration and diesel backup generation systems.

Distribution-Level Energy Security Plan Gaps

The District's current Energy Security Plan appropriately addresses emergency preparedness, fuel continuity, infrastructure coordination, and emergency response structures. However, several operational gaps remain associated with continuity during prolonged distribution-level outage conditions.

Many critical facilities continue relying heavily upon diesel backup generation systems for emergency continuity. Although these systems remain operationally important, they face limitations associated with fuel delivery dependency, maintenance reliability, finite runtime capability, and operational scalability during extended emergency conditions.

Existing feeder configurations were not originally designed for sustained localized continuity independent from broader restoration timelines. Distribution infrastructure also lacks widespread capability for coordinated feeder segmentation and localized operational sustainment during prolonged outages.

Many distributed energy resources currently operate without sufficient telemetry integration or interoperability with utility operational systems. As a result, existing distributed solar and storage assets may remain unavailable during outage conditions despite installed operational capability.

Current planning frameworks also lack standardized methodologies capable of evaluating outage sustainment capability, infrastructure dependency risk, communications survivability, continuity readiness, and operational prioritization across critical infrastructure systems.

The 72-Hour Distribution-Level Resilience Framework

The proposed 72-hour resilience framework establishes an operational planning construct for sustaining continuity of critical services during prolonged outage conditions.

The 72-hour benchmark reflects a realistic operational threshold during which fuel logistics, telecommunications continuity, transportation access, centralized restoration capability, and emergency coordination systems may experience significant degradation. Federal emergency preparedness exercises consistently identify the first 72 hours following major disruptions as the most operationally critical period for infrastructure continuity and emergency response coordination.

The framework prioritizes continuity of healthcare systems, emergency response operations, telecommunications infrastructure, water and wastewater systems, resilience hubs, government continuity facilities, affordable housing developments, and vulnerable population centers.

The framework assumes varying operational states across the distribution system. Normal operating conditions represent stable grid-connected operations. Constrained emergency operations involve partial feeder outages, coordinated load prioritization, and limited dispatch capability. Prolonged outage operations require feeder segmentation capability, localized sustainment strategies, distributed dispatch coordination, and continuity support for critical infrastructure systems.

This framework establishes measurable operational planning constructs capable of supporting future modernization efforts.

Future distribution-level resilience planning requires coordination across operational analytics, critical infrastructure prioritization, feeder modernization, sequencing deployment, and emergency operational management. The proposed framework illustrated in Figure 1 establishes a structured planning architecture designed to support continuity of critical services during prolonged outage conditions while enabling scalable modernization of distributed operational infrastructure throughout the District.

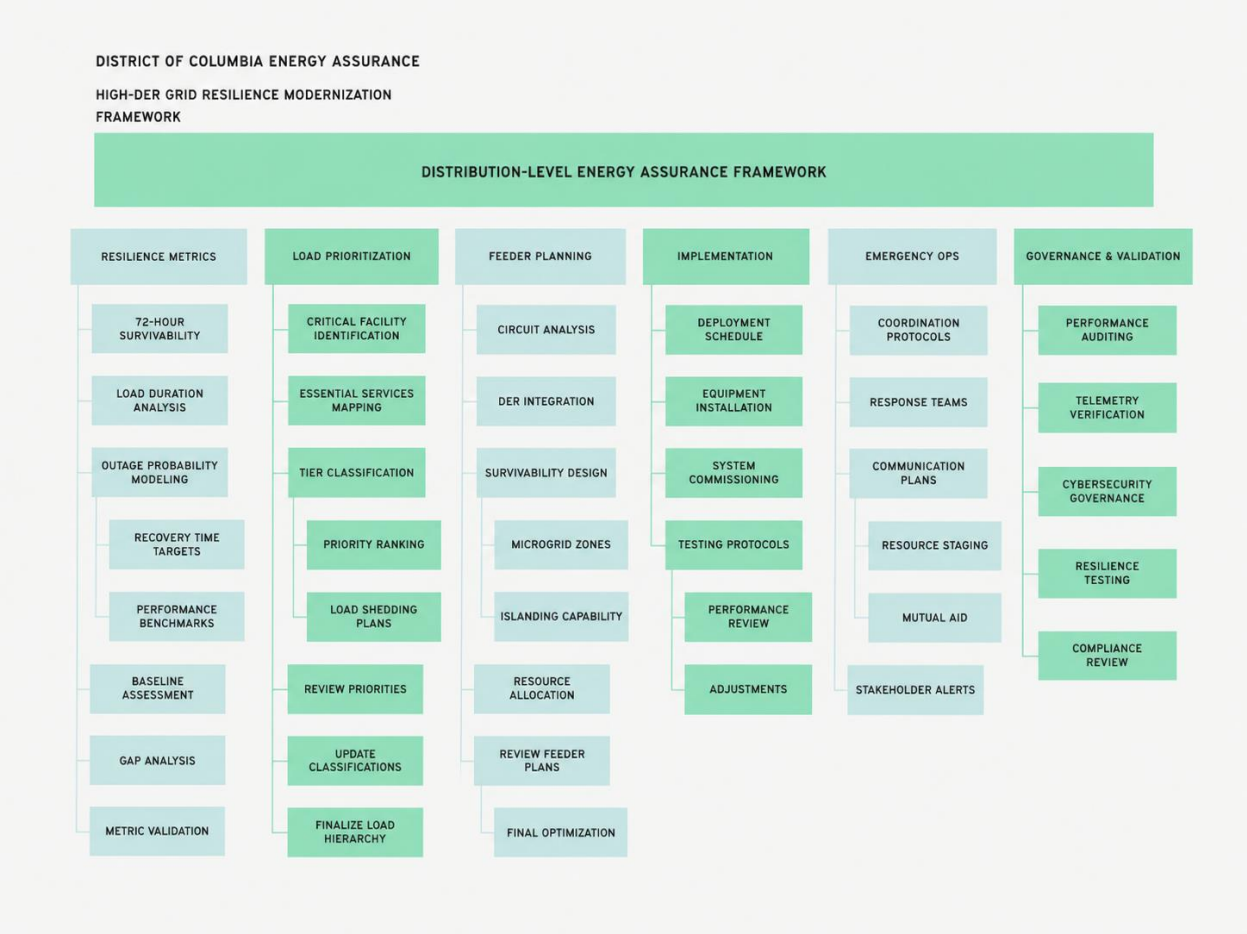

Figure 1 Distribution-Level Energy Security Plan Framework for High-DER Urban Resilience Planning

