

A LANDSCAPE ASSESSMENT OF IEEE STANDARDS

**Active standards, gap analysis, and future
requirements for electric distribution grids**

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Executive Summary

The electric distribution grid is undergoing an unprecedented transformation driven by the growth of distributed energy resources (DERs) and electrification, grid modernization objectives, and increasingly ambitious decarbonization targets for 2030, 2040, and 2050. This transformation is supported by IEEE standards and guides which cover a broad range of technical areas. Standards such as IEEE 1547 and 2030, on DER integration and smart grid operations, have provided valuable guidance to grid transformation efforts. However, as the grid evolves, new standards are needed to address emerging sector needs.

This report contains four core contributions:

First, it catalogs over 150 active IEEE standards and guides applicable to the distribution grid, organized and contextualized into twelve thematic areas: system planning, power quality, reliability & resilience, DER, smart-grid, electric vehicle integration, communications and cybersecurity, protection, equipment management, environmental impacts, metering and analytics, and data sharing & privacy.

Second, the report identifies critical standardization gaps that must be addressed to support grid modernization, resilience, and energy transition goals. The standardization gaps identified span DER hosting capacity analysis, interconnection study procedures, distribution system resilience metrics, electric vehicle integration, and advanced use cases for smart meters. Closing these gaps is critical to ensuring the continued relevance of IEEE standards and providing best practices and norms for emerging industry needs. Together a new set of IEEE standards and guides can accelerate DER adoption while enhancing system resilience and energy affordability.

Third, the report provides guidance on the prioritization of future standards development to align with national climate and grid modernization targets. Using a multi-criteria scoring approach to prioritize standardization gaps, *the report identifies four key areas for near-term action: standardized planning objectives, a standard resilience valuation methodology, a standard resilience metric focused on social impact, and standardized hosting capacity evaluation.*

Fourth, the report translates these priorities into a proposed roadmap for IEEE standards development outlining near-, medium-, and longer-term opportunities to address the identified gaps.

I | Introduction

The **Institute of Electrical and Electronics Engineers (IEEE)** is a U.S.-based nonprofit professional association that serves practitioners in electrical engineering, electronics, and related technical fields, and is dedicated to advancing technology for the benefit of humanity^[1]. Through the IEEE Standards Association (IEEE SA), IEEE develops consensus-based technical standards that provide common reference points for the design, operation, and interoperability of electrical and electronic systems, including the electric power grid^[2]. Within IEEE SA, standards projects typically produce one of three types of documents^[3]:

- **Standards:** documents with mandatory technical requirements and clear conformance criteria.
- **Recommended Practices:** documents in which procedures and positions preferred by IEEE are presented.
- **Guides:** documents in which alternative approaches to good practice are suggested, but no clear-cut recommendations are made.

These levels of requirement are reflected in the standard “verbs” used in IEEE documents, “shall” for requirements, “should” for recommendations, and “may” for options.

IEEE standards are developed through a formal, consensus-driven process. New work is initiated through a Project Authorization Request (PAR), a structured document that defines the scope, need, and purpose of the proposed standard. The PAR is reviewed by the New Standards Committee (NesCom), which makes a recommendation to the IEEE SA Standards Board on whether the project should be approved^[4]. Once approved, a Working Group is formed to draft the document and resolve comments, and a balanced balloting group reviews and votes on the draft before it is submitted for final approval and publication. IEEE standards are then maintained through periodic review and revision to ensure they remain aligned with current technology, industry practice, and regulatory needs^[5].

This report uses that framework to provide a landscape assessment of IEEE standards relevant to the electric distribution grid and to identify where additional standards or guides are warranted in various related areas. The following section elaborates further on the scope of this report. Readers not currently active in IEEE standards activities can use this assessment as an orientation to the existing standards landscape and as a guide to potential areas for engagement, whether by participating in Working Groups, proposing new PARs, or aligning internal utility practices with emerging IEEE guidance.

|| | Active IEEE Standards for Electric Distribution Grids

1. SYSTEM DESIGN, PLANNING AND MODELING

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 3001.4–2020	IEEE Recommended Practice for Estimating the Costs of Industrial and Commercial Power Systems ^[6]	2030
IEEE 3002.2–2018	IEEE Recommended Practice for Conducting Load-Flow Studies and Analysis of Industrial and Commercial Power Systems ^[7]	2028
IEEE 1729–2025	IEEE Approved Draft Recommended Practice for Electric Power Distribution System Analysis ^[8]	2035

The IEEE 3000 Standards Collection broadly covers system design, planning, and modeling from individual components to the system level^{[9][10]}. In the **IEEE 3001** series, some standards cover design and integration of specific components, such as metering or controllers, while **IEEE 3001.4–2020** advises on overall distribution system cost estimation^[6]. At the system level, **IEEE 3002** standardizes network studies, including load flow, short circuit and harmonics, while **IEEE 3006** focuses on reliability studies, including guidance on collecting and analyzing reliability data^[11].

Several additional standards deal with system modeling. The **IEEE 2781–2022** Guide details load modeling approaches, noting that the traditional component and measurement-based methods for load modeling covered by the guide will likely need to be hybridized for future needs^[12]. **IEEE 1729–2025** provides updated guidance on distribution system modeling, extending the use of IEEE test feeders to support a broader set of use cases including steady-state, dynamic, event-based, and stochastic modeling^[13]. The standard also identifies priority areas for research and development in distribution modeling^[14]. **IEEE 2749–2023** is concerned with distribution risk assessment, with guidance that can inform both planning and operations^{[15][16]}.

- ➔ There are few standards directly concerned with specifying or providing datasets for modeling, apart from some work on standardized test feeders, and data availability remains a significant barrier to richer and more widespread modeling efforts.
- ➔ There are no IEEE standards or guides on forecasting, whether of supply, demand, prices, etc. However, some IEEE working groups and PARs are actively exploring this increasingly important topic.

Key Active Enhancements

PAR P3597 defines standard interfaces for control and protection components to power systems simulation tools. This activity reflects the increased need for EMT and transient stability modeling to understand the interactions between inverter-based resources, advanced controllers, and protection systems^[17].

Under the IEEE Distribution System Analysis Subcommittee, the **Distribution Test Feeder Working Group** is actively expanding the set of standard test feeders available, to cover a greater diversity of contexts (rural vs urban, international, etc.) and application areas (protection focused, DER focused, etc.)^[18].

On forecasting, **PAR P3436** is focused on developing a guide for electric vehicle load prediction^[19]. The **IEEE Working Group on Energy Forecasting and Analytics** develops tutorials and publishes special journal issues on forecasting methodologies and evaluation methods for a variety of use cases^[20].

2. POWER QUALITY AND VOLTAGE REGULATION

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1159–2019	IEEE Recommended Practice for Monitoring Electric Power Quality ^[21]	2029
IEEE 1250–2018	IEEE Guide for Identifying and Improving Voltage Quality in Power Systems ^[22]	2028
IEEE 519–2022	IEEE Standard for Harmonic Control in Electric Power Systems ^[23]	2032

Standardized definitions and methods for power quality measurement are covered in IEEE standards but are also addressed by IEC 61000-4-30^[24]. ANSI C84.1 complements these guides by defining nominal system voltages and acceptable steady-state voltage ranges for 60 Hz distribution systems in North America^[25]. **IEEE 1159–2019** describes power quality quantities, sets nominal levels for them, and lists monitoring devices, applications, and the interpretation of monitoring data^[21]. It includes some guidance on sensor specifications and placement. **IEEE 1159.3–2025** defines a file format for power quality data transfer^{[26][27]}.

There is some overlap between power quality measurement standards and standards on metering and monitoring systems (see Section 11), some of which may support power quality data collection.

On the power quality management side, **IEEE 1409–2012** focuses specifically on power electronic equipment to enhance distribution power quality. **IEEE 1453–2022** focuses on localizing and mitigating sources of flicker while **IEEE 1250–2018** focuses on evaluating and improving voltage

quality^{[28][22]}. **IEEE 519–2022** sets design goals for electrical systems with linear and nonlinear loads, focusing on steady-state voltage and current harmonic distortion at the point of common coupling^[23]. Voltage regulation is handled at the equipment level, with standards in the **C57** series dealing with performance and test methods for specific equipment, such as transformers and voltage regulators.

➔ While standards coverage of power quality is extensive, there is a lack of standards to support an emerging vision of power quality monitoring and management that sees diverse edge devices providing extensive power quality data which is communicated and analyzed at scale to inform issue identification and mitigation, particularly in the context of DER proliferation which introduces novel power quality impacts.

Key Active Enhancements

PAR P1564 is updating recently inactivated standard IEEE 1564–2014, which defines event, site, and system-level voltage sag indices^[29]. Quantifying and monitoring voltage sags at the distribution level is increasingly important for understanding impacts of DERs and setting ride-through thresholds^{[30][31]}.

