

# Optimizing Distributed Energy Resource Hosting Capacity Through Grid Reinforcement and Non-Wires Alternatives in the United States

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**Abstract-** Distributed energy resources (DERs)—including distributed photovoltaics, behind-the-meter storage, flexible demand, and electrified end uses—are transforming U.S. distribution systems while exposing a persistent planning and interconnection constraint: hosting capacity. Hosting capacity is commonly defined as the amount of DER that can be accommodated without adversely impacting power quality or reliability under specified control configurations and without requiring infrastructure upgrades. Yet hosting capacity is not an immutable feeder attribute; it is strongly sensitive to analytical methods (snapshot vs. time-series; deterministic vs. probabilistic), modeling assumptions (e.g., inverter settings), data quality, and governance choices regarding what constitutes an acceptable violation or mitigation. This article provides a secondary analysis synthesizing peer-reviewed research, national laboratory reports, interconnection standards resources (IEEE 1547 family implementation guidance), and public regulatory/utility records to develop an integrated technical–economic–regulatory framework for expanding hosting capacity through complementary strategies: targeted grid reinforcement and non-wires alternatives (NWAs). Comparative case evidence from New York’s Brooklyn-Queens Demand Management program, California’s integration capacity analysis ecosystem, and Hawaii’s hosting-capacity mapping and inverter experience is used to extract transferable mechanisms and failure modes. Synthesized findings indicate that hosting capacity should be communicated as a scenario-dependent range; that advanced inverter functionality and flexible demand can expand feasible DER penetration but require validated settings, telemetry, and verification; and that integrated distribution planning linking hosting capacity analytics to locational value and benefit-cost screening improves comparability between wires and non-wires portfolios while strengthening transparency for interconnection stakeholders. (Electric Power Research Institute [EPRI], 2018; Jain et al., 2020; Narang et al., 2021).

**Keywords –** Hosting capacity; distributed energy resources; non-wires alternatives; distribution system planning; integration capacity analysis.

## I. INTRODUCTION

Distribution systems in the United States are increasingly shaped by rapid adoption of distributed energy resources (DERs), particularly distributed photovoltaics (PV), distributed storage, and flexible or electrified loads. These resources can lower emissions, improve resiliency, and unlock new grid services, but they also stress distribution networks that were historically engineered for largely one-directional power flow and comparatively stable operating envelopes. As DER penetration rises, interconnection backlogs and upgrade cost uncertainty have become practical bottlenecks, elevating hosting capacity from a niche engineering term into a planning and market signal that influences siting, procurement, and regulatory oversight (EPRI, 2018; U.S. Department of Energy [DOE], 2016).

Hosting capacity is commonly defined as the amount of DER that can be accommodated without adversely impacting power quality or reliability under existing control configurations and without requiring infrastructure upgrades. This definition is operationally useful because it links DER integration potential to binding distribution constraints (e.g., voltage limits, thermal ratings, protection coordination, reliability considerations). However, it also embeds an important caveat: hosting capacity is conditional on assumptions about “existing control configurations,” including how voltage regulation devices operate, what inverter functions are enabled, and whether active management is permitted or feasible (EPRI, 2018).

Utilities have traditionally expanded hosting capacity through grid reinforcement (e.g., reconductoring, transformer upgrades, substation expansion, changes to voltage regulation equipment). Such investments produce durable physical capacity but can be capital intensive and slow, and they can

perform poorly under near-term uncertainty where the “need” may be local, seasonal, or sensitive to DER adoption patterns. In response, regulators and utilities have expanded interest in non-wires alternatives (NWA), which are portfolios of non-traditional solutions—distributed generation, energy storage, energy efficiency, demand response, and controls—that can defer or replace wires solutions when they deliver reliable, locationally targeted capacity relief (E4TheFuture, 2018; DOE, 2016).

A central challenge is that hosting capacity is frequently communicated as a single number on a map or at a node, while the research consensus increasingly indicates that hosting capacity is best represented as a scenario-dependent range. Estimates can shift substantially depending on whether analyses use conservative worst-case snapshots or time-series simulation, whether advanced inverter capabilities are modeled, and whether data inputs accurately reflect “as-operated” conditions. These methodological and data issues affect not only engineering conclusions but also stakeholder trust, because published hosting capacity results influence developer siting, interconnection queues, and perceptions of transparency (Jain et al., 2020; Nagarajan & Zakai, 2022; Horowitz, 2019).

This paper expands an existing manuscript into a publication-ready journal article by developing an integrated framework for hosting capacity expansion that explicitly connects (a) hosting capacity analysis methods and uncertainty, (b) technical levers (reinforcement, inverter controls, storage, flexible demand), and (c) governance mechanisms (standards implementation, data validation, procurement and measurement/verification, benefit-cost analysis). The paper addresses three research questions: What methodological choices most strongly shape hosting capacity estimates and their interpretability? Which technical strategies expand hosting capacity under different binding constraints? What institutional mechanisms enable credible comparison and implementation of wires and non-wires portfolios at scale? (EPRI, 2018; DOE, 2024; Horowitz et al., 2020).

