Flexible Grid-Integrated Distributed Technologies (FLEX-GRID) Review for Energy Security

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ABSTRACT: Electricity demand is increasing due to increasing use in new buildings and digital infrastructure, creating a need for flexible capacity in power systems. **Flex**ible, **gr**id **i**ntegrated **d**istributed technologies (FLEX-GRID) are gaining attention as one approach to coordinate distributed technologies to support system flexibility.

This paper examines how distribution-level FLEX-GRID platforms coordinate distributed technologies and the system benefits these deployments have demonstrated. It first describes the operational architecture of FLEX-GRID platforms, including aggregation platforms, control strategies, communications systems, and measurement and verification approaches that enable distributed technologies to function as dispatchable assets. The paper then reviews recent FLEX-GRID deployments in the United States. Finally, it discusses technical and institutional barriers that influence broader adoption of stakeholders' engagement plans for the FLEX-GRID platforms and outlines practical solutions emerging from existing programs. Results indicate that coordinated distributed technologies can enable buildings and communities to actively contribute to grid reliability, energy affordability, and energy security.

Keywords: Flexible, Grid Integrated Technologies (FLEX-GRID); distributed technologies; demand flexibility; energy resilience; energy security; FERC Order 2222

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1. INTRODUCTION

U.S. power systems are entering a period of rising electricity demand, and growing reliance on weather-dependent on-site generation. Figure 1 shows how projected U.S. summer peak demand until 2035 has shifted upwards across different reporting years 2023, 2024, 2025 (NERC ESD 2025). These trends increase the need for flexible resources capable of balancing supply and demand. The projected retirement of power plants will reduce capacity by 99.7 GW in the next decade (NERC ESD 2025). Traditionally, grid flexibility has been provided by centralized generation assets. However, rapid growth of distributed technologies, including behind-the-meter (BTM) generation, residential batteries, mobile storage resources, and smart appliances, creates new opportunities for flexible, grid-integrated coordination of distributed technologies (FLEX-GRID). FLEX-GRID platforms coordinate such distributed technologies and flexible loads so they can collectively provide grid services. This concept broadly encompasses the aggregated distributed flexibility platforms analyzed in recent DOE studies (Downing et al. 2023). Aggregated FLEX-GRID portfolios can deliver services traditionally provided by conventional power plants, including peak load management, demand response, and frequency support. Aggregated distributed technologies already represent over 30 GW of flexible capacity and could expand significantly as digital control platforms mature (U.S. Department of Energy 2023). Recent assessments suggest that deploying approximately 80–160 GW of aggregated distributed flexibility by 2030 could meet about 10–20% of peak demand, helping accommodate rapid load growth while lowering overall grid costs. (Razdan et al. 2025).

Regulatory and market developments have further accelerated interest in FLEX-GRID. In the United States, the Federal Energy Regulatory Commission's Order No. 2222 enables distributed technologies to participate in wholesale electricity markets. The rule removes barriers that previously prevented small, distributed technologies from competing with conventional generation in energy, capacity, and ancillary service markets (Federal Energy Regulatory Commission 2020, 2025).

While many early FLEX-GRID discussions focus on wholesale market participation, coordinated distributed technologies also provide significant value on the distribution-level. Neighborhoods with BTM generation, residential batteries, flexible loads, and mobile storage loads can collectively respond to grid conditions, support local distribution networks, and improve resilience during periods of stress. Understanding how these systems operate and how they scale is therefore increasingly important for energy system planning. (National Renewable Energy Laboratory 2025).