Distribution-level resilience is not a static condition but a dynamic operational process that evolves as outage conditions progress over time. Future resilience planning must therefore account for operational transition states associated with fault isolation, emergency dispatch prioritization, segmented continuity operations, and gradual system restoration. The operational framework illustrated in Figure 2 demonstrates how utility coordination, distributed energy resources, feeder segmentation capability, and resilience infrastructure may support continuity of critical services throughout prolonged outage conditions.

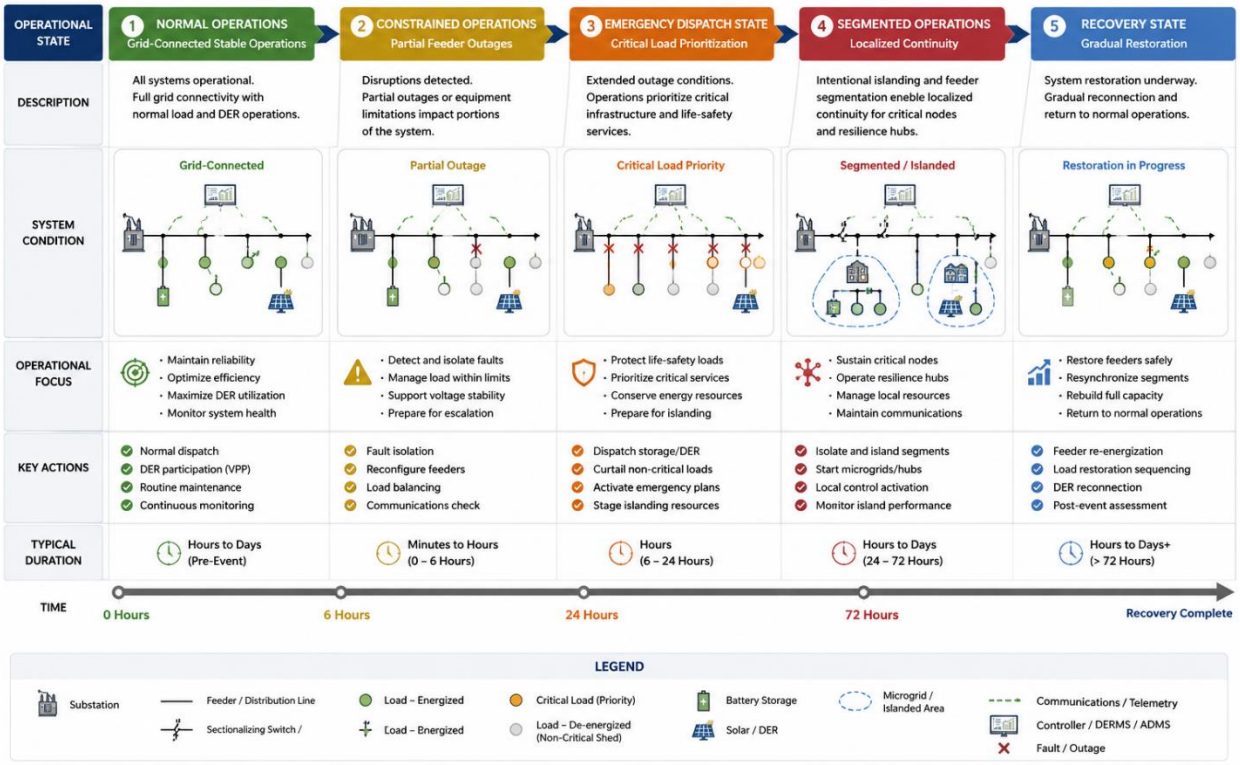

Figure 2 72-Hour Emergency Operational Transition States: System Evolution and Operational Priorities During a Prolonged Outage

Quantitative Resilience Metrics and Performance Analytics

Future resilience planning requires measurable operational indicators capable of guiding modernization priorities, resilience investment strategies, and emergency operational sequencing.

Feeder survivability methodologies should evaluate how effectively specific distribution segments can sustain continuity of critical services during constrained operating conditions. These methodologies should account for infrastructure interdependencies including telecommunications dependency, distributed energy penetration, sectionalization capability, storage availability, and operational adaptability under degraded system states.

A proposed survivability framework may classify feeders into Tier 1 Critical Continuity Feeders, Tier 2 Strategic Support Feeders, and Tier 3 Conventional Restoration Feeders. Tier 1 feeders would prioritize hospitals, emergency communications systems, water infrastructure, and government continuity functions.

Outage sustainment thresholds should become measurable planning indicators. Operational targets may include 72-hour continuity capability for designated healthcare systems, 48-hour continuity capability for emergency telecommunications infrastructure, minimum distributed storage sustainment capability for resilience hubs, and continuity targets for affordable housing and emergency shelter infrastructure.

Future emergency operations will increasingly depend upon whether distributed generation and storage systems remain dispatchable and interoperable during degraded operating conditions. Utilities should therefore evaluate telemetry continuity performance, storage dispatch availability, inverter operational readiness, and feeder-level distributed resource participation capability during constrained system states.

Communications resilience metrics should additionally evaluate cloud dependency exposure, operational visibility degradation risk, telemetry continuity capability, and communications redundancy during prolonged outage conditions.