## II. LITERATURE REVIEW

Hosting capacity has matured into a multi-purpose tool that sits at the intersection of interconnection screening, proactive distribution planning, and public transparency. Its growth has been reinforced by initiatives to publish hosting capacity maps, which aim to improve siting decisions and reduce interconnection delays. The DOE’s U.S. atlas of hosting capacity maps indicates that, as of May 2024, dozens of utilities and state agencies across many U.S. jurisdictions had published public hosting capacity maps. This expansion suggests a broad policy and industry belief that hosting capacity disclosure can be a market-shaping instrument, not merely an internal engineering study (DOE, 2024).

However, early hosting capacity map deployments also revealed shortcomings—particularly around data quality, model calibration, and the risk that maps could be interpreted as precise “guarantees.” A dedicated national laboratory and stakeholder report on hosting capacity data validation emphasizes that user confidence depends on accuracy and that early public HCAs sometimes contained inaccuracies, motivating best practices for validation procedures. This literature signals that hosting capacity’s value depends on trust, which requires technical validation and transparent documentation of assumptions (Nagarajan & Zakai, 2022).

### Definitions and constraint categories

The canonical definition of hosting capacity focuses on the maximum DER that can be interconnected without violating constraints under specified control configurations and without requiring infrastructure upgrades. Within this definition, “constraints” commonly include voltage (overvoltage and undervoltage), thermal loading (lines, transformers), protection coordination (misoperation, nuisance trips, fault contribution), and reliability or operational flexibility considerations. One EPRI technical brief frames hosting capacity as multi-dimensional and driven by both DER characteristics (location, technology, controls) and grid conditions (configuration, impedance, load levels, voltage regulation). It also emphasizes that realistic “boundary conditions” should drive decision-making and that the sheer combinatorial space of impact factors explains why hosting capacity results are sensitive to modeling choices (EPRI, 2018).

The literature increasingly differentiates between hosting capacity that is “static” (reflecting a snapshot of worst-case conditions) and hosting capacity that is “dynamic” or time-aware (reflecting duration and frequency of violations over a time-series). This distinction matters because distribution systems can tolerate some short-duration excursions under certain standards and equipment thermal inertia. Fact sheets describing advanced hosting capacity concepts emphasize that acceptable duration of voltage deviations and transformer overloading is partly a matter of utility operating practice and standards interpretation, suggesting that hosting capacity is partly a governance choice about risk acceptance rather than a purely physical quantity (Horowitz, 2019; Horowitz, 2019/utility fact sheets).

Snapshot hosting capacity analyses evaluate a small set of operating cases designed to reflect worst-case conditions. They are computationally efficient and consistent with screening processes, but they can be overly conservative or misleading when they ignore violation durations and device operations (e.g., regulator tap changes over time). EPRI illustrates this dilemma by showing that a system-wide hosting capacity analysis becomes computationally massive when many impact factors and timepoints are considered, highlighting why

utilities use simplified methods while acknowledging the resulting sensitivity (EPRI, 2018).

Time-series methods (often quasi-static time series, QSTS) simulate feeder operations over many timepoints, capturing time-varying load, DER output, and operations of voltage regulation devices. A peer-reviewed study proposing a dynamic hosting capacity methodology for distributed PV uses full-year power flow analysis and formulates time-aware metrics for annual results. The study reports that dynamic hosting capacity can be materially higher than static hosting capacity in the studied cases, demonstrating that method choice can change conclusions about how “full” a feeder is and whether upgrades are truly required (Jain et al., 2020).

Probabilistic hosting capacity approaches treat DER siting, load allocation, and operating conditions as uncertain, producing distributions of feasible DER penetration rather than a single threshold. Review literature highlights probabilistic modeling and validation as key needs for hosting capacity practice, while emphasizing that the translation of probabilistic results into decisions requires standardization and governance frameworks (Singh & Al-Durra, 2023).

The methodological frontier is not limited to more timepoints. It also includes scalable automation, quality assurance, and data-driven approaches that leverage smart meter data or other measurements when detailed circuit models are incomplete—particularly at the secondary network level. Federal interconnection innovation efforts and hosting capacity research presentations referenced by DOE’s interconnection roadmap initiatives suggest a growing emphasis on process automation, improved data reporting, and the integration of hosting capacity tools into accelerated interconnection pathways (DOE, 2025).

#### **Advanced inverters and standards-based controllability**

A major pathway for increasing hosting capacity is the use of advanced inverter capabilities to support voltage regulation and grid stability. In the U.S. context, adoption and implementation of the IEEE 1547-2018 interconnection and interoperability standard, alongside associated testing and guidance, represent a foundational shift toward treating DER inverters as grid assets rather than passive devices. A national laboratory technical report summarizing IEEE 1547-2018 indicates that the revised standard was published in April 2018, contains major new requirements relative to the 2003 version, and requires careful study to determine appropriate settings and configurations for implementation (Narang et al., 2021).

Implementation is not merely a matter of device capability; it requires settings governance. A clause-by-clause summary report of the IEEE 1547-2018 requirements explicitly frames implementation as requiring appropriate information to calculate settings and clarifies that different clauses target

different audiences and technical fluency levels. This reinforces the practical reality: hosting capacity benefits from inverter controls are conditional on whether utilities and authorities governing interconnection requirements can specify, test, and monitor settings in a repeatable way (Narang et al., 2020).