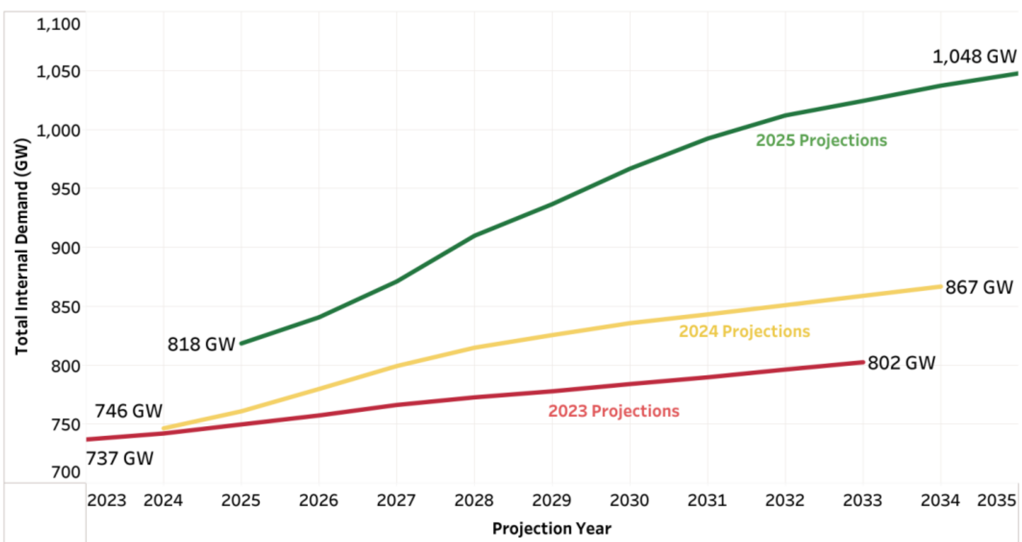

Figure 1.| Evolution of U.S. summer peak demand projections across reporting years (2023–2035).*Source: North American Electric Reliability Corporation (NERC), electricity supply and demand data, ESD 2025*

2. Operational Architecture of Distribution-level FLEX-GRID Platforms

Distribution-level FLEX-GRID platforms coordinate distributed technologies located in homes, buildings, and commercial facilities so they can collectively provide grid services. Typical resources include BTM generation, battery storage, mobile storage loads, thermostats, and other controllable loads. While any single device provides limited flexibility, aggregation enables these assets to respond at scale to grid conditions and adds redundancy, so performance can remain consistent even when some devices opt out, are offline, or become temporarily unavailable. FLEX-GRID platforms therefore integrate device connectivity, aggregation software, control algorithms, communications infrastructure, and measurement and verification frameworks that allow distributed assets to function as reliable, coordinated grid resources.

2.1 Layered Architecture of FLEX-GRID Platforms

Most operational FLEX-GRID platforms follow a layered system architecture linking distributed devices with aggregation platforms and grid operators.

- Device layer: Distributed technologies including BTM systems, static battery storage, mobile storage, and controllable loads.
- Site control layer: Building or site energy management system that monitors device status and enforces operating limits such as battery state-of-charge limits and thermal comfort constraints.
- Aggregation layer: The FLEX-GRID platform that collects device telemetry, forecasts resource availability, and determines dispatch strategies for aggregated portfolio.
- Grid interface layer: Communication between the aggregation platform, utilities, and electricity markets for scheduling, dispatch, and settlement.

This layered architecture reflects the operational requirements of distributed energy coordination. Coordination across these layers enables distributed devices to operate collectively as a flexible resource for grid operations (Abdelkader et al. 2024; Kaiss 2025).

Figure 2 illustrates the layered architecture of a distribution-level FLEX-GRID and the integration of distributed technologies at the building level, including BTM generation and storage configurations, bidirectional power flows, and communication pathways between devices, aggregation platforms, and grid operators.

2.2 Distributed Technology Resource Modeling and Aggregation

At the core of FLEX-GRID platforms is a modeling layer that translates heterogeneous distributed technologies into comparable flexibility products. Operationally, flexibility is the ability to deviate from baseline consumption or generation profile. Batteries and mobile storage charging are modeled using state-of-charge dynamics and inverter limits, while thermostats and HVAC are represented using thermal comfort constraints and building thermal response. Water heaters and other flexible loads are typically modeled via temperature bounds and recovery constraints. Scalable aggregation requires simplified device models and uncertainty representations that remain computationally tractable for large portfolios (Abdelkader et al. 2024; Kaiss 2025).

Two aggregation strategies are commonly used. Portfolio (top-down) aggregation represents many devices as a single composite resource using simplified power and energy constraints. Device-level (bottom-up) aggregation retains individual device models and determines dispatch actions subject to device and customer constraints. Top-down models align easily with market products and system-level planning, but they can overlook feeder-level constraints and localized operating conditions. Bottom-up approaches offer higher operational fidelity, but they require more comprehensive data pipelines and greater computational resources.

Distribution-level modeling adds a layer of resilience and equity constraints. For example, a neighborhood FLEX-GRID that provides outage support cannot schedule battery discharge solely for market revenues if doing so materially reduces backup energy for medically vulnerable customers. Encoding customer protections, participation choice, and equitable benefit allocation into FLEX-GRID design, rather than treating them as external program features is critical (Speetles et al. 2023).