Table 1 summarizes proposed operational resilience metrics, continuity thresholds, telemetry performance indicators, dispatch response targets, and governance benchmarks supporting future distribution-level energy security planning within the District of Columbia. The metrics are intended to establish measurable operational objectives for feeder survivability, resilience hub sustainment capability, distributed energy resource coordination, cybersecurity governance, interoperability compliance, and emergency restoration prioritization during prolonged outage conditions.

The table provides a structured framework for evaluating operational readiness, continuity capability, and resilience performance across modern high-distributed-energy-resource electric distribution systems. Collectively, these targets support resilience-oriented planning methodologies capable of improving operational visibility, emergency coordination capability, distributed dispatch responsiveness, infrastructure prioritization, and long-term modernization accountability within future urban electric distribution environments.

Table 1 Resilience Metrics and Operational Targets

Metric Category	Operational Metric	Proposed Target	Strategic Purpose
Feeder Survivability	Tier 1 Feeder Continuity	Minimum 72 Hours	Sustain critical infrastructure and life-safety operations during prolonged outages
Feeder Survivability	Tier 2 Feeder Continuity	24-48 Hours	Support community continuity and strategic service restoration
Telecommunications Resilience	Telemetry Availability	>95% Operational Availability	Maintain operational visibility and DER coordination capability
DER Coordination	DER Dispatch Response Time	<5 Minutes	Enable rapid emergency dispatch and continuity support
Resilience Hubs	Resilience Hub Sustainment Duration	48-72 Hours	Support community sheltering and continuity operations
Storage Operations	Battery Storage Operational Availability	>90% During Emergency Conditions	Improve localized continuity capability and dispatch reliability

Operational Coordination	DERMS Communication Latency	<2 Seconds for Critical Dispatch Signals	Support real-time distributed operational coordination
Cybersecurity Governance	Secure Communications Compliance	100% Encryption and Authentication Compliance	Protect operational integrity and interoperability
Restoration Operations	Critical Infrastructure Restoration Priority	Tier 1 Restoration Within Initial Emergency Window	Prioritize hospitals, emergency communications, and water systems
Interoperability	Advanced Inverter Interoperability Compliance	Full IEEE 1547-2018 Compliance	Support coordinated grid-support operational capability
Operational Validation	Resilience Testing Frequency	Annual Operational Validation Exercises	Verify continuity readiness and operational coordination
Distributed Operations	Feeder Segmentation Capability	Priority Feeders Equipped for Segmented Operations	Support localized continuity and island-capable operations
Emergency Communications	Communications Redundancy Capability	Dual-Path Critical Communications	Improve survivability under degraded operating conditions
Community Resilience	Population Coverage for Resilience Hubs	Priority Coverage for Vulnerable Communities	Support equitable resilience planning and continuity access
Governance and Security	Operational Audit and Compliance Review	Annual Performance and Governance Review	Maintain accountability and continuous modernization oversight

Future resilience planning should evaluate resilience hub accessibility, population coverage capability, sustainment duration, and operational continuity under localized island conditions. Achieving these objectives requires spatial prioritization methodologies capable of identifying which distribution feeders, infrastructure assets, and community continuity zones require enhanced survivability support during prolonged outage conditions. The conceptual model illustrated below demonstrates how feeder classification, resilience hubs, distributed storage deployment, and critical infrastructure prioritization may support coordinated continuity planning within modern urban distribution systems.

Figure 3. presents a conceptual spatial resilience planning model illustrating how distribution feeders, resilience hubs, hospitals, telecommunications infrastructure, and distributed battery storage systems may be prioritized during prolonged outage conditions. The diagram classifies feeders into survivability tiers based on critical infrastructure importance and continuity requirements while demonstrating how feeder segmentation, localized continuity zones, and distributed energy resources can support coordinated restoration and sustainment of essential services across an urban distribution system.

Figure 3 Feeder Survivability and Critical Infrastructure Prioritization Model: Spatial Prioritization of Distribution Feeders, Resilience Hubs, and Critical Infrastructure

Advanced Inverters and IEEE 1547-2018 Operational Integration

Advanced inverters are becoming increasingly important operational components within modern distribution systems.

Historically, inverter-based systems were designed primarily to disconnect during disturbances in order to avoid unintentional islanding conditions and equipment damage. IEEE 1547-2018 compliant inverter technologies fundamentally alter this paradigm by introducing grid-support operational functionality.

These capabilities include voltage ride-through, frequency ride-through, Volt-VAR support, Volt-Watt response, frequency-watt functionality, dynamic reactive power support, interoperability, telemetry integration, and remote operational configurability.

These functions improve voltage management, reduce unnecessary distributed resource disconnections, improve feeder operational flexibility, and support coordinated operational management across distribution systems.

Future operational evolution may increasingly involve grid-forming inverter functionality capable of supporting localized voltage and frequency stability during intentional islanding conditions.

Current inverter fault current behavior remains substantially different from traditional synchronous generation systems. Conventional synchronous generators may provide fault currents between approximately 3 and 7 per unit under certain operating conditions, while inverter-based systems are frequently limited to approximately 1.1 to 2 per unit because of semiconductor thermal constraints. This distinction creates important implications for protection coordination and operational planning.

The District's modernization efforts under Formal Case No. 1050 provide an important regulatory foundation for continued integration of advanced inverter technologies.

DERMS and Operational Coordination Architecture

Distributed Energy Resource Management Systems are increasingly necessary for coordination across decentralized infrastructure environments.

As distributed energy penetration increases, continuity capability becomes increasingly dependent upon real-time situational awareness and coordinated dispatch management across distributed infrastructure systems. DERMS platforms improve operational visibility by integrating telemetry and operational awareness across distributed solar systems, battery storage systems, flexible loads, and distributed infrastructure assets.

DERMS platforms can support feeder-level dispatch coordination, emergency operational management, distributed storage optimization, virtual power plant functionality, and continuity support during abnormal operating conditions.