Empirical and simulation-based evidence indicates that inverter functions such as Volt/VAR and Volt/Watt can expand hosting capacity in many voltage-constrained feeders, but the magnitude varies by feeder characteristics and settings. A multi-institution conference paper describes methods to determine feeder-wide advanced inverter settings and reports that Volt/VAR functions improved hosting capacity substantially across sampled feeders (with large variability), while noting the lack of guidelines and tools to determine effective settings. This highlights both potential and constraint: the same function can produce different outcomes depending on feeder X/R ratios, topology, and reactive power availability (Rylander et al., 2016).

Field-oriented work in Hawaii provides additional insight into how inverter voltage controls function in practice. A national-laboratory technical report documenting simulation and field pilot findings describes autonomous Volt/VAR and Volt/Watt controls as candidates to increase PV hosting capacity when voltage constraints bind, particularly because they can operate without communications, but it also notes the tradeoff with energy production and the need for careful validation and understanding of system impacts (Giraldez Miner et al., 2018).

The literature also stresses that advanced inverter benefits can be constrained by other limits (thermal, protection) and may require coordinated management systems (DERMS) at higher penetrations. A peer-reviewed techno-economic comparison of traditional upgrades, autonomous Volt/VAR controls, and coordinated DERMS for PV integration reports that Volt/VAR controls offered a low-cost option for hosting capacity expansion in studied feeders but could not mitigate all violations at high penetration levels, and that DERMS could expand hosting capacity further at the cost of increased curtailment relative to autonomous controls. This supports a portfolio view: inverter functions are valuable but not universally sufficient (Horowitz et al., 2020).

#### **Non-wires alternatives: definitions, performance risk, and implementation practices**

NWAs are widely defined as grid investments or projects using non-traditional transmission and distribution solutions—distributed generation, energy storage, energy efficiency, demand response, and software/controls—to defer or replace the need for traditional infrastructure. A case-study report synthesizing leading U.S. NWA efforts explicitly provides such a definition and emphasizes that NWAs often combine multiple measures rather than relying on a single technology (E4TheFuture, 2018).

The NWA literature emphasizes that the central challenge is not only technical feasibility but also performance assurance. Grid reinforcement projects typically deliver deterministic capacity once built, while NWA portfolios deliver capacity relief through the sustained performance of many distributed assets and participants. This introduces performance and persistence risk, which must be managed through procurement design, measurement and verification, and incentives or penalties tied to delivery. Practice-oriented guidance, such as an implementation playbook developed through expert interviews across many states, emphasizes best practices for operationalizing non-wires programs, including early identification of grid needs, clear procurement processes, and performance metrics (Rocky Mountain Institute, 2018).

A major empirical anchor in U.S. NWA discourse is New York's Brooklyn-Queens Demand Management program, designed to address an overload condition on subtransmission feeders serving specific substations. An order establishing the program identifies the overload condition and frames the program as a portfolio approach to defer traditional infrastructure investments in targeted neighborhoods. The program became widely cited as an early, large-scale demonstration of NWA procurement and governance under near-term capacity need (New York Public Service Commission, 2014).

#### **Locational value, benefit-cost analysis, and comparability between wires and non-wires**

Because NWAs typically target a specific grid constraint at a specific location and time, their economic value depends on locational avoided costs: the deferral or avoidance of a particular wires project. A Berkeley Lab report on locational value emphasizes that DER benefits for distribution systems are often realized primarily through their role as NWAs, deferring or mitigating traditional investments where distribution capacity is insufficient to meet expected future needs. The report documents approaches and tools to estimate locational value and includes numerous case studies of regulatory and utility practice, reinforcing the idea that valuation must be tied to identifiable distribution needs rather than generic system averages (Frick et al., 2021).

Comparability also requires standardized benefit-cost analysis principles. A national standard practice manual for DER benefit-cost analysis provides a policy-aligned framework for cost-effectiveness screening, emphasizing symmetry in costs and benefits, explicit reference cases, and the importance of accounting for relevant impacts consistent with jurisdictional objectives. This framework is used across jurisdictions to structure evaluation of portfolios that may include energy efficiency, demand response, distributed generation, storage, and electrification measures—precisely the components often assembled for NWAs (Woolf et al., 2020).

In peer-reviewed economic modeling, the locational marginal value of DER as NWAs has been formalized by monetizing marginal costs associated with constraints and investment alternatives. Such models clarify a key planning insight: if DER portfolios are to replace wires capacity, the relevant incentive must reflect the marginal avoided cost of local constraints, not merely energy value. This is methodologically aligned with distribution planning that uses hosting capacity to identify constraints and locational value methods to quantify the economic significance of relieving them (Andrianesis et al., 2020; Laws & Webber, 2024).

#### **Institutionalization through distribution planning and transparency regimes**

Hosting capacity and NWA strategies do not operate in a vacuum; they are institutionalized through distribution planning requirements, regulatory proceedings, and transparency mandates. California's Distribution Resource Planning ecosystem provides a prominent example, in which integration capacity analysis (ICA) has been developed as a tool to calculate hosting capacity at circuit nodes and to support both interconnection and planning. A CPUC decision describing DRP processes explicitly characterizes ICA as calculating available load and generation hosting capacity based on thermal and steady-state voltage considerations, among others, and subsequent working group materials discuss refining methods and incorporating smart inverter functions into ICA values (California Public Utilities Commission, 2018; Rule 21 Working Group Two, 2018).