PAR P3139 is developing guidance on power quality data analytics, covering established and upcoming methods to extract insight from diverse power quality data including time series magnitudes, phasors, point-on-wave measurements, etc.^[32].

3. RELIABILITY AND RESILIENCE

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 3006.2–2016	IEEE Recommended Practice for Evaluating the Reliability of Existing Industrial and Commercial Power Systems ^[33]	2026
IEEE 1806–2021	IEEE Guide for Reliability-Based Placement of Overhead and Underground Switching and Overcurrent Protection Equipment up to and Including 38 kV ^[34]	2031
IEEE 1366–2022	IEEE Guide for Electric Power Distribution Reliability Indices ^[35]	2032
IEEE 1782–2022	IEEE Guide for Collecting, Categorizing, and Utilizing Information Related to Electric Power Distribution Interruption Events ^[36]	2032



The **IEEE 3006** standards series focuses on power systems reliability, including individual standards for data collection (**IEEE 3006.9-2013**), reliability assessments (**IEEE 3006.2-2016**) and impact evaluation of preventative maintenance (**IEEE 3006.3-2017**)^{[11][33]}.

IEEE 1806-2021 defines analytical techniques for reliability-focused system design, specifically focusing on the placement of switching and overcurrent protection^[34].

The **IEEE 1366-2022** guide defines distribution reliability indices and their calculations for substations, circuits, and regional distribution systems^[35].

- ➔ Resilience is a relatively new topic for IEEE standardization and is the topic of a few active PARs; standardized metrics that capture nuanced aspects of resilience, such as identifying differential impacts based on community vulnerability or how impacts vary for outages of different durations, are still lacking.

Key Active Enhancements

PAR IEEE P3006.1 – IEEE Draft Recommended Practice for Reliability Planning and Design of Industrial and Commercial Power Systems, intends to extend 3006 coverage to the planning stage, providing guidance on planning systems for reliability targets^[37].

PAR P2856 defines resiliency for distribution systems and provides guidance on measuring and reporting resiliency metrics^{[38][39]}. It is led by the Distribution Resiliency Working Group under IEEE PES^[38].

Standards or guides on enhancing system resilience through physical or operational upgrades are currently limited; one example is **PAR P3443** which provides guidance on assessing and enhancing the physical resilience of substations across planning, design, construction, operations, and maintenance in the face of extreme environmental and man-made hazards^[40].

4. DISTRIBUTED ENERGY RESOURCES

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1547-2018	IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces ^[41]	2028
IEEE 1547a-2020	IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces — Amendment 1: To Provide More Flexibility for Adoption of Abnormal Operating Performance Category III ^[42]	2030
IEEE 2030.11-2021	IEEE Guide for Distributed Energy Resources Management Systems (DERMS) Functional Specification ^[43]	2031

IEEE 1547 is the core standard series for the interconnection of DER at the distribution level, with principal standard **IEEE 1547-2018** detailing requirements for, and testing of, interconnection and interoperability between DER and utility systems^[44]. The standard series covers performance, operation, testing, safety, and maintenance of DER interconnections. It also deals with specific considerations such as response to abnormal conditions, power quality, and islanding. Targeted standards in the series include **IEEE 1547.9-2022** which provides guidance on energy storage integration^{[45][46]}, **IEEE 1547.3-2023** which provides guidance on the cybersecurity considerations of DER interconnection^{[47][48]}, and **IEEE 1547.4-2011** which provides guidance on the design and operation of DER-powered optionally island-able systems^[49]. **IEEE 1547.7-2013** is an inactive-reserved standard that is not undergoing revision; it provides guidance for conducting engineering studies to assess the potential impacts of DER on distribution systems, spanning power flow, transient, dynamic, and protection studies^[50]. It outlines best practices and criteria for determining the scope and extent of such studies based on DR and system characteristics.

The **IEEE 2030** series, discussed further in Section 5, complements **IEEE 1547** through standardization and guidance on smart grid technologies which enable effective DER integration, among other value adds^[44]. Some of the standards in the 2030 series relate very specifically to smart grid solutions for DER management. For example, **IEEE 2030.11-2021** provides guidance on the functional specifications for Distributed Energy Resources Management Systems (DERMS) which aggregate DERs to enable grid services^[43]. The guide deals with implementation and interoperability considerations for DERMS.

- ➔ More advanced use cases of DERs for synthetic inertia or islanded system operation using grid forming inverters are not yet extensively covered in DER standardization efforts.

Key Active Enhancements

PAR P1547 is active and continuing to update and refine the 1547-2018 DER interconnection standard based on industry feedback^[51].

5. SMART GRID AUTOMATION AND INTEROPERABILITY

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 2030-2011	Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads ^[52]	Revision in progress
IEEE 2030.2-2015	Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure ^[53]	2025
IEEE 2030.2.1-2019	Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems ^[54]	2029
IEEE 2030.3-2016	Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications ^[55]	2026
IEEE 2030.7-2017	IEEE Standard for the Specification of Microgrid Controllers ^[56]	2027
IEEE 2030.8-2018	IEEE Standard for the Testing of Microgrid Controllers ^[57]	2028
IEEE 2030.13-2024	Guide for the development of a functional specification for electric transportation fast charging station management and control systems ^[58]	2034

The **IEEE 2030** series use an interoperability reference model that maps the data flow needed to support reliable, secure, two-way power flows, and defines the supporting communications infrastructure, including links for electric-vehicle integration^{[59][60][61]}. **IEEE Std 2030** was the first all-encompassing IEEE standard on smart grid interoperability, providing a roadmap for establishing the framework in developing IEEE national and international standards^{[62][63][52]}. The standard establishes the smart grid interoperability reference model (SGIRM) and provides a knowledge base addressing terminology, characteristics, functional performance, and evaluation criteria. **IEEE 2030-2011** provide guidelines for smart grid interoperability of the EPS with end-use applications and loads^[52].

For storage, **IEEE 2030.2** builds on IEEE 2030 and aims to provide a comprehensive guide for discrete and hybrid energy storage systems that are integrated with electric power infrastructure, including end-use applications and loads^{[53][61]}. **IEEE 2030.2.1-2019** standard applies to both stationary and mobile battery energy storage systems (BESS). It provides

guidance on connection methods (including DR interconnection), design, operation, and maintenance practices, as well as an overview of engineering considerations for BESS^[54].

IEEE 2030.3–2016 is established to provide a comprehensive set of test procedures for energy storage equipment and systems applied in electric power systems^[55].

Another key standard within the IEEE 2030 series is **IEEE 2030.7**, detailing technical specifications and requirements for microgrid controllers and their reliability. It establishes a standardized control framework for the microgrid energy management system (MEMS), to support both autonomous microgrid operation and coordinated control when interconnected with the main utility grid^{[60][56]}.

Addressing another segment of power infrastructure, **IEEE 2030.13** offers guidance on developing functional specification for electric vehicle (EV) fast charging stations. These stations may incorporate multiple fast chargers and local energy resources, with the capability to integrate DERs like solar, energy storage systems, and controllable loads, enabling operation as microgrids^{[58][60]}.

Key Active Enhancements

P2030 is active and this revision enhances the information on the seven-domain grid model, refines the application of the IEEE Smart Grid Interoperability Reference Model (SGIRM) framework following best practices, and introduces a digital version of the SGIRM^[64].

PAR P2030.7 is focused on providing technical specifications and requirements for microgrid controllers applicable across all microgrids, configuration or jurisdiction. It outlines control methods used by microgrid operators to manage assets and facilitate interactions with the electric power system^[56].

PAR 2030.14 IEEE Draft Guide for Virtual Power Plant Functional Specification for Alternate and Multi-Source generation is active and continuing to update. Requirements for grid interconnection and integration, and for interoperability with other EPS systems are being addressed^{[65][60]}.

6. TRANSPORTATION ELECTRIFICATION

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 2030.1.1–2021	IEEE Standard for Technical Specifications of a DC Quick and Bidirectional Charger for Use with Electric Vehicles ^[66]	2028

IEEE Std 2030.1.1–2021 provides guidance and specifications for interoperability between electric vehicles and DC fast chargers, addressing critical aspects of external charger integration. It ensures effective communication and control between vehicle systems and charging equipment, facilitating standardized and reliable fast-charging operations^{[66][67]}. In vehicle-to-grid (V2G) mode, electric vehicles are treated as distributed energy resources and subject to grid integration standards. These standards address power regulations, safety, power quality, and grid codes to ensure reliable EV integration. As previously mentioned, IEEE 1547 outlines the interconnection requirements for DERs on the power grid, and UL 1741 complements this by specifying standards for DER components such as power converters, controllers, and safety features^{[41][68][69]}.