Emergency operating environments may differ substantially from normal grid conditions. During prolonged outages or degraded communications states, utilities may experience reduced telemetry availability, delayed communications response times, partial operational visibility loss, and constrained dispatch capability across distributed infrastructure systems.

DERMS operational architecture should therefore incorporate fallback operational states capable of supporting continuity under degraded communications conditions. These fallback states may include predefined local control modes, segmented feeder operational autonomy, localized storage dispatch logic, and inverter-based voltage support functionality designed to maintain continuity when centralized coordination capability becomes constrained.

Operational dispatch prioritization should additionally establish hierarchical coordination logic during emergency conditions. Under constrained operating environments, distributed operational resources may need to prioritize healthcare infrastructure, emergency telecommunications systems, water infrastructure, resilience hubs, and emergency shelters before supporting lower-priority discretionary loads.

Future aggregation methodologies should also recognize operational constraints associated with interoperability variability, communications latency, telemetry synchronization limitations, and cybersecurity protection requirements.

Operational coordination architectures should define emergency feeder states, dispatch hierarchy, restoration sequencing, interoperability governance, and operational transition states between grid-connected and segmented operating conditions.

Effective continuity planning during prolonged outage conditions requires coordinated operational management across utility control systems, distributed energy resources, critical infrastructure facilities, and localized resilience assets. The operational hierarchy illustrated below demonstrates how DERMS-enabled coordination, emergency dispatch prioritization, and distributed operational control may support continuity of essential services during constrained operating conditions within modern urban distribution systems.

Figure 4 illustrates the operational coordination hierarchy supporting continuity of critical services during prolonged outage conditions. The diagram demonstrates how utility operations, DERMS coordination, critical infrastructure prioritization, distributed energy resource dispatch, and localized autonomous controls interact to maintain resilience across modern urban distribution systems. The figure also highlights command flow, telemetry exchange, emergency dispatch prioritization, and fallback operational capability under constrained communications and degraded grid conditions.

At the top layer, the Utility Control Center and Emergency Operations functions provide system-wide situational awareness, outage assessment, restoration strategy coordination, and operational oversight through integration with Advanced Distribution Management Systems (ADMS). This layer establishes operational priorities, restoration objectives, and emergency coordination directives across the distribution system.

The second layer represents the DERMS coordination platform, which performs distributed dispatch optimization, feeder segmentation coordination, resilience hub management, load prioritization, and operational balancing across distributed infrastructure assets. This layer serves as the primary orchestration and decision-support function during emergency operations.

The third layer identifies Critical Infrastructure Priority Targets including hospitals, emergency communications systems, water and wastewater infrastructure, emergency shelters, government continuity facilities, and public safety operations. This layer demonstrates how priority-based dispatch and continuity decisions are structured to sustain essential services during prolonged outage conditions.

The fourth layer illustrates Distributed Operational Assets including battery energy storage systems, advanced inverters compliant with IEEE 1547-2018, distributed solar generation, microgrids, electric vehicle fleet resources, and flexible building loads. These resources provide localized operational support, dispatchable energy capability, voltage and frequency support, and continuity services during constrained operating states.

The fifth layer represents Local Autonomous Controls and Device Intelligence, including inverter autonomous operating modes, localized storage dispatch capability, voltage and frequency stabilization functions, islanding controls, and degraded communications operation. This layer demonstrates how localized continuity can be maintained even when centralized communications or coordination capability becomes constrained.

Directional arrows throughout Figure 4 illustrate command flow, telemetry exchange, operational feedback loops, dispatch signals, and coordination pathways across the operational hierarchy. Collectively, the figure demonstrates how coordinated operational management, distributed intelligence, and resilience-oriented dispatch governance may support continuity of critical services during prolonged outage conditions within modern urban electric distribution systems.