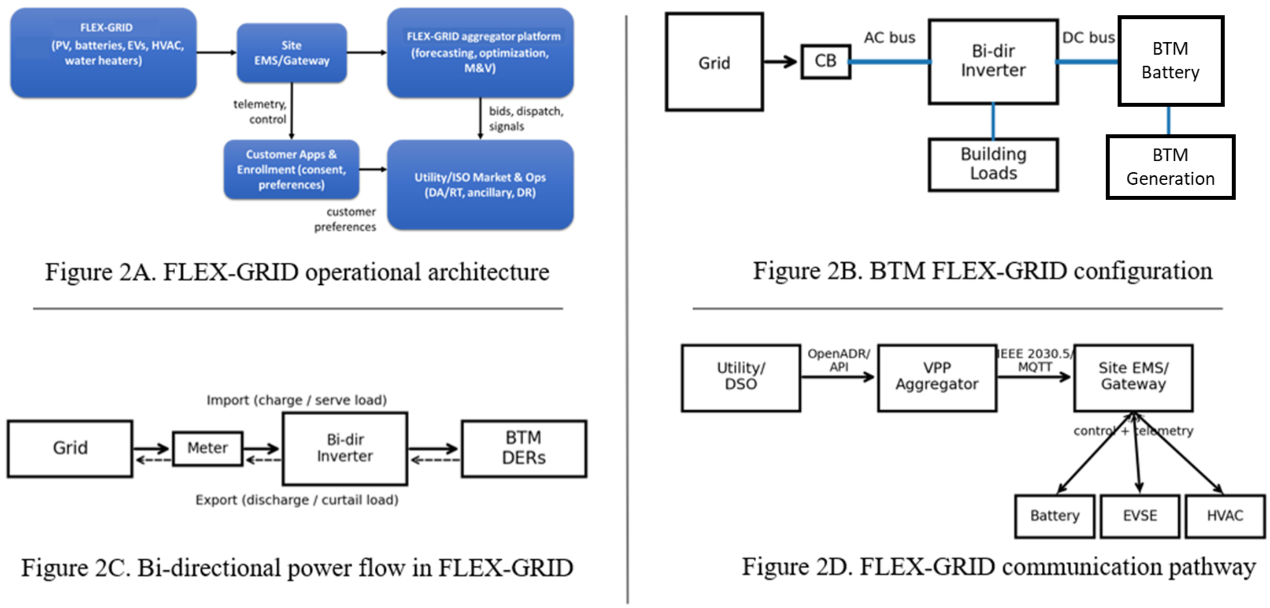

Figure 2A. FLEX-GRID operational architecture

Figure 2B. BTM FLEX-GRID configuration

Figure 2C. Bi-directional power flow in FLEX-GRID

Figure 2D. FLEX-GRID communication pathway

Figure 2. Operational architecture and building-level integration in distribution-level FLEX-GRID systems:(2A) Layered architecture linking distributed technologies, site energy management systems, and an aggregation platform. (2B) BTM generation and battery storage connected through a bidirectional inverter.(2C) Bidirectional power flow between buildings and the grid during dispatch events. (2D) Communication pathways enabling utilities or distribution system operators to transmit signals to the aggregation platform for device-level coordination.

2.3 Control Strategies: Hierarchical, Distributed, and Adaptive Control

FLEX-GRID control systems must deliver grid services while respecting device constraints and customer preferences. Most operational platforms use hierarchical control architectures in which a supervisory optimizer determines portfolio-level dispatch targets while local controllers translate those targets into feasible device actions. Model predictive control is commonly used to update dispatch schedules as new forecasts and telemetry become available, enabling the system to adjust to changing demand, on-site generation, and device availability.

From a distribution-level energy flexibility perspective, adaptive control has a specific value proposition: it can learn local response curves for flexible loads, quantify the probability of delivery, and adjust incentives or scheduling to ensure reliability (Couraud et al. 2023). This requires accurate baseline estimation, identification of response heterogeneity across households, and explicit accounting of rebound effects (e.g., HVAC “catch-up” load after curtailment). These issues are not academic; they determine whether a FLEX-GRID can be treated as firm capacity by planners and operators. Effective control strategies ensure that aggregated distributed technologies can deliver reliable flexibility for grid operations.

2.4 Communications, Interoperability, and Telemetry: the FLEX-GRID Nervous System

Communications infrastructure functions as the operational "nervous system" of FLEX-GRID platforms. The distributed technology ecosystem requires interoperability to reduce integration cost allowing vendor portfolios to participate in aggregation programs.
Three layers of communication are particularly important. Device-to-site integration within buildings typically relies on gateways or energy management systems (EMS) that interface with multiple device protocols (Rao et al. 2025). Aggregator-to-device communication often use standards such as OpenADR for automated demand response messaging (Bienert & Samad 2021; OpenADR Alliance 2013). Grid-facing communication standards such as IEEE 2030.5 support secure management of distributed technologies and interconnection with utility systems (IEEE 2018, 2023; SunSpec Alliance 2024).

2.5 Measurement and Verification (M&V): Making Flexibility Bankable

FLEX-GRID portfolios function as grid assets only when their flexibility can be measured, verified, and settled with confidence. M&V frameworks translate device responses into quantifiable energy or capacity services recognized by utilities and system operators. Performance is typically evaluated relative to a baseline representing electricity consumption in the absence of control actions.