- The area of electric vehicles in particular is replete with standardization efforts from non-IEEE entities, making coordination between IEEE and others more critical.

Key Active Enhancements

IEEE P2690 is an IEEE Draft Standard for Charging Network Management Protocol for Electric Vehicle Charging Systems^[70]

7. COMMUNICATIONS AND CYBERSECURITY

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1901–2020	IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications ^[71]	2030
IEEE 1615–2019	IEEE Recommended Practice for Network Communication in Electric Power Substations ^[72]	2029
IEEE 1815.1–2015	IEEE Standard for Exchanging Information Between Networks Implementing IEC 61850 and IEEE Std 1815(TM)[Distributed Network Protocol (DNP3)] ^[73]	2025
IEEE 2030.5–2023	IEEE Standard for Smart Energy Profile Application Protocol ^{[14][20][74]}	2033
IEEE 1711.2–2019	IEEE Standard for Secure SCADA Communications Protocol (SSCP) ^[75]	2029

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1686-2022	IEEE Standard for Intelligent Electronic Devices Cybersecurity Capabilities ^[76]	2032
IEEE 2030.102.1-2020	IEEE Standard for Interoperability of Internet Protocol Security (IPsec) Utilized within Utility Control Systems ^[77]	2030

The **IEEE 1901** family defines standards for data transmission over existing electrical lines – commonly referred to as broadband over power lines (BPL). It specifies both physical (PHY) and medium-access control (MAC) layers, supporting applications such as high-speed home networking to smart grid and industrial IoT^{[71][78]}. Many other aspects of networking are covered under IEEE 802 family of standards^[59], including standards for wired and wireless communication such as Ethernet (**802.3**)^[79], Wi-Fi (**802.11**)^[80], Bluetooth and low-rate wireless networks (**802.15**)^[81], and network management and security protocols (**802.1**)^[82].

Multiple other IEEE standards support aspects of smart grid communication and smart metering functionality. **IEEE 1377** defines protocol for secure, interoperable meter data exchange between utility meters and end devices^[83]. **IEEE 1815** covers electric power system communications^[59]^{[84][73]}. **IEEE 2030.5** is a leading standard for coordinated management of DERs across utility and non-utility systems. It extends beyond SCADA by supporting a wider range of devices and enabling utilities to scale DER integration and control^{[85][86][74]}.

As communication standards like IEEE 2030.5 enable greater DER integration, robust cybersecurity becomes essential, prompting the role of IEEE standards focused on securing grid communications and control systems. **IEEE 1547.3-2023** provides guidance on the cybersecurity considerations of DER interconnection^{[47][48]}. **IEEE 1711.2-2019** outlines secure communication protocols for legacy SCADA serial communications^[75]. **IEEE 1711.1** enhances earlier standards and specifies a cryptographic protocol to secure serial links, providing integrity and optional confidentiality regardless of hardware or protocol^[87]. **IEEE 1686-2022** specifies cybersecurity requirements for intelligent electronic devices (IEDs)^[76]. **IEEE 2030.102.1-2020** provides IPsec configuration guidance to ensure secure VPNs in utility control systems^[77]. **IEEE P2658** provides guidance on a framework for testing and verifying cybersecurity controls in electric power systems^[88].

Together, these IEEE cybersecurity standards support secure communication, device protection, VPN configuration, and testing frameworks essential for safeguarding modern electric utility infrastructure^[59].

Key Active Enhancements

PAR P1377 Standard for Utility Industry Metering Communication Protocol Application Layer (End Device Data Tables) is active and defines a table-based data structure for exchanging utility application data between an End Device and other devices. It does not prescribe device design, data transport protocol, or internal data storage formats^[83].

PAR 1815 standard is active and defines a communication profile for DERs using IEEE 1815 (DNP3). It maps IEC 61850-7-420:2021 data objects to fixed DNP3 data points, supports key DER and IBR functions from standards such as IEEE 1547-2018, IEEE Std 2800-2022, and IEEE Std 1547.9-2022, and includes provisions for logging and historical data in both written and electronic formats for implementation^[84].

PAR 1711.1 Draft Standard for a Cryptographic Protocol for Cyber Security of Substation Serial Links: Substation Serial Protection Protocol is a trial use standard that defines cryptographic protocol for cybersecurity of serial links with integrity and optional confidentiality, independent of underlying communications protocol^[87].

P2658 Guide for Cybersecurity Testing in Electric Power Systems outlines guidance for testing and verifying cybersecurity controls in EPS covering services, applications and comprehensive lifecycle testing^[88].

8. PROTECTION AND GROUNDING

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 3004.3-2020	IEEE Recommended Practice for the Application of Low-Voltage Fuses in Industrial and Commercial Power Systems ^[89]	2030
IEEE 2748-2023	IEEE Recommended Practice for Fault Diagnosis and Protection in Smart Distribution System ^[90]	2033
IEEE 3003.1-2019	IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems ^[91]	2029

The **IEEE 3004** series cover protection design and coordination at a systems level. Some example standards from this series include IEEE 3004.3-2020 on selection and application of fuses in distribution, IEEE 3004.5-2025 on the selection and application of circuit breakers, and IEEE 3004.11-2019 on recommended practices for bus and switchgear protection^[91]. **IEEE 2748-2023** provides recommendations on fault diagnosis and protection in smart distribution systems touching on hardware, software, and communication needs with preliminary discussion of changes introduced by DER and enhanced measurements and analytics^[90].

Several standards in the **IEEE C37** series also touch on protection, but at the device or tool level. Examples include: **IEEE C37.104–2022**, a guide on automatic reclosing, covering fundamentals, applications, and coordination practices; **IEEE C37.230–2020**, a guide on protective relays in distribution; and **IEEE C37.300–2024** which includes guidance on protection schemes, among other tooling, implemented in substation centralized protection and control systems^[92].

➔ Protection considerations in the context of growing DER penetrations are touched on in **IEEE 1547**, though advanced protection approaches are out of scope^[93]. Protection in the context of DER integration therefore remains underserved by current standardization.

The **IEEE C62** series is concerned with surges and insulation coordination, with standards covering surge arrestors, transient voltage suppressors, and test methods^[94].

The **IEEE 3003** series cover grounding, with IEEE 3003.1–2019 the only active standard, on recommended practices for systems grounding broadly^[95].

Key active enhancements

PAR P3561 defines the important components and applications of a fault location, isolation, and service restoration (FLISR) system^[96].

The **Surge Protective Devices Committee** has many active efforts to update and add standards^[97]. Of note is **PAR PC62.220** which discusses the role and application of surge protective devices in smart grids, detailing appropriate surge protection of specific smart grid technologies^[98].

9. EQUIPMENT SPECIFICATIONS, INSTALLATION, MANAGEMENT AND SAFETY

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 3004.3–2020	IEEE Recommended Practice for the Application of Low-Voltage Fuses in Industrial and Commercial Power Systems ^[99]	2030
IEEE 1863–2024	IEEE Guide for Overhead Alternating Current (AC) Transmission Line Design ^[100]	2034
IEEE 1584–2018	IEEE Guide for Performing Arc-Flash Hazard Calculations ^[101]	2028
IEEE 2845–2023	IEEE Trial-Use Standard for Testing and Evaluating the Dielectric Performance of Celebratory Balloons in Contact with Overhead Power Distribution Lines Rated up to 38 kV System Voltage ^[102]	2033

IEEE standards coverage of specifications, installation, management, and safety considerations for individual power system components is extensive. As already touched on in other sections, **IEEE C37** covers switchgears, relays, and circuit breakers^[92]. Transformer specifications are

covered in the IEEE C57 series; a few standards outside this series deal with highly specific technical aspects of transformers, such as **IEEE 1276-2020** on the application of high-temperature insulation materials in liquid-immersed power transformers^[103]. The **IEEE 3007 series** focus on operations, maintenance, and safety at a system level. While these standards are widely referenced and used, they are currently inactive, and it does not seem that they are being actively revised^[11].

The **IEEE 400** series cover testing of underground cables^[104]. **IEEE 1863-2024** provides guidance on AC overhead line design across both distribution and transmission, covering electrical, structural, and meteorological considerations. **IEEE 2417-2022** provides guidance on prevention, detection and response to underground cable failures that can release toxic gas and large amounts of energy, leading to fires or explosions. IEEE does not have standards specifically on utility wood poles; **ANSI O5.1-2022** is the standard used in practice in North America, covering minimum specifications, materials, dimensions, and classes for poles^[105].

Arc flashes are a major safety concern in power systems; **IEEE 1584-2018** provides guidance on performing arc-flash hazard calculations, to determine the hazard distance and incident energy to which workers may be exposed^[101].