In addition, states have broadened distribution planning obligations. Berkeley Lab summarizes that a substantial number of U.S. jurisdictions require regulated utilities to file some form of distribution system plan, sometimes focused on grid modernization or DER integration and often including evaluation of non-wires options. This suggests a structural trend: hosting capacity and NWAs increasingly become regular components of regulatory planning cycles rather than exceptional pilots (Schwartz et al., 2025).

Finally, wholesale and federal market rules influence feasibility of flexible portfolios. A federal register entry and related federal materials describe how Order No. 2222 requires organized markets to create participation models for DER aggregations and address coordination among RTOs/ISOs, DER aggregators, and distribution utilities. This matters for hosting capacity and NWAs because aggregated DERs may rely on wholesale revenue stacking to remain economically viable, but they also must not undermine distribution reliability constraints, requiring explicit coordination provisions (Federal Energy Regulatory Commission, 2020).

### **III. THEORETICAL FRAMEWORK**

This article frames hosting capacity expansion as an integrated socio-technical planning problem with three coupled layers: engineering feasibility, economic portfolio selection, and institutional governance. Hosting capacity becomes a boundary object connecting these layers because it translates technical constraints into a metric that can influence market behavior and regulatory decision-making (EPRI, 2018; DOE, 2024).

**Engineering feasibility layer.** Hosting capacity is determined by the constraint that binds first under specified operating conditions and control settings. The constraint set typically includes voltage, thermal loading, and protection coordination, and the relevant binding condition can change with DER controls or changes in load shape. Crucially, feasibility is not solely about device ratings; it is about device behavior over time, including voltage regulation dynamics, inverter response curves, and potential interactions among many DER devices (EPRI, 2018; Jain et al., 2020).

**Economic portfolio selection layer.** Hosting capacity expansion strategies can be expressed as competing or complementary portfolios: (a) grid reinforcement projects that raise physical capacity and typically yield durable reliability improvements, and (b) NWA portfolios that reshape net load or provide targeted flexibility to defer or replace reinforcement. Comparability requires a reference case and an accounting framework that treats costs and benefits symmetrically and aligns with jurisdictional policy objectives. Locational value methods map the economic value of flexibility to the avoided cost of specific local upgrades and thus provide a bridge between hosting capacity (where constraints bind) and NWA valuation (what it is worth to defer them) (Woolf et al., 2020; Frick et al., 2021).

**Institutional governance layer.** Even when a portfolio is technically feasible and economically attractive, implementation depends on governance mechanisms that allocate authority over settings, data, procurement, and verification. Standards implementation guides and clause summaries emphasize that inverter settings require careful study and stakeholder engagement, while hosting capacity validation guidance shows that trust in published results requires standardized QA/QC and data governance. Procurement governance (contracts, performance metrics, measurement and verification) is similarly central for NWAs because performance persistence is the core risk differentiating NWAs from wires solutions (Narang et al., 2020; Nagarajan & Zakai, 2022; Rocky Mountain Institute, 2018).

**From these layers, the framework advances two propositions to guide analysis.**

Proposition 1 (hosting capacity is endogenous to controllability). Hosting capacity is not only a function of the physical network; it is also a function of controllability—whether utilities and governing authorities can specify, test, and

rely on inverter functions, coordinated DER management systems, and flexible demand behavior. As controllability increases, more hosting capacity expansion can be achieved through software-defined approaches rather than purely through hardware expansion, but this shifts reliance onto governance and validation systems (Narang et al., 2021; Horowitz et al., 2020).

Proposition 2 (optimal expansion is portfolio-sequenced, not binary). Effective hosting capacity expansion is typically achieved through a sequence of interventions: near-term operational changes and flexibility procurement to address localized or uncertain constraints; mid-term targeted reinforcement where flexibility cannot provide sufficient reliability; and long-term modernization (data, automation, standards implementation, transparency tooling) that reduces the marginal integration cost of future DER. Integrated distribution planning guidance frames this kind of iterative planning cycle, and state planning requirements reflect a trend toward formalizing these steps in regulatory processes (DOE, 2016; Schwartz et al., 2025).

(Figure is conceptually grounded in definitions and implementation considerations described in the hosting capacity and planning literature.) (EPRI, 2018; DOE, 2016; Nagarajan & Zakai, 2022).

#### IV. METHODS RESEARCH DESIGN AND POSITIONING

This study is a secondary analysis that synthesizes peer-reviewed research, national laboratory technical reports, standards-implementation resources, and public regulatory and utility documents to expand an existing manuscript into a publication-ready journal article. No original feeder simulations, experimental measurements, or proprietary datasets are introduced, and no primary numerical results are fabricated. The “Results/Findings” section therefore reports synthesized patterns and propositions derived from published evidence rather than new empirical estimates (Nagarajan & Zakai, 2022; Singh & Al-Durra, 2023).