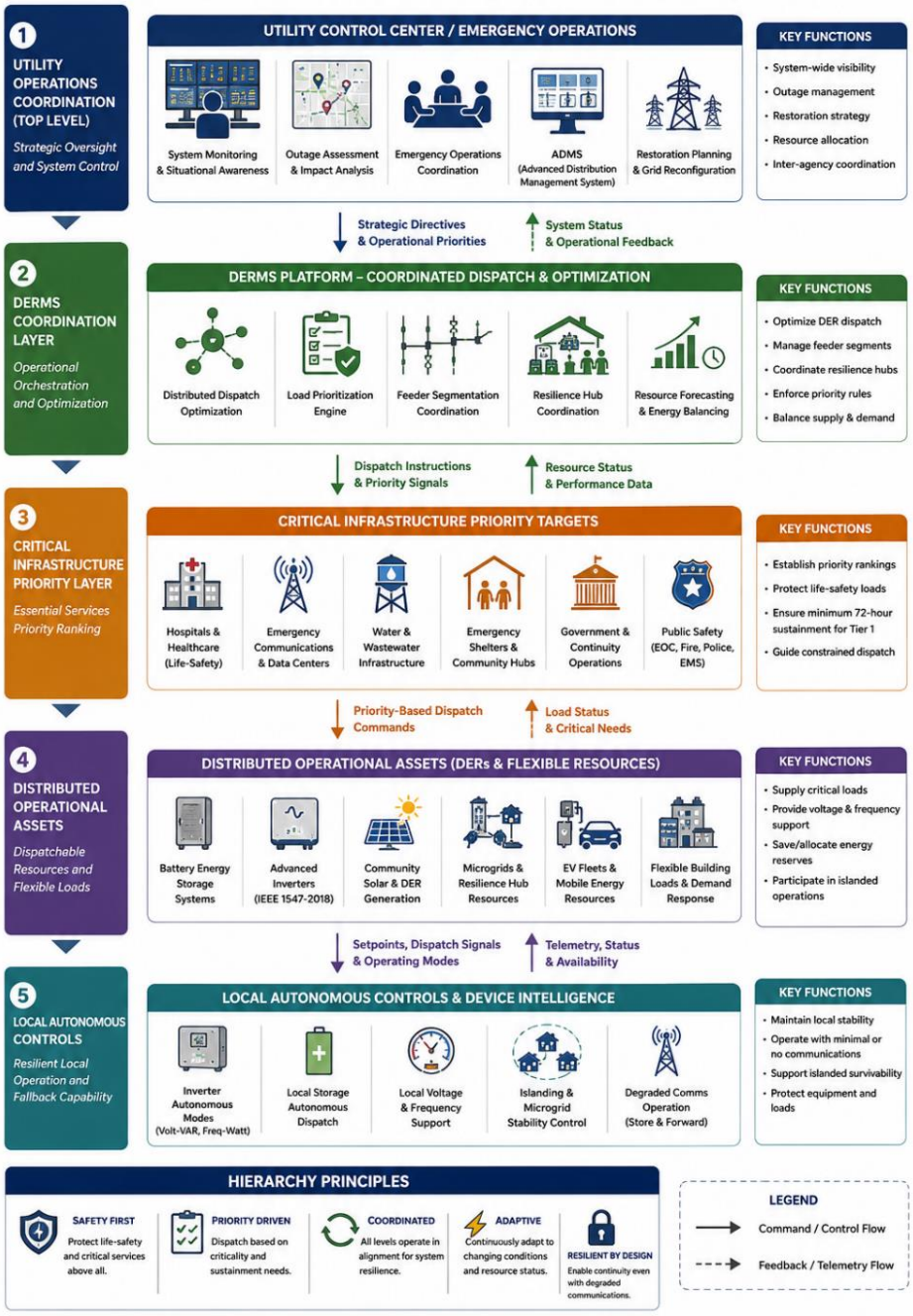

Figure 4 DERMS Emergency Dispatch Hierarchy for Coordinated Distribution-Level Resilience Operations: Operational Coordination Framework for Critical Infrastructure Continuity During Prolonged Outages

Future distribution-level resilience planning requires coordinated operational integration across utility control systems, distributed energy resource management platforms, feeder infrastructure, resilient communications networks, and critical infrastructure support systems. The proposed operational architecture in Figure 5 demonstrates how distributed operational coordination, advanced inverter functionality, battery storage integration, resilience hubs, telecommunications

infrastructure, and feeder segmentation capability can support continuity of critical services during prolonged outage conditions within modern urban electric distribution environments.

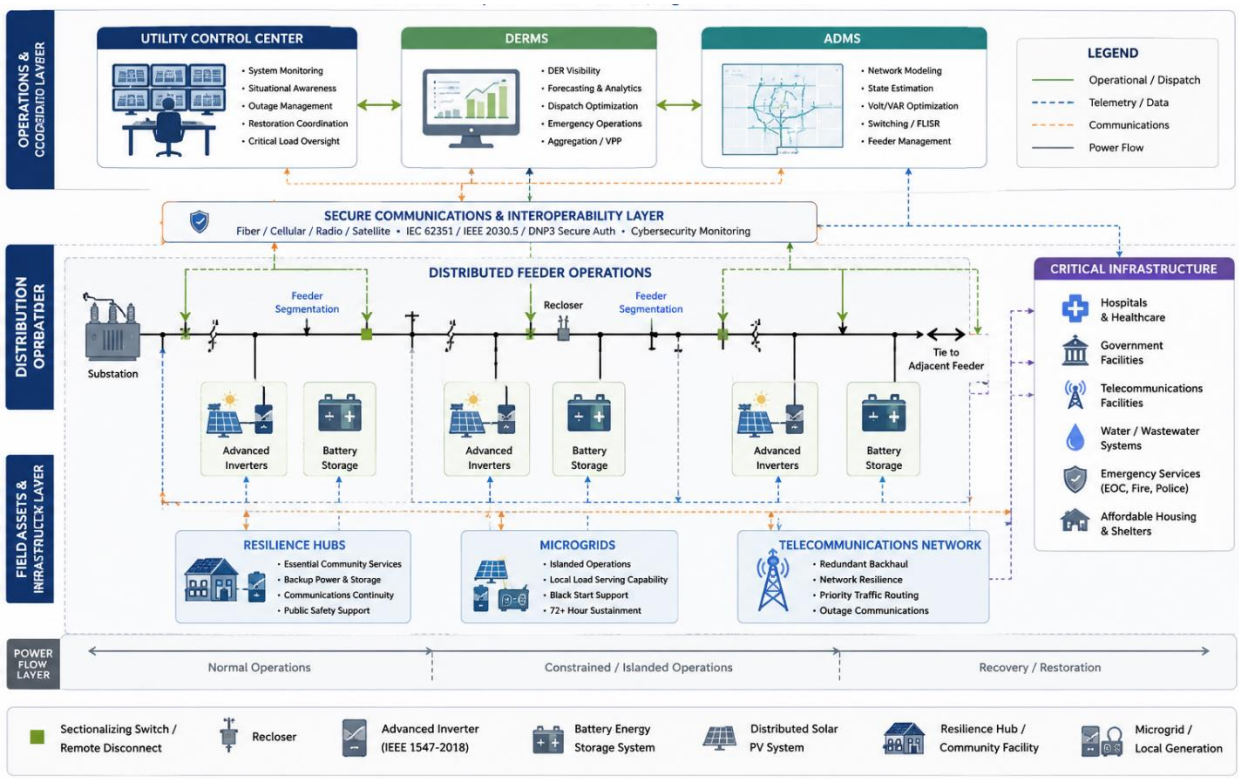

Figure 5 Proposed Distribution-Level Operational Architecture for Coordinated High-DER Grid Resilience

Economic and Infrastructure Investment Considerations

Future resilience modernization efforts must balance operational reliability objectives with affordability considerations, infrastructure investment prioritization, and long-term ratepayer impacts.