In a testament to the coverage and specificity of IEEE standards, the **IEEE 2845 series**, consisting of a single active standard, addresses safety procedures to mitigate outages caused by distribution line contact with metallic celebratory balloons^[102].

- ➔ Resilience is an emerging area of IEEE standardization; this should percolate to standards around equipment for grid hardening and resilience enhancement.

Key Active Enhancements

PAR P1814 provides guidance on distribution system design to enhance worker safety, covering equipment and protection system design^[106].

PAR P3546 outlines best practices for developing and maintaining arc flash electrical safety programs across substations, underground and overhead lines, and associated equipment, covering all stages from planning and analysis to PPE, procedures, and risk mitigation for AC and DC systems^[107].

PAR 2845 is active and supersedes the 2023 trial standard. This standard tests the dielectric performance of foil party balloons near energized distribution lines to reduce balloon-related electrical faults and outages^[108].

PAR 3476 covers unique identification numbers for electric grid assets, including generation, transmission, substations, distribution, storage, and EV charging stations, to support traceability^[109].

10. ENVIRONMENTAL AND SUSTAINABILITY IMPACTS

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1127-2023	IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility ^[110]	2033
IEEE 1613.1-2023	IEEE Standard for Environmental and Testing Requirements for Devices with Communications Functions used with Electric Power Apparatus ^[111]	2033

A few IEEE standards deal with assessing the environmental and sustainability impacts of distribution components. **IEEE 1127-2023** provides guidance on integrating community and environmental acceptance and compatibility criteria into substation design, construction, and operation^[110]. **IEEE 1613.1-2023** defines environmental testing requirements for communications networking equipment installed in transmission and distribution facilities^[111].

Key Active Enhancements

Life cycle assessment is a key tool in environmental and sustainability impact assessment, it offers a systematic approach to evaluating the environmental impact of a product or process across its entire life, from raw material extraction to final disposal. IEEE standards are currently lacking coverage of life cycle assessment for distribution system components; some work in this area is ongoing for specific component types. **PAR PC57.151** will provide guidance on life cycle assessments for transformers and shunt reactors^[112]. **PAR P3567** will do the same for fiber-reinforced composite electric power equipment^[113].

PAR P3560 will provide guidance on assessing the carbon footprint of EV supply equipment^[114].

11. METERING, MONITORING, AND ANALYTICS

SELECTED REPRESENTATIVE STANDARDS

NUMBER	TITLE	EXPIRATION
IEEE 1459-2025	IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions ^[115]	2035
IEEE/IEC 60255-118-1-2018	IEEE/IEC International Standard — Measuring relays and protection equipment — Part 118-1: Synchrophasor for power systems — Measurements ^[116]	2028
IEEE C37.239-2010	IEEE Standard for Common Format for Event Data Exchange (COMFEDE) for Power Systems ^[117]	2030
IEEE 2815-2024	IEEE Guide for the Technical Specification of the Smart Distribution Transformer Terminal ^[118]	2033

Standards for electric metering measurements in North America are covered by the ANSI C12 series, with ANSI C12.1-2024 being the core standard defining acceptable performance criteria for watt-hour meters^[119]. **IEEE 1459-2025** extends the metrology specifications of ANSI standards to dispel confusion on the definition of power quantities under varied waveform conditions^[115]; **IEEE 1159-2019** provides guidance on monitoring power quality quantities^[21]. Several IEEE standards cover technical aspects of meters beyond measurement, with rich standards on communications. **IEEE 1704-2021** defines standards for hardware interfaces and signals between metrology devices and communication modules^[120]. **IEEE C57.13-2016** standardizes requirements for instrument transformers that intercede between meters and system infrastructure^[121]. IEEE 2815-2024 guide outlines the functional and technical specifications for smart distribution transformer terminals used in distribution network monitoring and operation^[118]. Meter communication considerations are covered by **IEEE 1901 series** which covers power line communication and **IEEE 2030.5-2023** which defines a communication protocol for utility management of customer consumption to enable demand response and other applications, this standard constitutes the link between smart metering and smart grid applications^[74].

Additional IEEE standards cover different meter types or measured quantities. **IEEE 2960-2023** provides guidance on lab testing of DC electric meters^[122]; **IEEE 644-2019** presents standard procedures to measure electric and magnetic fields around AC power lines^[123].

Synchrophasors provide high resolution (10s-100s of Hz) time-synchronized measurements of voltage and current magnitudes and phase angles; they are increasingly valued to support state estimation, oscillation monitoring, and high frequency event detection. Synchrophasor measurement is standardized in **IEEE/IEC 60255-118-1-2018**^[116]. **IEEE C37.118.2-2024** standardizes synchrophasor data communication^[124]. **IEEE C37.242-2021** provides guidance on synchronization, calibration, testing, and installation of synchrophasor devices^[125]. **IEEE C37.247-2019**

standardizes the role and functionality of phasor data concentrators, which aggregate synchrophasor data from multiple devices^[126]. There is increasing interest in going beyond synchrophasors to deploy point-on-wave sensors that continually measure AC power waveforms (kHz); this is essentially a continuous, synchronized version of digital fault recorder data. IEEE standards and guides on this measurement type are minimal. The only relevant standards are both expired: **IEEE/IEC C37.111-2013** defines COMTRADE^[127], a format for exchange of transient waveform and event data; **IEEE C37.239-2010** defines a format for event data exchange^[117]. Updates to these standards are being considered^{[128][129]}. The Power System Relaying and Control Committee is considering the need for continuous point-on-wave standards^[130].

- ➔ Data from smart meters, synchrophasors, and other monitoring devices needs to be processed through appropriate analytics to derive operationally useful insights. This is a nascent area for IEEE and there are no IEEE standards and guides on data analytics for distribution applications, though some are under development.

Key Active Enhancements

PAR P3005.7 defines the best practices for the use of electrical metering in industrial and commercial energy management. It covers meter types, placement, power quality monitoring, and metering techniques^[131].

The Sensors Subcommittee of the Power Systems Instrumentation and Measurement Committee is actively developing several new standards, guides, and technical notes, including **P2681** which will provide guidance on testing MV smart grid sensors^[132].

PAR P3159 provides guidance on understanding and evaluating electricity meter operating error from meter measurements themselves^[133].

A few data analytics standards are under development. **P3139** is developing guidance on power quality data analytics^[32]. The relatively recent **IEEE Working Group (WG) on Machine Learning for Power Systems** has two task forces exploring the development of standards, guides, and other activities related to reinforcement learning for power systems control and generation of synthetic power systems data^[134].

12. DATA SHARING AND PRIVACY

Data sharing and privacy are related and cross-cutting issues across many power systems applications and components. In general, privacy concerns drastically limit the sharing of distribution system data, including for research and development applications. However, emerging load types especially large data centers and AI computing clusters, are creating highly dynamic, dense, and often opaque demand patterns. Enhanced visibility into these data-intensive loads is critical for accurate forecasting, effective demand-response coordination,

and long-term distribution planning. Broader data access, under standardized privacy and anonymization frameworks, would enable utilities, researchers, and system operators to jointly optimize system performance while safeguarding proprietary and sensitive information.

- While many IEEE standards deal with secure data communications, standards discussing broad data sharing and privacy considerations are essentially absent. A tangentially relevant example is **IEEE 2800-2022** (and **PAR P2800.2**) which discusses standardization and sharing of IBR models for the purposes of validating interconnection requirements^[41].

Key Active Enhancements

Synthetic data generation or the anonymization of real-world data are two pathways to overcome data privacy concerns and increase data sharing. The relatively recent **IEEE WG on Machine Learning for Power Systems** has a task exploring generation of synthetic power systems data^[134].

III | Enabling the Grid of the Future

Identifying and prioritizing standardization gaps is guided by the evolving expectations of future power systems. To meet ambitious decarbonization goals while reliably supporting rapid electrification and growing digital demand, power grids worldwide must undergo a profound transformation. Distribution systems will be at the center of this change as rising DER penetration and transport electrification will amplify low-voltage power-flow volatility and more frequent extreme weather events will test the resilience of vulnerable low-voltage infrastructure. At the same time, rapid demand growth from digital infrastructure, particularly for artificial intelligence (AI) applications, introduces new demand profiles at the local and regional scale while also requiring a very high bar of supply reliability and quality. A brief overview of the goals set for the coming decades — 2030, 2040, 2050 — and the scale of investment and expansion they demand, contextualizes and motivates the IEEE standardization gaps identified in this report.

2030 | The United States federal goal of 100% clean electricity by 2035 drives unprecedented grid modernization requirements^[135]. By 2035, grid capacity must triple from 2020 levels to meet federal goals^[136]. Wind and solar will provide 60–80% of generation. At the same time, an estimated \$2 trillion will need to be invested in grid modernization by 2030 just to maintain reliability^[137]. Globally, transmission and distribution networks will have to expand at an annual rate of two million kilometers till 2030 in order to reach 2050 net-zero (NZE) targets^[138]. At a more localized level, digital infrastructure will drive substantial demand growth, requiring targeted grid strengthening.