##### Evidence hierarchy and inclusion criteria

Evidence was selected with a hierarchy consistent with engineering-policy synthesis: (a) peer-reviewed journal articles and conference papers on hosting capacity methods and inverter controls; (b) official national laboratory technical reports and DOE publications on hosting capacity, planning, and validation; (c) public regulatory orders and filings documenting NWA programs and hosting-capacity mapping initiatives; and (d) well-documented practice guides used cautiously to describe implementation processes. Priority was

given to sources from U.S. Department of Energy (DOE), National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (Berkeley Lab/LBNL), Electric Power Research Institute (EPRI), Federal Energy Regulatory Commission (FERC), and the California Public Utilities Commission (CPUC), as well as peer-reviewed journals in power systems and energy policy (EPRI, 2018; DOE, 2024; Nagarajan & Zakai, 2022; Federal Energy Regulatory Commission, 2020).

#### Case selection and comparative logic

Three U.S. cases were selected because they exemplify distinct but influential pathways for hosting capacity expansion through reinforcement-NWA integration:

- **New York City (NYC)** — the Consolidated Edison Brooklyn-Queens Demand Management (BQDM) program demonstrates geo-targeted procurement and regulatory reporting designed to defer traditional infrastructure for a defined overload risk (New York Public Service Commission, 2014; Consolidated Edison Company of New York, Inc., 2018).
- **California** — CPUC’s institutionalization of Integration Capacity Analysis and working group refinement illustrates how hosting-capacity-style tools become embedded in planning and interconnection governance, including efforts to incorporate smart inverter functions into ICA values (California Public Utilities Commission, 2018; Rule 21 Working Group Two, 2018).
- **Hawaii**— Hawaiian Electric’s public locational value maps and NREL’s inverter pilot documentation provide evidence of hosting capacity governance where inverter behavior is operationally salient, while also offering explicit disclaimers about map scope and secondary-system constraints (Hawaiian Electric, n.d.; Giraldez Miner et al., 2018).

The comparative approach is not intended to rank programs but to identify mechanisms that transfer across institutional and technical contexts. Analytic generalization is pursued through a structured coding of constraints addressed, methods used, solutions deployed, and governance features (case documentation, standards, validation) (DOE, 2016; Frick et al., 2021).

#### Analytic procedure

Documents and studies were coded along five dimensions aligned with the theoretical framework: (a) primary constraint category (voltage, thermal, protection); (b) hosting capacity method (snapshot, time-series, probabilistic); (c) intervention category (reinforcement, inverter controls, DERMS, flexible demand/NWA portfolios); (d) valuation approach (locational value, BCA reference case); and (e) governance tools (standards, QA/QC plans, reporting cadence, procurement mechanisms). Results are presented as synthesized findings and

cross-case comparisons supported by multiple sources per claim where feasible (EPRI, 2018; Woolf et al., 2020; Nagarajan & Zakai, 2022).

## V. RESULTS/FINDINGS

Because this is a secondary analysis, “findings” are synthesized patterns supported by triangulation across peer-reviewed studies and public governance documentation. Five findings emerged as most consequential for publication-ready guidance.

**Finding 1: Hosting capacity is best interpreted as a scenario-dependent range indexed by assumptions**

The literature consistently frames hosting capacity as sensitive to assumptions about grid configuration, load levels, DER characteristics, and control settings. EPRI explicitly notes that realistic boundary conditions should drive decision-making and that hosting capacity analysis is “multi-dimensional,” implying that a single published value without context can be misleading. This is particularly important for public hosting capacity maps, because stakeholders may interpret map values as deterministic “headroom” rather than as outputs conditional on method and assumptions (EPRI, 2018; DOE, 2024).

NREL’s hosting capacity materials for policymakers and utilities similarly emphasize that hosting capacity cannot be represented by a single number, and that it represents a point beyond which upgrades or control changes may be needed. This framing aligns with the proposition that hosting capacity is endogenous to controllability and suggests that hosting capacity communication should provide scenario context (e.g., whether advanced inverter functions are assumed, whether the results consider time-series constraints, and what violation thresholds are used) (Horowitz, 2019; Horowitz, 2019).

**Finding 2: Time-series and dynamic hosting capacity approaches often identify materially different integration limits than snapshot methods**

Dynamic hosting capacity research demonstrates that method choice can change hosting capacity estimates. A peer-reviewed dynamic hosting capacity methodology based on full-year simulation shows that capturing time dependence, including device operations and time-aware metrics, can yield higher hosting capacity than static snapshot methods in studied cases. The key mechanism is that short-duration excursions and device operations over time change the effective constraint boundary relative to a worst-case snapshot, although acceptance of short-duration violations depends on standards interpretation and utility practice (Jain et al., 2020; Horowitz, 2019).

This finding supports a governance implication: regulators and utilities must define what constitutes an acceptable violation duration and specify the time-series metrics used for public-facing results. Without such definitions, hosting capacity maps

may be inconsistent across utilities and may erode stakeholder confidence when observed conditions diverge from published values (Nagarajan & Zakai, 2022; California Public Utilities Commission, 2018).