Traditional infrastructure expansion approaches often require substantial capital investment associated with feeder upgrades, substation expansion, and conventional capacity reinforcement. However, increasing deployment of distributed energy resources, advanced inverter functionality, battery storage systems, and coordinated operational management may provide opportunities to defer portions of future infrastructure expansion requirements under certain operating conditions.

Future utility planning frameworks should increasingly evaluate resilience-oriented non-wires alternatives capable of providing localized operational support, peak load reduction, voltage management, continuity capability, and feeder operational flexibility without requiring equivalent levels of conventional infrastructure expansion.

Investment prioritization methodologies should therefore incorporate avoided outage cost valuation, infrastructure deferral potential, operational flexibility benefits, and continuity support capability when evaluating modernization investments. Prolonged electric service interruptions can produce substantial economic losses associated with healthcare disruption,

telecommunications failure, commercial interruption, transportation degradation, and emergency response constraints.

Future resilience modernization strategies should additionally consider affordability impacts across vulnerable populations. Investments supporting resilience hubs, affordable housing continuity, and critical public infrastructure may provide disproportionate societal benefits during prolonged outage conditions.

Battery Energy Storage and Community Resilience Architecture

Battery energy storage systems provide operational flexibility capable of supporting both normal grid operations and continuity of critical services during prolonged outages.

Storage systems can mitigate feeder congestion, reduce thermal overloads, support localized voltage regulation, improve operational adaptability, defer infrastructure upgrades, and provide dispatchable continuity capability during emergency conditions.

The District should prioritize storage deployment across healthcare facilities, resilience hubs, affordable housing developments, emergency shelters, telecommunications infrastructure, and strategically important public infrastructure.

Existing District initiatives including Ward 7 resilience hub projects and the St. Elizabeths microgrid provide operational examples of distributed resilience infrastructure supporting continuity under emergency conditions.

Future planning should evaluate resilience hub accessibility, vulnerable population proximity, distributed storage sustainment capability, and continuity duration under localized operating conditions.

Distribution System Modernization and Planning Evolution

Future distribution systems require modernization beyond traditional reliability-focused planning methodologies.

Advanced distribution operating environments introduce technical considerations involving reverse power flow conditions, feeder congestion, dynamic voltage management, evolving fault current behavior, feeder segmentation capability, and telemetry integration.

Traditional planning approaches focused primarily on thermal loading and conventional reliability metrics are increasingly insufficient for modern distribution operating environments.

Utilities should increasingly evaluate continuity sustainment capability, infrastructure prioritization, operational adaptability, and restoration coordination during prolonged outage conditions.

Pepco hosting capacity modernization efforts already recognize the need for substantial planning evolution to support future distributed solar growth within the District. ElectrifyDC

hosting capacity analyses indicate that local solar generation may need to increase significantly over the next two decades to support District clean energy objectives.

These deployment trajectories imply increasing operational dependence upon advanced distribution coordination capability.

Cybersecurity and Operational Governance

Operational continuity increasingly depends upon secure communications architectures, telemetry integrity, and interoperability governance rather than solely physical infrastructure survivability.

Modern distribution systems increasingly depend upon distributed telemetry systems, cloud coordination platforms, remote operational management technologies, and interoperability frameworks capable of supporting decentralized operational coordination across large numbers of distributed infrastructure assets.

Future resilience frameworks should therefore integrate encrypted communications architectures, authentication protocols, inverter settings governance, certificate management methodologies, telemetry protection, and continuous cybersecurity monitoring.

The District should additionally evaluate cybersecurity implications associated with IEEE 2030.5 interoperability frameworks, IEC 62351 utility communications security considerations, and DNP3 Secure Authentication methodologies.

Potential operational risks include unauthorized inverter configuration changes, telemetry degradation, coordination failures, communications disruption during outages, and cloud dependency risks affecting operational visibility.

Cybersecurity governance should therefore become integrated directly into future resilience modernization strategies.

Figure 6 shows the integrated governance, cybersecurity, operational coordination, and resilience security architecture supporting continuity of critical services within modern high-distributed-energy-resource urban distribution systems. The framework demonstrates how policy oversight, operational validation, cybersecurity protections, distributed coordination infrastructure, and resilient energy assets interact across multiple operational layers to maintain secure and reliable continuity during prolonged outage conditions.

The upper layers represent institutional oversight and operational governance functions including regulatory alignment, performance auditing, resilience testing, telemetry verification, compliance review, and incident response coordination. The middle layers illustrate cybersecurity protections and operational coordination systems including DERMS, ADMS, utility SCADA, telemetry infrastructure, feeder coordination, and emergency dispatch platforms supporting real-time situational awareness and distributed operational management.

The lower operational layers represent distributed infrastructure assets including advanced inverters, battery energy storage systems, resilience hubs, microgrids, distributed solar generation, flexible loads, and electric vehicle integration supporting localized continuity

capability and resilient energy operations. The final layer illustrates continuity outcomes associated with hospitals, emergency communications systems, government facilities, water infrastructure, affordable housing, emergency shelters, and public safety operations.

Directional flows throughout the figure demonstrate governance oversight, telemetry exchange, operational feedback, and cybersecurity protection across all operational layers. Collectively, the framework illustrates how secure interoperability, operational validation, distributed coordination, and resilience governance may support continuity security within future urban electric distribution systems.