2040 | By 2040, the European Commission has recommended cutting net greenhouse-gas (GHG) emissions to 90% below 1990 levels, a target intended to keep the EU on a credible pathway to climate neutrality by 2050 and net negative emissions thereafter. Achieving this target hinges on first delivering the 55% reduction already slated for 2030 and then rapidly scaling up mitigation across every sector. To meet the target, the commission has determined that clean power must scale up to meet a demand of 5210 TWh, constituting up to 87% of total electricity supply. Other building blocks of this significant decarbonization effort including increased use of biofuels, green hydrogen expansion, and carbon capture^{[139][140]}.

2050 | Reaching global net-zero by 2050 will require a \$21.4 trillion investment in grids, with annual investment tripling from \$274 billion in 2022 to \$871 billion during the 2040-to-2050 period^[141]. The transition will require an estimated 80 million kms of new grid infrastructure — as much as the entire existing global grid^[141].

IEEE standards play a pivotal role in realizing this vision. They distill collective technical expertise and field experience into practical guidance, accelerating the safe adoption of emerging

technology, in turn allowing the sector to learn from the successes and failures of first movers. The iterative refinement of IEEE 1547 standards for DER interconnection is a perfect example of how lessons learned from early deployments can quickly propagate through the sector. Since IEEE standards are often developed through collaboration between researchers and practitioners, they can help disseminate cutting edge techniques to advance the entire sector. Finally, IEEE standards help lower barriers to innovation, assuage concerns about new technologies, build stakeholder confidence, and support the regulatory approvals needed for massive grid investments.

Altogether, this makes IEEE standards and guides instrumental in realizing a resilient, reliable, responsive and decarbonized future grid.

IV | Critical Standardization Gaps

The following section identifies critical standardization and guidance gaps that should be prioritized by IEEE. For each gap, corresponding themes matching those used to structure the standards inventory are identified. While the current standards summary of Section II covered standards by theme, the gaps relate to multiple themes, this reflects the reality that IEEE coverage of individual components and applications is often very thorough, and that the most urging needs now arise at the intersections of technologies, sectors, and disciplines. Closing these gaps will require coordination across multiple IEEE Societies and Working Groups to maintain alignment between standards related to topics such as planning, operations, cybersecurity, and data exchange.

The gaps are synthesized in Table I, which includes multi-dimensional scoring of each, ultimately feeding into a suggested prioritization and timing of gap filling efforts by IEEE. This prioritization surfaces near-term opportunities where targeted standards development can provide the largest system-wide value, particularly around standardized planning objectives and DER hosting-capacity assessment, development of resilience valuation and social-impact metrics, establishment of open data frameworks for distribution modeling, and guidance on advanced smart-meter applications that support widespread grid-edge visibility.

1. COMPREHENSIVE OPEN DATA FOR DISTRIBUTION MODELING

Themes | *System Design, Planning and Modeling, Data Sharing and Privacy*

IEEE test distribution feeder models play an important role in enabling the development of new distribution solutions (evidenced by the number of citations of^{[142][143]}). These open models are considered canonical by both developers and prospective users of new distribution technologies, enabling developers to test their approaches in realistic contexts and giving users confidence that novel solutions will work in practice. However, the test feeders alone fall short of enabling realistic modeling for technology development and validation^[144].

To overcome these limitations, there is need for a new generation of open-access datasets that integrate measurements, ideally time-synchronized, high-resolution voltage, current, and load time series, with detailed network metadata including geographic information, device parameters, etc. Data sharing and usability will be greatly facilitated if datasets adhere to standardized schemas aligned with IEEE C37.239 (COMFEDE), IEEE 1159.3 (PQDIF), and IEC CIM data models, which would enable seamless sharing and use across utility, academic, and vendor platforms.

More comprehensive open datasets are especially critical for accelerating AI and machine-learning applications in power-systems, across varied applications including forecasting, control, and anomaly detection. The current scarcity of representative test cases and scenario data constrains the development of robust AI models that generalize across varied network topologies and operational conditions. Coordinating open data creation with IEEE's ongoing work under P3139 (power-quality data analytics), P3159 (meter error evaluation), and P2681 (smart grid sensor testing) would help establish data frameworks and sources for open data efforts.

A major roadblock to data sharing in the power sector is concern around privacy. IEEE guidance on the sensitivity of different data sources, anonymization methods, privacy-preserving analytics, and synthetic-data generation could accelerate progress in this area^[144]; this relates closely to Gap 11 described further in the section.

With regard to the particular open data sets that should be prioritized, high-resolution load datasets, with at least minutely temporal resolution and capturing sufficient seasonal and climatic diversity should be the first priority. Realistic load data enables the development and validation of valuable algorithms for forecasting and control. By driving realistic power flow simulations, this data can also support validation of situational awareness and fault localization algorithms. IEEE should develop standardized load datasets that align with IEEE test feeder models. To this end, IEEE working groups can partner with organizations such as Pecan Street, NREL's SmartDS, EPRI's DRIVE, that have collected high-resolution, and even disaggregated, household load data^[145].

Subsequent work should focus on developing time-synchronized voltage and current datasets suitable for electromagnetic-transient (EMT) and stochastic analyses, together with open, well-documented models for controllers, inverter-based resources (IBRs), and measurement devices.

Finally, the establishment of a permanent IEEE data repository or federated data-exchange framework, possibly hosted under the IEEE DataPort platform, would institutionalize these activities and ensure mechanisms for access, citation, and governance of open distribution-system datasets.

2. FORECASTING GUIDES AND STANDARDS

Themes | *System Design, Planning and Modeling, Reliability and Resilience*

Forecasting is a growing priority in energy systems with more dynamic demand and supply. Intermittent, distributed renewables and end-use electrification motivate forecasting at higher spatial and temporal resolution than utilities have traditionally conducted, while also motivating more sophisticated techniques for long-term forecasting to inform system planning. Currently, forecasting methodologies are highly varied across utilities^[146].

IEEE's coverage of forecasting, however, remains sparse. The only ballot-ready project is the guide for EV charging load forecasting at dispatch centers. In the absence of more IEEE guidance, forecasting methodologies and efforts tend to be ad hoc and fragmented, making comparison and validation challenging. Currently, stakeholders turn to varying non-IEEE sources such as IEC TR 63043:2020 for renewable energy power forecasting technology^[147] and IEC 62325-450:2013 framework for energy market communications^[148]. At the same time, forecasting methodologies are growing increasingly complex — and potentially opaque. Emerging international efforts on probabilistic and ensemble forecasting (e.g., IEA Wind Task 36 and NREL's hybrid statistical-physics methods) are pushing industry practice beyond the deterministic approaches typically used in North America.

While standardizing forecasting methods may be too prescriptive, IEEE can play a leading role by defining standardized protocols for forecast evaluation and uncertainty quantification. Establishing shared accuracy metrics would significantly improve comparability across tools and vendors. Standardized evaluation metrics would, in turn, help utilities more effectively select forecasting approaches or vendor solutions. Improvements in forecast quality enabled by such frameworks can reduce operational costs and enhance reliability.

Consistency in evaluation practices is also essential for regulators and planners, who increasingly rely on demand and DER forecasts to justify multi-billion-dollar investment programs. Transparent, auditable evaluation standards would increase confidence in long-term forecasts used in rate cases and investment proceedings, reducing the opacity and methodological variability that currently characterize many integrated resource plans^[149].

In the near term, standardized evaluation of demand forecasts should be prioritized, as these are already informing long-term infrastructure investments and enhancements. Medium-term priorities should include standardized evaluations for distributed renewable and AI/data-center load forecasts, which are emerging as major sources of uncertainty in local grid planning. Further out, standardized evaluations can support the choice of climate and weather forecasts which inform resilience planning; this work could align with IEEE P2856 (Resilience Metrics) and P3139 (Power-Quality Data Analytics) to integrate forecast-driven resilience assessments into distribution-planning processes, as discussed in Section 3.

3. DISTRIBUTION NETWORK PLANNING GUIDES AND STANDARDS

Themes | *System Design, Planning and Modeling, DER, Reliability and Resilience*

IEEE lacks comprehensive standards for distribution system planning criteria and procedures. While the IEEE 3000-series provides strong guidance on system design and reliability assessment, there is still no unified IEEE standard that establishes a consistent framework for distribution system planning. As a result, planning practices vary widely across utilities and jurisdictions, particularly in integrating DER forecasting, hosting capacity, resilience valuation,

and electrification impacts. Best practices that integrate reliability and resilience targets into planning, building on recent progress at IEEE on both these fronts, could bring significant value to the industry and help justify investment plans to regulators.