For distribution-level FLEX-GRID portfolios to function as energy security assets, planners require metrics that are comparable to traditional resources. Three metrics are most relevant. Capacity metrics describe the maximum sustained net power change deliverable during an event window. Energy metrics describe the total deliverable energy across the event duration. Reliability metrics describe the probability of delivery under uncertainty such as device dropout, forecast error, and distribution constraints. These metrics allow distributed flexibility to be evaluated alongside conventional generation resources (Abdelkader et al. 2024; Kaiss 2025). Table 1 below summarizes M&V metrics used to evaluate distribution-level FLEX-GRID portfolios performance. They provide a common framework for verifying delivered capacity, energy, response speed, and resilience outcomes. They verify dispatch, evaluate the program to establish confidence in FLEX-GRID resources as operational grid assets.

Table 1. M&V metrics for distribution-level FLEX-GRID reliability and energy-security performance

Metric	Definition	Why it matters	Example M&V approach
Deliverable capacity (P90)	Power change deliverable with 90% confidence over the event window	Allows FLEX-GRID to be treated as a firm reliability resource	Historical performance-based derating; real-time telemetry validation
Deliverable energy	Total MWh deliverable over the specified duration	Determines outage support and multi-hour peak relief	Battery discharge integration; for loads, baseline-adjusted net reduction
Response time	Time to reach the committed power level after the dispatch signal	Determines eligibility for fast services and reliability events	Timestamped event logs; high-rate telemetry subset
Customer resilience reserve	Minimum backup energy is maintained for protected customers	Aligns FLEX-GRID dispatch with energy security goals	SoC floor constraints; post-event SoC reporting

Note. P90 indicates the deliverable level that is expected to be met or exceeded 90% of the time, a common risk-based framing for resource adequacy discussions.

2.6 BTM FLEX-GRID Solutions for Large Loads: Data Centers as Flexible Grid Assets

Large commercial loads, especially data centers, are an emerging opportunity for FLEX-GRID participation. These facilities pair high, relatively predictable electricity demand with controllable on-site assets such as power electronics, UPS batteries, backup generators, and advanced cooling systems, typically managed through a building energy management system (EMS). Together, these resources can deliver demand reduction, load shifting, and, in limited cases, export services while maintaining stringent reliability requirements. Flexibility can be provided through several mechanisms, including UPS battery dispatch, workload shifting, cooling system optimization, and coordinated use of backup generation during grid events—enabling participation in demand response and ancillary service markets without compromising operational reliability. (Energy Systems Catapult 2025; RMI 2024; Mytton et al. 2023; Takci et al. 2025).

Because data center operations prioritize uptime and service continuity, FLEX-GRID contracts typically use conservative deliverability commitments, opt-out triggers, and protected backup reserves to ensure grid participation does not compromise core operations.

3. U.S. FLEX-GRID Deployments and Observed System Benefits

3.1 California's DSGS Storage FLEX-GRID: Emergency Reliability at Scale

California's Demand Side Grid Support (DSGS) program compensates residential batteries and flexible loads for providing reliability support during periods of grid stress. The program created a pathway for rapid scaling of residential battery aggregation as an emergency flexibility resource, effectively functioning as a FLEX-GRID capacity program. Public filings indicate that the storage FLEX-GRID option under DSGS grew rapidly, reaching approximately 240 MW of aggregated battery capacity by 2024 (Tesla 2024). The program uses event-based dispatch signals and standardized M&V procedures to confirm delivered energy during reliability events.

DSGS illustrates how large fleets of BTM batteries can be coordinated using the operational architecture described in Section 2: enrolled devices receive dispatch signals, respond within specified time windows, and report performance through standardized telemetry. Unlike market-optimized FLEX-GRID models, DSGS focuses on emergency reliability events rather than participation across multiple wholesale market products. This simplified structure reduces integration complexity and accelerates program enrollment.

Several design lessons emerge from this deployment. First, simple event-based program structures combined with M&V can scale rapidly. Second, customer-facing controls such as backup reserve settings help reconcile grid dispatch with household resilience needs. Third, state-level reliability programs can serve as mechanisms that accelerate distributed technology aggregation prior to full wholesale market integration under FERC Order No. 2222.

3.2 Hawaiian Electric Grid Services FLEX-GRID: Contracted Capacity and Frequency Response

Hawaii's island grids provide a test case for FLEX-GRID deployment because high on-site weather-dependent generation and limited interconnection increase the need for fast and locally available flexibility resources. A grid services contract approved by the Hawaii Public Utilities Commission aggregates residential BTM generation plus storage systems to provide capacity and frequency response services across multiple island grids (Clancy & Goldstein 2019). Public program information indicates that the portfolio includes more than 80 MW of battery capacity and about 100 MWh of storage, paired with more than 25 MW of BTM distributed generation (Swell Energy 2021).