**Finding 3:** Advanced inverter functionality can expand hosting capacity, but only when settings governance and validation are institutionalized

Standards implementation resources emphasize that IEEE 1547-2018 adds major technical requirements and that implementation requires careful study of underlying concepts and settings. Clause summaries highlight that different stakeholders must interpret and apply requirements, implying that the hosting capacity value of advanced inverter functions depends on governance processes that establish default settings, confirm conformance, and manage updates over time (Narang et al., 2021; Narang et al., 2020).

Technical evidence indicates that feeder-wide settings design is non-trivial. A study proposing methods to determine recommended advanced inverter settings reports substantial hosting capacity improvements in some feeders with Volt/VAR functionality and emphasizes the lack of guidelines. Field and simulation work in Hawaii similarly indicates that autonomy-based voltage controls are strong candidates in voltage-constrained feeders because they can operate without communications, but their impacts on power quality and energy production must be understood and validated (Rylander et al., 2016; Giraldez Miner et al., 2018).

California's ICA ecosystem provides governance evidence: working group documentation indicates that utilities were working with software vendors to incorporate Volt/VAR and other smart inverter functions into ICA calculations, and that until incorporated, such impacts could be considered in supplemental review processes. This suggests that hosting capacity outputs are institutionally co-evolving with inverter standards and interconnection rules and that transparency tools require continuous methodological maintenance to remain policy-relevant (Rule 21 Working Group Two, 2018).

**Finding 4:** NWAs expand effective hosting capacity when they deliver verifiable, locationally targeted relief aligned with binding constraints

BQDM illustrates that NWAs act as hosting capacity interventions by reshaping the binding condition (e.g., peak load) that drives an overload risk. The order establishing BQDM identifies an overload condition on subtransmission feeders serving specific substations and approves a programmatic portfolio approach. Such programs effectively create "virtual headroom" by reducing or shifting demand and/or deploying local resources, thereby deferring the need for immediate reinforcement (New York Public Service Commission, 2014).

Subsequent Con Edison implementation documentation describes the BQDM program scope and emphasizes ongoing quarterly reporting, supporting an interpretation that performance tracking and program governance were core components of making an NWA credible. Independent federal documentation also describes BQDM as seeking to procure substantial demand reduction measures to defer approximately \$1 billion of traditional infrastructure investments, indicating that NWAs have been treated as material capacity tools in policy discourse when aligned with defined grid needs (Consolidated Edison Company of New York, Inc., 2018; Federal Energy Regulatory Commission, 2015).

The NWA literature indicates that performance assurance is the key differentiator: because NWAs depend on distributed portfolios, procurement design and measurement and verification are essential. Implementation playbooks emphasize that utilities must identify procureable needs early enough, specify performance requirements clearly, and create procurement pathways that can attract third-party participation while protecting reliability (E4TheFuture, 2018; Rocky Mountain Institute, 2018).

**Finding 5:** Hosting capacity optimization increasingly depends on integrating transparency tools with valuation frameworks and market coordination

California's ICA and related planning processes demonstrate institutional integration: ICA is not only a map; it is part of a regulatory cycle that ties distribution planning to interconnection processes, with explicit decision text describing ICA as calculating available hosting capacity at circuit nodes. This supports a broader conclusion that hosting capacity tools become decision-relevant when they are embedded in planning governance (e.g., QA/QC plans, update cycles, and linkage to interconnection screens) rather than treated as one-off studies (California Public Utilities Commission, 2018).

Hawaii's locational value maps illustrate a complementary transparency approach: the maps indicate approximate remaining hosting capacity on the primary distribution network while explicitly noting that secondary systems may have different availability. This "bounded transparency" provides a model for communicating hosting capacity in a way that supports planning and siting while reducing the risk of over-interpretation. Such disclaimers are consistent with the data validation literature's emphasis on accurate, trusted outputs and explicit communication of limitations (Hawaiian Electric, n.d.; Nagarajan & Zakai, 2022).

Finally, market rules influence NWA viability. Federal documentation describing Order No. 2222 emphasizes that RTO/ISO tariffs must address metering and telemetry requirements and coordination between market operators, aggregators, and distribution utilities. For hosting capacity

optimization, this implies that flexible DER portfolios may rely on wholesale participation to sustain economics, but such participation must be coordinated with distribution constraints to avoid undermining reliability. Consequently, hosting capacity expansion via NWAs and managed DERs increasingly requires cross-jurisdictional operational protocols (Federal Energy Regulatory Commission, 2020).

Table 1 provides a comparison of key studies and authoritative sources that underpin these findings.