This gap could be addressed through the development of an IEEE guide for distribution system planning that harmonizes planning inputs, study procedures, and evaluation metrics. Such a guide could be structured to align with and integrate existing guidance on distribution planning — such as established in DOE’s DSPx initiative, NARUC’s planning principles, and EPRI’s DRIVE methodology — while also integrating resilience and probabilistic approaches from IEEE P2856 and IEEE 1729. The guide should explicitly address emerging challenges, including high-density data center and EV load growth, non-wires alternatives, and climate adaptation. Finally, providing guidance on how to connect planning outcomes to transparent investment justifications would improve regulatory confidence and advance shared objectives for equitable, data-driven grid modernization.

4. DISTRIBUTION POWER QUALITY MONITORING AND ASSESSMENT

Themes | *Power Quality and Voltage Regulation, Metering, Monitoring, and Analytics, DER*

Power quality (PQ) data is typically considered and collected in a spatially and temporally narrow manner, for example through expensive, high-resolution PQ meters that are temporarily deployed for PQ surveys at sensitive load sites. However, the proliferation of inverter-based resources (IBRs) and power electronics broadly in distribution networks heightens both the prevalence and consequence of PQ issues in distribution. For example, IBRs are known to increase harmonic distortion^[150]; at the same time, IBRs are susceptible to tripping due to power quality deviations, driving the need for well-defined ride through requirements^[151].

Beyond harmonics, additional PQ challenges are emerging, including voltage unbalance driven by uncoordinated single-phase DER deployments, sub-synchronous oscillations arising from IBR interactions, and high frequency switching noise that is often not detected by conventional PQ meters. Many existing measurement frameworks remain centered on 60 Hz fundamental quantities, whereas future distribution monitoring will need to support broadband frequency and time-domain analytics at sub-cycle resolution.

In this context, **IEEE standards and guides to enable more pervasive and richer PQ monitoring in distribution**, followed by analysis and mitigation methods, would be valuable to the industry, helping to assuage concerns about adverse PQ impacts by and on DERs and thereby to accelerate DER deployment. Specifically, IEEE could define standardized requirements for PQ data acquisition, synchronization, and reporting frequency across devices such as advanced metering infrastructure (AMI), distribution PMUs, and smart inverters. Harmonizing these interfaces with IEEE 1159 (PQ Monitoring), IEEE 1159.3 (PQDIF format), and the emerging IEEE P2681 (smart grid sensor testing) would enable scalable and interoperable monitoring architectures.

IEEE can also provide guidance and standards on establishing a utility power quality monitoring program, covering numbers, locations, and types of sensors to deploy. Such a guide could include adaptive placement methodologies using feeder topology, DER concentration, and historical PQ incident data to optimize sensor coverage. Guides or standards can also discuss how resulting measurements can be processed into useful aggregate power quality performance metrics, similar to existing metrics for voltage sags defined in IEEE 1564-2014. Future metrics could extend to harmonic distortion indices, phase unbalance severity, and dynamic voltage quality scores compatible with resilience assessment frameworks. The development of standardized PQ metrics should also leverage modern analytics, including AI-driven event classification and PQ signature libraries, while aligning with IEC 61000-series electromagnetic compatibility standards and IEEE P2800 guidance for bulk power-connected IBR performance. Work on this gap could align well with Gap 10 on advanced smart-metering use cases and with the IEEE P3139 project on power-quality data analytics, establishing a coherent end-to-end framework from measurement to interpretation.

5. DISTRIBUTION RESILIENCE METRICS

Themes | *Reliability and Resilience*

While IEEE P2856 is under development, no current IEEE standards comprehensively address distribution system resilience definitions, metrics, and assessment procedures^[38]. Utilities lack standardized approaches to define and quantify distribution system resilience, develop resilience improvement strategies, measure resilience performance over time, and compare resilience across different systems^[152]. IEEE P2856 aims to establish a foundational taxonomy of resilience concepts: covering absorptive, adaptive, and restorative capabilities, and further work focused on translating these qualitative definitions into quantitative metrics.

One of the key gap areas not currently addressed by developing IEEE standards is a methodology to quantify the value of resilience in terms of societal and economic benefits; such a framework would enable utilities and regulators to evaluate and justify resilience investments based on transparent, evidence-based metrics rather than subjective decision-making. The absence of standardized valuation methods leads to significant inconsistency in cost-benefit analyses for resilience investments including grid-hardening, DER microgrid development, and undergrounding initiatives. An IEEE resilience-valuation guide could build on DOE's Grid Resilience Metrics Framework, NARUC's Resilience Valuation Principles, and emerging probabilistic approaches that link resilience outcomes with customer interruption costs and critical-load weighting.

A further gap concerns the development of a societal-impact metric for storm and disaster events. Although this remains a critical area, IEEE has not yet initiated formal work in this domain. Such a metric could quantify community-level disruption through indicators such as outage duration weighted by critical-load importance (e.g., hospitals, water facilities),

business downtime, and the proportion of vulnerable customers affected. The leadership team is prioritizing the publication of the initial set of resilience metrics under P2856 before expanding to these broader domains. Over the longer term, IEEE could pursue an enhanced alternative to the Interruption Cost Estimator (ICE) model, specifically tailored to long-duration, high-impact events. This framework would explicitly capture impacts on end-users, thereby linking technical system performance with socioeconomic outcomes.

Future work on resilience metrics should also be coordinated with IEEE 1729 and the 3000-series, as well as emerging planning and forecasting standards, to ensure the resilience indicators are directly embedded in system design, planning, operations, and investment decisions.

6. ELECTRIC VEHICLE INTEGRATION GUIDANCE AND STANDARDIZATION GAPS

Themes | *Transportation Electrification, Communications and Cybersecurity*

IEEE has assembled a layered portfolio of standards that addressed most, but not all, technical facets of electric-vehicle integration. At the grid edge, IEEE 1547 remains the cornerstone interconnection rule for treating vehicles and aggregations of chargers as DERs. On the charging side, IEEE 2030.1.1 provides functional and electrical specifications for a DC fast and bidirectional chargers, while the recent IEEE 2030.13-2024 standard specifies functional requirements for fast charging station management systems and their unique characteristics and capabilities, including interactions with the bulk power system and other nearby DERs^[153]. For operational communications, the IEEE 2030.5 protocol with its V2GAC profile that's under test provides a standardsbased implementation guide for SAE J3071^{[154][155][156]}. Together these standards give utilities a credible toolkit for interconnection and control.

Several gaps nevertheless remain. IEEE offers no specification for megawatt-class heavy-duty vehicle charging, an area now led by ChargePoint's Megawatt Charging System (MCS) initiative, which targets power charging of up to 2,000 A for heavy-duty vehicles^[157]. Connector harmonization is also outside IEEE's scope; an SAE task force is standardizing Tesla's North American Charging Standard (NACS) plug as SAE J3400 to address interoperability in the light duty segment^[158]. On the data side, the communication between charger and central management systems is driven by Open Charge point protocol (OCPP 2.0.1) under the Open Charge Alliance^[159] and IEC's EV charging and discharging management standard 63110^[160]. Whereas the communication between EV communication controller (EVCC) and EV supply equipment communication controller (SECC) is advanced through ISO 15118-20^[161].

In summary, IEEE standards now cover interconnection, site hardware, and utility-to-charger communications, but high-power connectors, backend communication standards, universal backend protocols, and unified cybersecurity frameworks are being filled by external bodies like SAE. Coordinated engagement with these external bodies will be essential for IEEE to close the remaining gaps and deliver a seamless, secure V2X ecosystem.

7. DISTRIBUTED ENERGY RESOURCES – HOSTING CAPACITY AND INTERCONNECTION STUDIES

Themes | *Distributed Energy Resources, System Design, Planning and Modelling*

Hosting capacity and interconnection studies are critical to enabling and accelerating the deployment of DERs in distribution networks. However, these studies are currently very varied in their specifics, with utilities individually defining their preferred study methodologies. As previously mentioned, IEEE's interconnection framework is anchored in IEEE 1547-2018, which prescribes requirements for, and testing of, interconnection and interoperability between DER and utility systems^[41]. Companion guides once filled the methodological gap for engineering studies, most notably IEEE 1547.7-2013 which provided guidance on assessing DER impacts on distribution networks, but this guide was withdrawn in 2024 with no direct replacement under development, leaving utilities without up-to-date guidance for conducting hosting capacity screening and impact studies^[50].