This program illustrates a distinct FLEX-GRID implementation in which flexibility is delivered through a contracted grid services framework rather than voluntary demand response events. Under this structure, participating resources must meet defined performance requirements while receiving fixed compensation for availability and dispatch. Operationally, the program highlights the importance of distribution-aware FLEX-GRID dispatch. Island grids face local feeder and voltage constraints, requiring coordination between the aggregation platform and distribution system operations. Recent studies show that incorporating distribution constraints such as voltage limits and transformer loading into FLEX-GRID dispatch algorithms can improve reliability and prevent local congestion (Huang et al. 2025; Qais et al. 2025). From a distribution-level energy perspective, BTM generation plus --storage FLEX-GRIDs can simultaneously improve household resilience and grid reliability. However, this model also underscores the importance of data governance and customer trust when coordinating large portfolios of residential devices.

3.3 ISO New England and ConnectedSolutions: Market-aligned Residential Flexibility

New England illustrates how FLEX-GRIDs can evolve from demand response traditions into more granular, battery storage-enabled flexibility resources. Residential BTM generation plus -storage portfolios aggregated by companies such as Sunrun have demonstrated the ability to dispatch thousands of distributed systems during peak demand periods. Residential FLEX-GRID exported more than 1.8 GWh back to the grid during summer peak periods (Sunrun 2022). At the market level, ISO-New England enables demand-side resources to participate in wholesale electricity markets alongside conventional generation (ISO New England 2025).

Complementing wholesale market participation, utility administered programs such as ConnectedSolutions provide a pay-for-performance incentives for residential batteries and flexible loads to reduce peak demand. Program evaluations indicate strong customer satisfaction and low opt-out rates, suggesting that program simplicity, predictable incentives, and automated dispatch mechanisms play a critical role in maintaining participation (Guidehouse 2024). The U.S. Department of Energy’s 2025 FLEX-GRID Liftoff update also highlights ConnectedSolutions as an example of how standardized communication protocols and digital control platforms can support scalable FLEX-GRID deployment (DOE 2025).

The New England experience highlights several design lessons. First, automation reduces customer effort and improves reliability of dispatch responses, Second, clear incentive structures translate system value into tangible household benefits, Finally, standardized data access and settlement processes are essential for enabling third-party aggregators to participate efficiently in market-aligned FLEX-GRID programs.

Table 2. Selected U.S. FLEX-GRID case examples summary

Case	Primary objective	Distributed Technologies	Reported scale metric	Key design lesson
CA DSGS Storage FLEX-GRID	Emergency reliability events	Residential batteries	240 MW capacity (2024)	Simple event design; robust settlement can scale quickly
HECO Grid Services (Swell)	Capacity; frequency response	BTM generation and storage (residential)	80 MW batteries/100 MWh storage	Contracted services require distribution-aware dispatch and strong customer consent
New England FLEX-GRID (Sunrun/ ConnectedSolutions)	Peak reduction; market-aligned dispatch	BTM generation and storage and flexible loads	1.8 GWh exported (summer season)	Automation; predictable incentives improve participation and delivery

Note. Scales are as reported in public sources and may reflect different definitions (capacity, energy delivered, or contracted service).

4. The U.K. FLEX-GRID Programs: Market Structure and Scaling Pathways with U.S.

The U.K. has developed FLEX-GRID platform aggregation through a different institutional pathway that differs from the U.S. While U.S. deployment is strongly tied to wholesale market access reforms (notably FERC Order No. 2222) and state reliability programs, the U.K. has emphasized balancing service markets, a national Demand Flexibility Service, and distribution-level flexibility procurement (NESO 2024; Department for Energy Security and Net Zero 2025).

Three differences are relevant for distribution-level energy flexibility. First, the market interface differs. The United States relies on ISO and RTO market rules with state oversight of distribution systems. Great Britain uses system balancing services and distribution network flexibility tenders. Their reforms further improve digital infrastructure and reduce barriers for distributed flexibility participation (Ofgem 2025). Second, consumer-facing routes are more centralized in Great Britain through supplier-led DFS participation and 'smart tariff' FLEX-GRIDs (e.g., EV smart-charging fleets), while U.S. participation is often structured as utility-administered programs (e.g., ConnectedSolutions) or state reliability programs (e.g., DSGS) (NESO 2024; Octopus Energy 2023). Third, the market and regulatory context differs: Great Britain's flexibility roadmap targets system-wide flexibility growth and coordination across markets, whereas U.S. energy system discussions often emphasize distributed technology market access, resource adequacy, and distribution constraints under diverse state regimes (Department for Energy Security and Net Zero 2025).