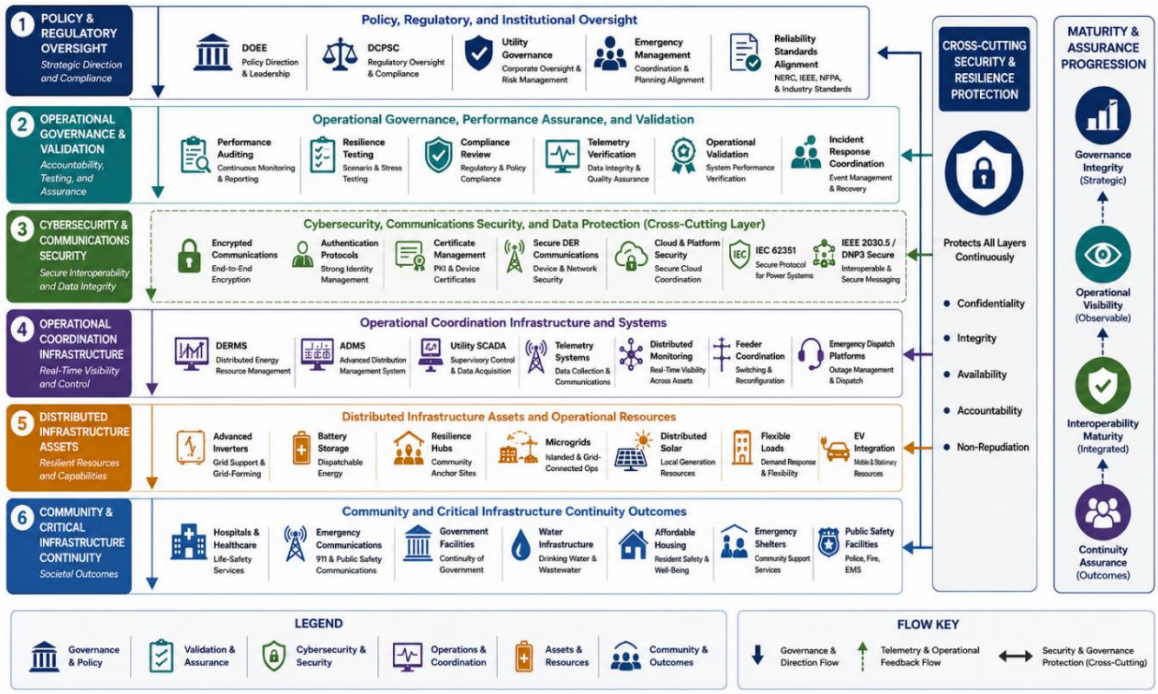

Figure 6 Cyber-Physical Resilience and Governance Framework: Integrated Operational Governance, Cybersecurity, and Continuity Security Architecture for High-DER Urban Distribution Systems

Future distribution-level resilience depends not only on physical infrastructure survivability, but also on secure operational coordination, interoperability governance, telemetry integrity, and continuous validation of distributed infrastructure performance. The governance architecture illustrated below demonstrates how cybersecurity protections, operational oversight, distributed coordination systems, and resilience security mechanisms may support continuity of critical services within modern urban electric distribution systems.

Performance Governance and Operational Validation

Future resilience modernization efforts should incorporate formal performance governance frameworks capable of supporting operational accountability and long-term institutional credibility.

Utilities and stakeholders will require measurable verification methodologies capable of evaluating whether resilience infrastructure performs effectively under constrained operating conditions rather than assuming operational readiness conceptually.

Performance verification methodologies should therefore evaluate continuity capability, distributed dispatch functionality, telemetry availability, interoperability consistency, and operational sustainment capability during emergency conditions.

Operational auditing should additionally evaluate distributed operational readiness, resilience infrastructure functionality, communications continuity performance, and coordination capability across evolving operational environments.

The District should also evaluate resilience validation exercises involving intentional islanding demonstrations, distributed storage dispatch coordination, feeder segmentation testing, and telecommunications continuity evaluation.

Compliance governance structures should support operational accountability, cybersecurity validation, interoperability consistency, and distributed operational reliability.

Technical Basis

This white paper is informed by publicly available technical, regulatory, resilience, and modernization literature including the District Department of Energy & Environment Energy Security Plan, Clean Energy DC, Climate Ready DC, ElectrifyDC Hosting Capacity studies, Synapse Energy Economics solar deployment analyses, IEEE Std 1547-2018, IEEE 2030.5 interoperability guidance, IEC 62351 communications security frameworks, U.S. Department of Energy Grid Modernization Initiative publications, DHS electric infrastructure resilience assessments, National Academies resilience studies, Energy Systems Integration Group technical publications, and publicly available utility modernization research related to inverter-based resources and distributed operational coordination.

Specific operational assumptions regarding inverter fault current contribution, distributed coordination capability, outage sustainment considerations, and feeder modernization requirements are based on publicly available industry literature and evolving utility operational practices associated with high-distributed-energy-resource electric systems.

Where quantitative projections or deployment trajectories are referenced, the paper relies upon publicly available District energy planning studies and related modernization assessments.

Regulatory and Policy Pathways

The proposed framework aligns directly with ongoing District modernization initiatives.

Formal Case No. 1050 established an important regulatory foundation for modernization of interconnection standards and advanced inverter operational integration.

Formal Case No. 1130 reinforces broader electrification and infrastructure modernization priorities necessary for long-term electric system transformation.

Formal Case No. 1142 further emphasizes affordability, utility modernization, infrastructure resilience, and long-term operational planning evolution.

Future resilience strategies should therefore integrate storage-integrated planning methodologies, resilience-oriented tariff modernization frameworks, operational flexibility considerations, and coordinated continuity capability into future utility modernization planning.

Figure 7 presents a phased modernization roadmap illustrating how the District of Columbia can transition from strategic resilience planning toward mature distribution-level operational implementation over time. The roadmap is organized into three progressive modernization phases spanning near-term, mid-term, and long-term implementation horizons.

Phase 1 focuses on foundational modernization activities occurring within the first one to two years, including development of resilience metrics, feeder survivability methodologies, pilot resilience hub deployment, advanced inverter operational standards, cybersecurity governance structures, and initial DERMS integration planning. This phase establishes the governance, planning, and operational assessment capabilities required to support broader modernization efforts.