As a result, utilities lack standardized methods for calculating or mapping hosting capacity. In practice, most U.S. utilities now rely on internally developed or state commission mandated hosting-capacity methods (e.g., California ICA, New York DPS HCA), which vary in data granularity, temporal resolution, and screening thresholds. A new IEEE guide could unify these approaches under a consistent analytical and data framework. A refreshed standard could also prescribe common, machine-readable data schemas for public maps and define workflows that synchronize distribution studies with transmission constraints, aspects currently addressed by IEC TS 63276:2024^[162] on grid-integration studies for distributed resources.

The priority would be standardization of hosting capacity evaluation metrics for static DER interconnections, followed by approaches to more complex dynamic DER interconnection. Subsequent efforts should incorporate time-series analysis, voltage-regulation interactions, and DER ride-through modeling to reflect operational hosting capacity. Data standardization would take time and effort but is also an important priority to streamline studies.

8. ADVANCED PROTECTION FOR HIGH DER PENETRATION

Themes | *Distributed Energy Resources, Protection and Grounding, System Design, Planning and Modelling*

The increasing deployment of DERs fundamentally alters distribution system fault behavior. Traditional radial protections schemes which are designed for unidirectional fault current can be miscoordinated or fail entirely in DER rich environments due to multidirectional or reversed power flows, the reduced fault current contribution from inverter-based resources (IBRs), and the dominance of converter control dynamics^[163]. While IEEE 1547-2018 and its companion guides address certain aspects of DER ride-through and anti-islanding, they do not comprehensively

cover how DERs affect conventional protection solutions and how advanced protection solutions can be leveraged in feeders with high DER penetrations.

Research is active on developing advanced protection schemes for DER including adaptive and communication-assisted protection, traveling-wave and differential protection for feeders with limited fault current, and AI/ML-based analytics leveraging high-resolution waveform and synchrophasor data^{[164][165]}.

IEEE guidance and standardization on advanced protection for DER-rich distribution systems can guide utilities to implement best practices for reliable and safe DER integration. Standardized approaches can also help accelerate DER deployment by streamlining protection design and mitigating concerns related to adverse protection impacts. Future IEEE efforts could develop application guides on adaptive protection coordination, IEC 61850-based communication schemes for protection devices, and interoperability requirements for microgrid protection controllers. This work would build on IEEE 2748-2023, which discusses recommendations for fault diagnosis and protection in smart distribution systems, considering the impact of DER connections^[90].

9. GUIDANCE ON DISTRIBUTION HARDENING METHODS

Themes | *Reliability and Resilience, Equipment Specifications, Installation, Management and Safety*

Increasingly frequent extreme weather events disproportionately impact the more extensive and more exposed infrastructure of the distribution network, significantly undermining reliability. There has been a nearly 70% increase in major power outages from weather-related events since 2000^[166]. At the same time, particularly in the western United States, distribution failures can intersect with extreme heat to exacerbate wildfire risk. In the face of climatic change, utilities must urgently undertake grid hardening, such as conductor replacement, structural reinforcement, selective undergrounding, and enhanced vegetation management.

There is currently no IEEE standardization of guidance on the range of distribution system hardening options, of which there are many^[167], and how to assess, select, and target hardening interventions. Other organizations, including DOE's Grid Modernization Laboratory Consortium (GMLC) and EPRI's Resilient Distribution Initiative (GRIDResilience), have proposed resilience taxonomies and documented case studies, but there is still no standard engineering guide which translates these concepts into standardized evaluation and selection methodologies.

Building on this foundation, IEEE guidance on targeting grid-hardening activities, including use of resilience and risk modeling, and cost-benefit optimization frameworks, could help ensure that limited hardening resources are deployed efficiently. Such guidance could include structural criteria developed in coordination with ASCE and outline methodologies for prioritizing hardening measures, for example in high fire-threat areas. This work would build

well on ongoing IEEE standardization efforts, including definitions of resilience from PAR P2856 and guidance on enhancing substation physical resilience from PAR P3443^{[38][40]}.

10. ADVANCED SMART METER USE CASES

Themes | *Power Quality and Voltage Regulation, Metering, Monitoring, and Analytics*

Smart meters have been broadly deployed in the United States to support automated billing, saving utilities on manual meter reading costs. As of 2022, nearly 120 million smart meters have been deployed, covering about 72% of all meter installations^[168]. Many smart meters, particularly more recent devices such as AMI Class 1 and Class 2 devices compliant with ANSI C12.20 and IEC 62053 standards, have capabilities far beyond their initial billing use case: they can measure higher resolution quantities such as voltage sags, swells, harmonics, and phase angle or frequency deviation^[169]. Smart meters therefore represent a dense, underutilized sensing network already embedded in the grid that can greatly expand distribution network visibility. Despite this potential, current standards largely overlook advanced smart meter use cases such as harmonic monitoring, voltage imbalance detection, and event-driven waveform capture.

IEEE can fill this gap by developing performance criteria, accuracy classes, and interoperability profiles for smart-meter based power quality monitoring, along with standardized data formats and reporting intervals compatible with IEEE 1159.3 (PQDIF) and IEC 61850-90-2. This would help utilities extend the value of existing infrastructure, support compliance with IEEE 519-2022 harmonic limits, and enable more resilient and efficient grid operation in the face of growing inverter-based loads. A near-term, low-effort priority would be guidance on advanced smart metering use cases and corresponding infrastructure needs to drive activity and investment in this area; this would be followed by technology and performance standards defining sampling rates, data granularity, and cybersecurity requirements for PQ-enabled meters.

11. DISTRIBUTION DATA SENSITIVITY AND SHARING GUIDANCE

Themes | *Data Sharing and Privacy, System Design, Planning and Modeling, Metering, Monitoring, and Analytics*

As noted in Section 12, IEEE guidance or standards on data sharing and privacy for distribution systems applications is highly limited. Without clear guidance on what constitutes sensitive data and how to properly anonymize data before sharing, utilities and other sector participants air on the side of caution and share almost no data. This inhibits research and development, knowledge sharing, and operationally relevant modeling activities (such as validation of end-use equipment behavior or IBR interconnection).

By providing guidance on data sharing and privacy considerations, IEEE can significantly increase the amount of data sharing for distribution use cases. A low-hanging fruit is to classify and publish categories of non-sensitive or de-identified data that can be shared without privacy risk. More open data will accelerate progress across numerous topics, as discussed in Gap 1 on open data. In general, greater data availability will enable richer and more robust distribution system applications and tools, spanning AI/ML solutions, digital twins, and probabilistic methods.

Following guidance on data sensitivity assessment, IEEE could develop recommended practices for anonymization, differential privacy, and synthetic data generation methods, building upon frameworks such as the DOE's Grid Data Initiative and NIST's Privacy Framework 1.0. Though requiring greater effort, these standardized approaches would be highly valuable for accelerating secure, widespread data dissemination.

In some cases, such as for data center or industrial load models, data owners consider the data simply too sensitive to share^[170]. IEEE can encourage sharing by identifying minimal shareable parameters or privacy-preserving subcomponents of data, and standard metadata definitions to support anonymized or synthetic dataset generation.

In other cases, such as for IBR models, data sharing is inhibited by a lack of standardization rather than privacy concerns. In such cases, IEEE standards can help align specifications for data or models to ease the usability of shared data. Recent progress through IEEE 2800-2022 and PAR P2800.2 on model validation and data exchange for inverter-based resources provides a strong foundation for broader data-sharing guidance.

12. PREDICTIVE MAINTENANCE

Themes | *Reliability and Resilience, Metering, Monitoring, and Analytics, Equipment Specifications, Installation, Management and Safety*

Predictive maintenance leverages varied monitoring data and targeted analytics to preemptively detect signs of equipment degradation and failure, so that proactive action can be taken and outages avoided. Given the increasingly long lead time to procure equipment such as transformers, predictive maintenance can have significant positive impacts on utility performance and revenue^[171]. High resolution sensors such as phasor measurement units (PMUs) and distributed fiber-optic sensing (DFOS), have already demonstrated value for monitoring asset health and measuring signatures of incipient failure^[172]. Online dissolved gas analysis (DGA), partial-discharge monitoring, and thermal imaging are likewise being incorporated into predictive maintenance frameworks for critical assets, including transformers, cables, and circuit breakers. ML/AI approaches are a promising tool for this use case, however more data sharing (also noted as a priority for IEEE standardization and guidance efforts in Section 11), is needed to enable accelerated and scaled analytics development and validation.

IEEE standardization and guidance can guide utilities on monitoring approaches and analytics techniques that are proven or emerging for predictive maintenance, thereby clarifying the opportunity space and accelerating progress. Because major equipment failures are relatively infrequent, it is often difficult to rigorously justify the investment costs of a predictive maintenance program. Here IEEE guidance can define probabilistic modeling approaches to quantify the value of predictive maintenance programs. This work could build on technical foundations similar to IEEE 2749-2023 (on risk assessment), IEEE 1806-2021 (on reliability-centered system planning), and IEEE P1205^{[16][34]}. IEEE can also build on the strength and depth of existing IEEE equipment standards, such as detailed transformer standards in the C57 series, to identify which quantities should be monitored and what signal signatures may indicate incipient failure or degradation.