Assessing how lessons transfer between the UK and US is an important question because not all UK design choices map cleanly onto the US regulatory structure. In the US, FLEX-GRID design cannot rely solely on market product definitions; it also depends on whether state regulators, utilities, RTOs/ISOs, and, where applicable, FERC-jurisdictional market rules can accommodate common enabling elements. Where feasible within these authorities, priority elements include standards-based signaling and telemetry, portfolio-level measurement/verification and risk management, customer protection provisions (e.g., backup reserves and opt-out options), and program designs that are simple for participants (NESO 2024; Ofgem 2025).

5. Barriers and Evidence-based Solutions to Scaling Distribution-level FLEX-GRID

Despite growing interest and early successful deployments, several technical and institutional barriers continue to influence the broader adoption of distribution-level FLEX-GRIDs. These challenges relate primarily to operational reliability, interoperability across distributed technologies, market participation frameworks, cybersecurity considerations, and customer engagement.

5.1 Reliability and Performance Uncertainty

The central challenge for FLEX-GRIDs is performance uncertainty across large portfolios of distributed devices. Aggregators may commit to deliver a specific amount of flexibility, but individual devices can become unavailable due to customer behavior, communication interruptions, equipment faults, or local operating constraints. Because the available response varies from event to event, portfolio capability is best described in terms of likelihood (e.g., "there is a 95% chance of delivering at least X kW") rather than as a guaranteed, fixed output. Treating flexibility probabilistically allows operators and aggregators to size commitments with appropriate margins, set performance guarantees tied to confidence levels, and manage risk through over-enrollment and reserves, improving reliability while limiting penalties when some devices fail to respond.

To manage non-delivery risk, i.e., the possibility that a portfolio delivers less flexibility than committed, several mitigation strategies have emerged. Aggregator platforms can use probabilistic forecasting to estimate device availability and expected response, and robust or stochastic optimization can incorporate uncertainty directly into dispatch decisions to reduce shortfalls. Reliability also improves with diversified portfolios that combine batteries, flexible loads, and mobile storage, because variation in individual device performance tends to average out at scale (Kaiss 2025). Finally, clear event windows, proactive customer communication, and protection of backup reserves can reduce opt-outs and improve predictability (Guidehouse 2024).

5.2 Interoperability and Vendor Fragmentation

The distributed energy ecosystem includes a wide range of device manufacturers, communication protocols, and energy management systems. This technological diversity can complicate device integration and increase the cost of enrolling new participants in aggregation programs. Standardized communication frameworks are therefore critical for scaling FLEX-GRID platforms (DOE 2025).

Protocols such as OpenADR enable automated demand response messaging, while grid-facing standards such as IEEE 2030.5-2023 provide secure communication interfaces for distributed technologies (IEEE 2018, 2023). Adoption of standards-based architecture can reduce integration costs and allow multi-vendor portfolios to participate in aggregation programs more easily (SunSpec Alliance 2024).

5.3 Market Access, Regulatory Alignment, and Revenue Stacking

Regulatory and market frameworks strongly influence the economic viability of FLEX-GRID deployments. Participation rules for distributed technologies differ across electricity markets, and aggregation frameworks are still evolving in many regions. While regulatory initiatives such as FERC Order No. 2222 have expanded opportunities for distributed technologies participation, practical implementation remains uneven.

Another challenge involves revenue stacking the ability of aggregated resources to provide multiple grid services simultaneously, for example, a battery portfolio may be capable of delivering peak demand reduction, ancillary services, and distribution support. Clear regulatory structures that define priority rules and enable multi-service participation can significantly improve the economic case for FLEX-GRID investments (Kaiss 2025; Hale 2024).

5.4 Data Governance, Privacy, and Cybersecurity

As shown in Figure 3, FLEX-GRID platforms rely on large numbers of networked devices. As such, cybersecurity and data governance are essential considerations. Aggregators must ensure secure communication between devices, control platforms, and utilities while protecting sensitive customer data. Layered cybersecurity architectures, including device authentication, encrypted communications, and continuous monitoring are increasingly adopted to mitigate these risks (Figure 4). Transparent data policies and customer consent frameworks are also important for building trust and encouraging participation (Korukonda et al. 2025).

Customer engagement plays a critical role in program success. Evidence from existing FLEX-GRID deployments shows that simple program designs, predictable incentives, and automated controls improve participation rates and reduce opt-outs during dispatch events. Programs that also preserve customer resilience, such as maintaining minimum battery reserve levels, tend to achieve higher long-term participation and satisfaction (Speetles et al. 2023).