Table 1  
 Comparison of key hosting capacity and NWA sources (peer-reviewed and authoritative)

Source	Type	Core contribution	Use in this manuscript
(EPRI, 2018)	Technical brief	Defines hosting capacity; documents impact factors and computational scaling tradeoffs	Definition and sensitivity framing
(Jain et al., 2020)	Peer-reviewed journal article	Proposes dynamic hosting capacity; time-aware metrics via full-year simulation	Method sensitivity and time-series importance
(Nagarajan & Zakai, 2022)	Technical report	Best practices for hosting capacity data validation; emphasizes trust and QA/QC	Governance and map credibility
(Narang et al., 2021)	Technical report	IEEE 1547-2018 implementation issues for voltage/reactive power control	Standards-based controllability
(Narang et al., 2020)	Technical report	Clause-by-clause guide to IEEE 1547-2018 requirements	Operationalization and stakeholder roles
(Rylander et al., 2016)	Conference paper	Methods for recommended advanced inverter settings; shows strong feeder dependence	Settings governance and variability
(Giraldez Miner et al., 2018)	Technical report	Simulations and field pilot findings for inverter voltage controls in Hawaii	Field-oriented feasibility and tradeoffs

Source	Type	Core contribution	Use in this manuscript
(Horowitz et al., 2020)	Peer-reviewed journal article	Techno-economic comparison: upgrades vs volt-var vs DERMS	Portfolio tradeoffs and curtailment
(Frick et al., 2021)	National lab report	Locational value of DERs, primarily as NWAs; methods and case studies	Locational value bridge to NWA valuation
(Woolf et al., 2020)	Practice manual	Benefit-cost analysis framework for DERs; policy-aligned principles	Portfolio comparability and reference cases
(New York Public Service Commission, 2014)	Regulatory order	Establishes BQDM; documents targeted overload condition	NWA governance and targeted need
(California Public Utilities Commission, 2018)	Regulatory decision / process	Institutionalizes ICA and DRP processes	Map integration with planning/interconnection
(Federal Energy Regulatory Commission, 2020)	Federal rule	Requires DER aggregation participation models and coordination	Market coordination implications

(Sources are cited in-text and in the reference list with DOIs where available.) (EPRI, 2018; Frick et al., 2021). Figure 2 provides a timeline of major U.S. hosting capacity and NWA developments referenced in this study.

Hosting Capacity and Non-Wires Alternatives — Selected U.S. Milestones  
 2014 : NYPSC issues order establishing the Brooklyn/Queens Demand Management (BQDM) program  
 2016 : DOE/ICF integrated distribution planning report frames hosting capacity within planning cycles  
 2018 : IEEE 1547-2018 published (modern DER interconnection and interoperability requirements)  
 2018 : California DRP governance documents institutionalize integration capacity analysis concepts  
 2020 : FERC Order No. 2222 final rule enables DER aggregation participation in organized wholesale markets  
 2021 : Berkeley Lab report synthesizes locational value of DERs, emphasizing NWAs  
 2022 : NREL/IREC publish hosting capacity data validation recommendations

2024 : DOE atlas documents expansion of public hosting capacity maps across U.S. jurisdictions

2025 : DOE i2X interconnection roadmap emphasizes improved data reporting and interconnection process innovations

(Timeline items are supported by the cited regulatory orders, DOE publications, standards implementation reports, and national laboratory documents.) (New York Public Service Commission, 2014; DOE, 2016; Narang et al., 2021; Federal Energy Regulatory Commission, 2020; Frick et al., 2021; Nagarajan & Zakai, 2022; DOE, 2024; DOE, 2025).

## VI. DISCUSSION

This synthesis supports a reframing of hosting capacity expansion: it is not a binary competition between “build wires” and “buy DER.” Rather, it is a portfolio and governance problem in which reinforcement and NWA serve different roles under different constraints, timelines, and uncertainty. The evidence indicates that grid reinforcement remains necessary for structural bottlenecks (e.g., persistent thermal overloads or device limitations) and for long-run reliability, while NWAs and control-based approaches are particularly valuable where a near-term constraint is localized, uncertain, or driven by peak conditions that can be reshaped through flexible demand and storage (DOE, 2016; E4TheFuture, 2018).

The methodological literature implies that hosting capacity is partly a governance artifact: utilities and regulators must decide the “rules of the game” for what constitutes an acceptable violation, what time-series metrics define compliance, and what controls may be counted as baseline conditions. Dynamic hosting capacity work suggests that integrating time dependence can materially change integration limits, but adopting dynamic approaches requires clear definitions of acceptable excursion durations and robust modeling of device operations. Without agreed definitions, hosting capacity values may be contested and may not be actionable in procurement or interconnection decisions (Jain et al., 2020; Horowitz, 2019).

The controllability proposition emerges strongly from inverter-related evidence. IEEE 1547-2018 implementation requires detailed decision-making about settings and responsibilities, and clause summaries emphasize that different clauses target different stakeholders and require different information. This may be underappreciated in policy discussions that treat “smart inverters” as simple plug-and-play solutions. In practice, realizing hosting capacity gains from Volt/VAR or Volt/Watt requires a settings governance architecture: default curve design, feeder-specific adjustments where warranted, conformance testing, and a mechanism for updating settings over time in response to changing feeder conditions and DER mix (Narang et al., 2020; Rylander et al., 2016).

The case evidence suggests a spectrum of governance maturity. California’s ICA ecosystem shows institutionalization through working groups and explicit attention to incorporating smart inverter functions into ICA calculations. NYC’s BQDM demonstrates a mature procurement-and-reporting approach designed to deliver measurable capacity relief. Hawaii’s locational value maps demonstrate a transparency strategy that increases information access while explicitly bounding interpretation through disclaimers about secondary systems. These differences indicate that hosting capacity optimization is not only a technical method choice but also an institutional design choice: how much transparency is provided, how it is validated, and how it is tied to procurement, interconnection screens, and planning cycles (California Public Utilities Commission, 2018; Consolidated Edison Company of New York, Inc., 2018; Hawaiian Electric, n.d.).