13. GRID-FORMING INVERTER-BASED RESOURCES

Themes | *Reliability and Resilience, Distributed Energy Resources*

Grid forming inverters can support islanded operation of distribution networks, maintaining voltage and frequency without a conventional synchronous source. This capability for advanced system management could potentially enhance power-system resilience and reliability: for example, during extreme weather events where the bulk grid may experience an outage, a distribution network can remain energized and operate as a DER-powered microgrid. Pilot projects of this type are already widespread^[173]. In a future vision where distribution networks contain many such islandable subsystems, grid-forming inverters can also enable system restoration and black-start support for both microgrids and feeder-level islands^[165].

IEEE can build on its extensive DER standardization and guidance work in the 1547 and 2030 series to provide guidance and standardization on this new use case of IBRs. This work would build on IEEE standards related to islanding and microgrid control, and synchronization dynamics for inverter-dominated systems.

A near-term, accessible priority would be to provide guidance on locating island-able IBR powered microgrids to enhance reliability and resilience. As such systems move past the pilot stage, this guidance would set the stage for standardization of GFM control modes (droop, virtual synchronous machine, and dispatchable virtual oscillator control), coordination across multiple grid-forming units, and interoperability with grid-following inverters and protection systems.

V | A Roadmap for Filling Standards Gaps

The full set of standards gaps of Section IV are synthesized in Table I below. The standards are sorted into groups and periods to indicate when they will be most relevant and important to address. Individual granular gaps, grouped under topics, are scored from one to five along three dimensions: level of effort, regret, and criticality, each of which is defined below. The scores are aggregated into an overall ranking score, where a lower score indicates a higher priority gap. The ranking is complemented by a timeline, to show how gap filling efforts order and build on each other, and when a gap becomes pressing relative to DER penetration rates. Four highest priority gaps that could concretely and immediately progress to IEEE working group efforts are highlighted; these comprise standardized planning objectives, resilience valuation, a resilience metric focused on social impact, and standardized hosting capacity evaluation.

Item	Level of effort [1-5] Regret [1-5] Criticality [1-5] Overall Ranking				Standardization Gap (top priority items marked in <i>green</i>)	Increasing DER penetration →		
	1 is always best – lowest effort, least regret, most critical, top priority					Near-term	Medium-term	Long-term
Comprehensive Open Data for Distribution Modeling								
1	2	2	3	11	Standardized high-resolution load profile datasets			
2	3	2	4	19	Standardized high-resolution voltage & current datasets			
3	4	3	3	25	Realistic models of controllers and inverters			
Forecasting								
4	3	1	2	6	Standardized evaluations for long-term load forecasting			
5	3	1	2	6	Standardized evaluations for long-term weather forecasting for reliability and resilience planning			
6	2	3	4	19	Guide on forecasting methods and evaluation			
Distribution Network Planning								
7	1	1	2	1	Standardized planning objectives, incl. for DER			
8	3	1	2	6	Guides on integrating resilience into planning			
Distribution Power Quality Monitoring and Assessment								
9	4	2	3	19	Guides on pervasive PQ monitoring – temporal & spatial resolution			
10	3	2	3	15	Standardized PQ performance metrics			

Item	Level of effort [1-5] Regret [1-5] Criticality [1-5] Overall Ranking				Standardization Gap (top priority items marked in green)	Increasing DER penetration →		
	1 is always best – lowest effort, least regret, most critical, top priority					Near-term	Medium-term	Long-term
Distribution Resilience Metrics								
11	2	1	1	1	Resilience valuation			
12	2	1	1	1	Social impact focused resilience metric			
13	3	2	3	15	Standardized resilience evaluation methods for cross comparability			
Electric Vehicle Integration								
14	2	2	2	6	Standardized backend communication protocol and cybersecurity framework			
15	2	2	3	11	Guides on integrating vehicle-to-everything (V2X) ecosystem under high electrification			
DER Hosting Capacity and Interconnection Studies								
16	2	1	1	1	Standardized metrics for hosting capacity evaluation w/o flexibility			
17	4	3	3	25	Standardized data formats and types for interconnection studies			
18	3	2	2	11	Standardized metrics for hosting capacity evaluation w. flexibility			
19	4	2	2	15	Guides on dynamic hosting capacity analysis			
Advanced Protection for High DER Penetration								
20	5	2	2	19	Standards on protection studies under high DER			
21	4	3	4	28	Guides on advanced protection methods			
Distribution Hardening Methods								
22	2	1	4	11	Guide on distribution hardening options			
23	4	2	3	19	Guides on analytical approaches to targeting hardening			
Advanced Smart Meter Use Cases								
24	1	1	3	5	Guides on advanced smart meter use cases (PQ, event detection, DR)			
25	3	2	3	15	Standards for meter firmware/hardware to enable advanced use cases			
26	4	2	3	19	Sampling and communications methods for advanced use cases			
Distribution Data Sensitivity and Sharing								
27	2	1	3	6	Guide on rating sensitivity of distribution data inventory			
28	3	3	4	25	Guide on distribution data sharing - anonymization, risks, benefits, etc.			
Predictive Maintenance								
29	2	1	4	11	Guides on proven techniques and use cases			
30	3	1	4	15	Guides on valuing predictive maintenance efforts			
Grid-forming IBRs								
31	3	2	2	11	Guides on locating islandable IBRs for resilience and reliability			
32	5	2	3	25	Standards on integration and control of optionally islandable IBRs			
33	5	2	3	25	Safety standards for optionally islandable IBRs			

TABLE I. Standards gaps roadmap. Standards are prioritized by period (near, medium, long-term) based on when they are likely to become most relevant and needed. Definitions of the scoring categories are below.

DEFINITIONS	
Level of effort	How challenging is it to produce guidance or a standard on given topic? Encompasses time, technical complexity, variety, and number of stakeholders.
Regret	What is the greatest possible downside of the effort? Reflects the risk that a standard may become obsolete or irrelevant if expected futures, like specific DER adoption levels or technologies don't materialize, leading to wasted effort on the part of IEEE.
Criticality	How critical is the guidance/standard to achieving clean energy integration and system performance targets?
Overall Ranking	For each gap item, we sum above three scores and then rank the item relative to all others; a lower number indicates higher priority.

NOTE: The ranking presented in this section is intended as a decision-support framework rather than a prescriptive ordering of IEEE standards opportunities. Scores reflect a qualitative, judgment-based assessment using the criteria and information available at the time of this analysis and are meant to help organize and compare opportunities, not to exclude other potential efforts. Individual utilities, regulators, and IEEE Working Groups may reasonably adjust the relative weighting of criteria or reprioritize topics based on their specific policy, system, and stakeholder contexts.

Beyond 2040, when DER penetration and electrification are expected to be significantly advanced, a suite of nascent concepts will be poised to evolve into full IEEE standards. Potential areas for standards development at that time include an **IEEE Guide for Sector Coupling Standards** integrating electricity with heat and mobility infrastructure; an **IEEE Standard for Advanced Energy Storage Integration** covering hybrid battery, thermal, and hydrogen systems for large scale storage system coordination; and an **IEEE Standard for Smart-City Energy Systems** that links microgrids, building automation, and edge intelligence under a common interoperability framework. These topic areas remain broad and uncertain; their specifics will crystallize as the energy system evolves toward 2040. They will also build heavily on the work of nearer-term standardization priorities. In any case, listing these topics here provides a long-term vision for the role and scope of IEEE standardization.

VI | Conclusion and Recommendations

This report surveys the current landscape of IEEE standards related to electric distribution systems, identifies critical gaps, and outlines a roadmap for future standards development aligned with grid modernization and decarbonization goals. Analysis in Section II confirms that IEEE's current standards portfolio underpins core functions of modern distribution systems including system planning, electrification, power quality, DER interconnection, smart grid automation, and cybersecurity. However, the review in Section IV highlights that rising DER penetration, rapid electrification, and climate-driven impacts demand standardization and guidance beyond the scope of existing standards.

The report identified key standardization gaps related to forecasting methodologies, distribution network planning, resilience metrics, electric vehicle integration, DER hosting-capacity assessment, advanced protection for high-inverter systems, and advanced use cases for smart meters. Where gaps exist, utilities and regulators are defaulting to a patchwork of regional or vendor-specific practices. These gaps, if unaddressed, risk increasing costs, further slowing interconnection queues, and creating regulatory uncertainty. A coordinated IEEE response is therefore essential to harmonize methodologies and, in turn, accelerate technology adoption that is vital to realizing the energy transition.

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