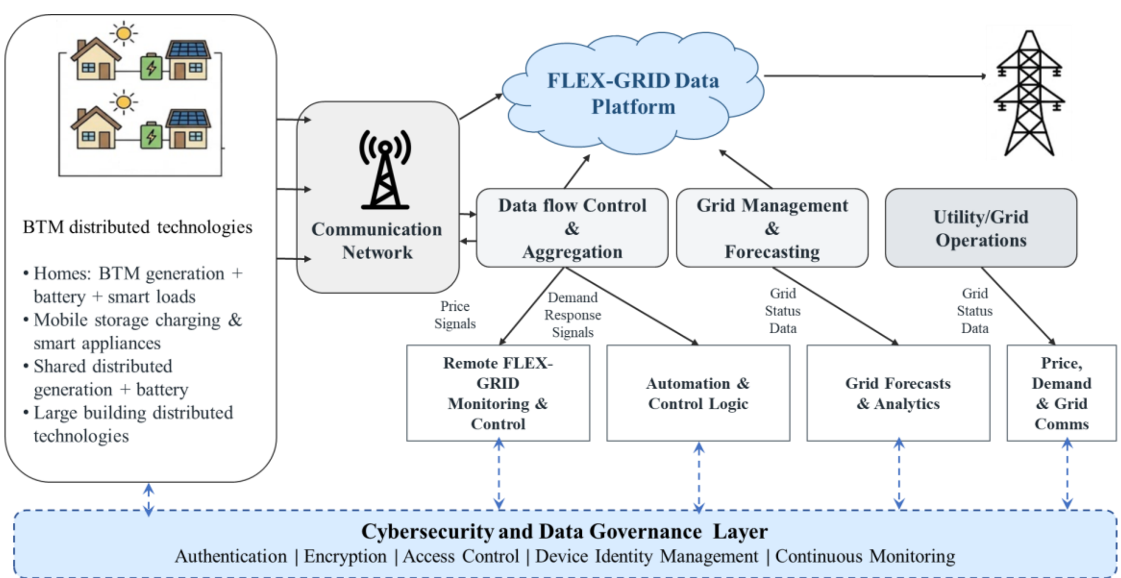

Figure 3.| Communications and data pipeline schematic for distribution-level FLEX-GRID operations.

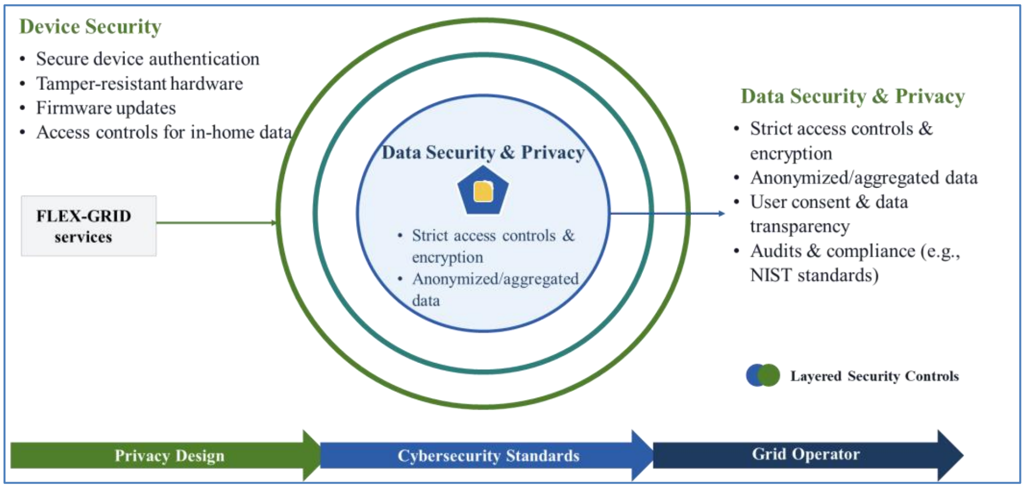

Figure 4. Layered cybersecurity and privacy design for distribution-level FLEX-GRIDs.

5.5 Distribution Constraints and Locational Value

While FLEX-GRID discussions often focus on wholesale markets, distribution systems critically determine flexibility without creating local congestion or voltage violations. As distributed technology penetration rises, the marginal value of flexibility becomes strongly locational: the same 5 MW discharge can relieve a constrained feeder in one neighborhood and overload a transformer in another. Therefore, distribution-aware FLEX-GRID dispatch is a technical and institutional requirement.

Solutions combine improved grid visibility with distribution-level coordination mechanisms. Technically, aggregators can integrate feeder constraint signals (hosting capacity limits, voltage constraints, transformer loading) into their optimization and can use inverter-based controls (Hasheminasab et al. 2024). Institutionally, utilities can provide standardized "flexibility envelopes" that specify how much export/import is permissible at specific times and locations. The Hawaii case demonstrates distributed distribution of grids of islands needing coordination on the local level.