Phase 2 represents the three-to-five-year operational scaling period during which DERMS platforms, distributed battery storage systems, resilience hub operations, telemetry integration, feeder segmentation capability, and interoperability standards are expanded across the distribution system. This phase establishes scalable operational coordination capability supporting distributed dispatch management and resilience-oriented planning integration.

Phase 3 illustrates the long-term modernization horizon extending from five to ten years, during which advanced segmented operations, grid-forming operational capability, dynamic distributed dispatch, adaptive resilience planning, integrated cyber-physical governance, and mature resilient distribution system operations become operationally integrated across the urban electric system.

The lower section of the figure visually demonstrates progression in governance maturity, operational coordination capability, interoperability evolution, and resilience growth across each implementation phase. Collectively, the roadmap establishes a phased, coordinated, and measurable pathway for achieving resilient, distributed, and future-ready urban electric distribution system operations within the District of Columbia.

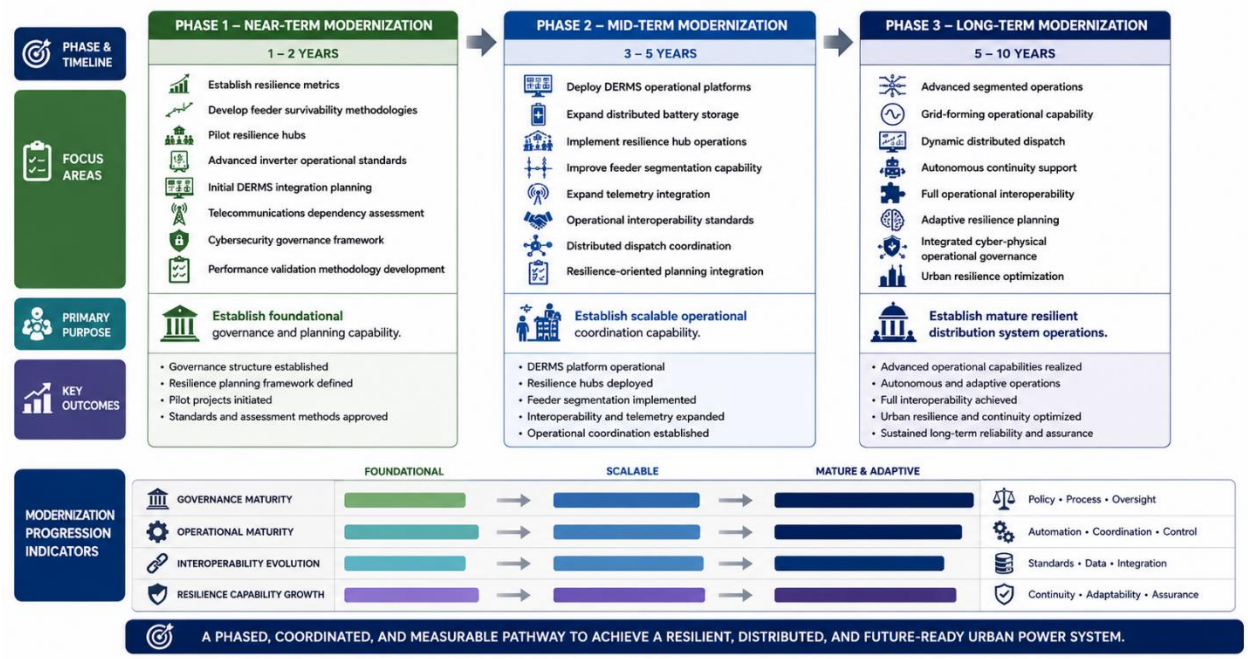

Figure 7 Implementation Roadmap for Distribution-Level Energy Security Plan Modernization: Phased Operational and Infrastructure Modernization Strategy for Urban High-DER Electric Systems

Achieving long-term distribution-level resilience requires phased modernization strategies capable of integrating operational governance, distributed coordination infrastructure, resilience planning methodologies, and advanced operational capabilities over time. The implementation roadmap illustrated above presents a structured modernization pathway designed to support progressive deployment of resilient distribution system capabilities throughout the District of Columbia.

National Relevance and Strategic Importance

The District of Columbia represents a nationally important case study for resilience modernization because of its dense urban infrastructure, ambitious climate objectives, rapidly evolving distributed energy environment, and increasing operational dependence upon digitally coordinated electric infrastructure systems.

Many resilience frameworks nationally remain focused primarily on emergency logistics and fuel continuity planning. Few frameworks explicitly address operational integration of inverter-based distributed infrastructure into distribution-level continuity strategies.

As distributed energy penetration increases nationally, urban electric systems will increasingly require modernization capable of supporting segmented operating capability, coordinated dispatch management, decentralized resilience architectures, and continuity during prolonged outage conditions.

The District therefore has the opportunity to establish a nationally significant benchmark for modernization of urban distribution-system resilience.

Conclusion

The District of Columbia is entering a new operational era defined by distributed energy deployment, electrification growth, telecommunications dependency, and increasing resilience requirements. Traditional resilience strategies centered primarily on centralized restoration and diesel backup generation are increasingly insufficient for modern distribution operating environments.

Future resilience requires coordinated integration of advanced inverter technologies, DERMS-enabled operational management, battery energy storage systems, segmented continuity capability, resilient communications infrastructure, operational validation methodologies, and distribution-level modernization strategies.

The District of Columbia is uniquely positioned to become a national modernization leader in the evolution of distribution-level energy security planning for urban electric systems. As electric infrastructure becomes increasingly decentralized, digitally coordinated, and operationally interconnected, resilience frameworks must evolve toward coordinated continuity architectures capable of sustaining critical services during prolonged emergency conditions.

The modernization pathway outlined within this framework positions the District not only to strengthen local resilience and operational readiness, but also to establish a nationally significant benchmark for urban distribution-system modernization, advanced inverter integration, coordinated dispatch capability, and resilient infrastructure governance.

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