Economic comparability remains the central barrier to scaling NWAs. The NSPM for DER benefit-cost analysis provides a structured pathway for defining reference cases and aligning cost-effectiveness tests with policy objectives, while locational value research emphasizes that deferral value is highly location-specific and tied to avoided projects. Yet even with strong frameworks, NWAs require implementable procurement mechanisms and measurable baselines. The BQDM evidence suggests that high-profile NWA programs become credible when they combine a clearly specified need, a bounded geography, active procurement, and ongoing reporting and approvals; absent these conditions, NWAs risk being treated as pilot programs rather than substitute capacity resources (Woolf et al., 2020; Frick et al., 2021; New York Public Service Commission, 2014).

The market coordination dimension is likely to become more important as aggregations scale under Order No. 2222. Federal register documentation identifies coordination requirements among RTO/ISO, aggregators, distribution utilities, and retail regulators, including metering and telemetry provisions. These requirements can be interpreted as governance infrastructure necessary to ensure that aggregated DER operation does not undermine distribution constraints. For hosting capacity and NWAs, the implication is that future portfolio design will often require explicit constraints management across institutional boundaries: distribution planning must anticipate and coordinate with market participation to avoid counterproductive dispatch patterns (Federal Energy Regulatory Commission, 2020).

## VII. LIMITATIONS

This manuscript is a secondary synthesis and does not include original feeder simulations, experimental results, or new empirical measurement of hosting capacity expansions. Findings are therefore expressed as synthesized patterns and propositions grounded in published research and public records

rather than as new quantitative estimates. In addition, the comparative case selection intentionally focuses on influential jurisdictions and may not generalize to all utility types (e.g., rural cooperatives, municipal utilities) or to feeders with very different topology and DER mixes (Nagarajan & Zakai, 2022; Schwartz et al., 2025).

A second limitation is that access to full-text peer-reviewed articles is sometimes restricted, particularly for certain commercial publishers. Where full text was not accessible, the analysis relied on national laboratory repositories, OSTI entries, regulatory filings, and other authoritative sources that provide sufficient detail to support claims. This constraint is partly mitigated by the breadth of technical reporting available through DOE and national laboratories in the hosting capacity and inverter standards domain (DOE, 2025; Narang et al., 2021).

Finally, the paper does not compute a jurisdiction-specific avoided cost calculator or formally apply NSPM tests to a specific utility project because doing so would require detailed cost and load forecasting data not consistently available in public sources and would risk creating pseudo-precision. Instead, the paper focuses on replicable mechanisms and decision structures that can be adapted once local data and reference cases are specified (Woolf et al., 2020; Frick et al., 2021).

### Implications

For distribution utilities, the evidence suggests that hosting capacity optimization should be pursued through integrated distribution planning that explicitly links hosting capacity analytics to solution selection, including both wires and non-wires portfolios. Utilities should publish hosting capacity outputs with clear assumptions, QA/QC practices, and update cycles; incorporate advanced inverter functions where standards adoption and device fleets make them reliable; and invest in telemetry and validation where coordinated management is expected to deliver capacity value (Nagarajan & Zakai, 2022; California Public Utilities Commission, 2018; Narang et al., 2020).

For regulators, the results support four priorities: define acceptable metrics for hosting capacity (including time-series considerations where used); require transparency about assumptions and limitations in published maps; ensure that cost-effectiveness screening frameworks allow fair comparison between wires and non-wires portfolios; and create governance structures that reward performance and verified outcomes rather than only capital deployment. Where wholesale aggregation is relevant, regulators and utilities should coordinate to ensure that market participation does not compromise distribution constraints (Woolf et al., 2020; Frick et al., 2021; Federal Energy Regulatory Commission, 2020).

For researchers, the synthesis identifies priority gaps: reproducible benchmarking and validation protocols for hosting capacity methods; quantitative evaluation of how advanced inverter settings and DERMS shift hosting capacity across feeder archetypes; empirical analysis of whether public hosting capacity maps reduce interconnection delays and upgrade costs; and integrated models that jointly represent distribution constraints, NWA procurement, and wholesale participation under operational coordination rules (Jain et al., 2020; Nagarajan & Zakai, 2022; Horowitz et al., 2020).

## VIII. CONCLUSION

Hosting capacity has become a core planning and governance metric for enabling DER deployment at scale while maintaining distribution reliability. The evidence synthesized here indicates that hosting capacity is best treated as a scenario-dependent range; that time-series methods and improved data validation can materially change interpretability and stakeholder trust; that advanced inverters and coordinated DER management can expand hosting capacity but require standards-based settings governance and verification; and that NWAs can substitute for wires investments when they deliver locationally targeted, verifiable relief aligned with binding constraints. A portfolio-sequenced planning approach linking hosting capacity analysis, locational value, benefit-cost screening, and procurement/verification offers a coherent pathway for scaling DER integration while minimizing total system cost and preserving reliability (EPRI, 2018; DOE, 2016; Frick et al., 2021; Woolf et al., 2020).

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