5.6 Customer Engagement, Resilience Outcomes and Customer Protection

This section consolidates the evidence on how customer participation and resilience objectives shape FLEX-GRID performance and long-term program viability. Table 2 summarizes representative FLEX-GRID deployments by U.S. state. Distribution-level flexibility depends heavily on household participation, making customer engagement critical to both the achievable scale of FLEX-GRIDs and their operational reliability. Programs that are difficult to understand tend to see lower participation, reducing available flexibility during system peak periods or other stressed grid conditions.

Table 2. Representative U.S. states with FLEX-GRID deployments and example primary sources

State	Program / deployment example	Implementing entity	Distributed technologies portfolio	Reported scale / metric	Primary source (state/utility)
California	Demand Side Grid Support (DSGS) Storage FLEX-GRID	CEC; program workshops/filings	Residential batteries	240 MW (2024)	California Energy Commission (DSGS workshop slides/filings)
Massachusetts	ConnectedSolutions (Residential Energy Storage Demand Reduction)	MA EEAC/Program evaluators	Residential batteries; thermostats	Evaluation report (2023 season)	MA EEAC/Guidehouse evaluation report
Vermont	Green Mountain Power BYOD/Powerwall programs	Utility + VT PUC approvals	Residential batteries	Enrollment cap lifted, expansion	GMP + VT PUC order/approval
Hawaii	Hawaiian Electric Grid Services (Swell)	Hawaii PUC / program announcement	BTM generation & storage (residential)	~80 MW batteries / 100 MWh (contracted)	Hawaii PUC-approved grid services contract / program materials
Texas	ERCOT Aggregated Distributed Energy Resource (ADER) pilot; utility FLEX-GRID partnerships	PUCT/ERCOT + utility announcements	Batteries, generators, flexible load	Pilot/program scale	PUCT/ERCOT pilot documentation + utility announcements

Evidence-based solutions emphasize simplicity, transparency, and equitable access. Pay-for-performance structures with clear event windows and predictable incentives help maintain participation. Program evaluations report that incentives and guaranteed payment structures can influence purchase and enrollment decisions for BTM generation and batteries, and satisfaction and retention improve when customers perceive fairness and control (Guidehouse 2024).

Distribution-level FLEX-GRIDs can be designed to prioritize outage resilience by reserving energy for critical loads and coordinating with distribution-level buildings (schools, clinics, cooling centers) (Karan 2024). Without the "resilience first" approach, FLEX-GRIDs may optimize for short-term grid value while undermining the energy security objective the local distribution-level is seeking. Customer protection mechanisms are an important component of community-scale FLEX-GRIDs programs. Participants must retain control over how their devices are used and understand the conditions under which resources get dispatched.

Common protection measures include opt-out provisions, customer-defined battery reserve levels, transparent compensation structures, and clear limits on device operation during dispatch events. Several U.S. battery aggregation programs reserve a minimum state-of-charge for backup power and allow participants to decline events without penalty under specified conditions. These measures help maintain customer trust and support long-term program participation (Guidehouse, 2024; Hale, 2024).

5.7 Incentive Structures, Adaptive Control Algorithms, and Pilot Programs to Build Trust

Incentives motivate enrollment and sustained availability, adaptive control improves delivery confidence under uncertainty, and pilots' de-risk new operating models for regulators, utilities, and communities. Simple incentive structures (Pay-for-performance event payments and seasonal capacity payments) reduce ambiguity for households. For battery-centric FLEX-GRIDs, a common trust mechanism is a protected backup reserve (customer-defined SoC floor) that the FLEX-GRID cannot violate. For flexible loads, incentives should account for comfort constraints and rebound effects by rewarding net performance over the event.

Adaptive control algorithms operationalize trust by reducing the probability of non-delivery and by minimizing ‘surprises’ to customers. At the portfolio level, model predictive control and robust/stochastic optimization can derate commitments based on real-time device availability and forecast error. Well-designed pilots are the institutional mechanism that turns the above into scalable practice. Pilots should be structured with (i) clear M&V and data governance, (ii) staged expansion criteria (e.g., enrollment thresholds and opt-out rates), and (iii) participants’ engagement plans. Transparent reporting by utilities and regulators can develop confidence that FLEX-GRIDs are bankable grid assets rather than ad-hoc demand response events. The growing pilot programs need continued funding for long-term success.

6. Conclusion

Flexible, grid-integrated distributed technologies (FLEX-GRID) emerging as operational grid resources capable of coordinating distributed generation, storage, and controllable demand. Evidence from recent U.S. deployments shows that aggregated distributed technologies can deliver peak reduction, short-duration capacity, and fast response services that support system reliability. Although barriers, interoperability challenges, evolving market rules, cybersecurity considerations, and distribution constraints remain, existing programs demonstrate practical pathways for scaling. As distributed technologies expand and electricity demand grows, FLEX-GRID platforms provide a pathway for buildings and communities to contribute directly to grid reliability and energy security.

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