

IEEE Guide for Smart Distribution Applications

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

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Transmission and Distribution Committee
of the
IEEE Power and Energy Society

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Abstract: Important smart distribution applications are categorized, descriptions of the critical functions involved are developed, important components of these systems are defined, and examples of the systems that can be considered as part of distribution management systems or other smart distribution systems are provided in this guide.

Keywords: capacity, distribution, efficiency, grid, hosting, IEEE Std 1854, market, power, power quality, reliability, smart

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Introduction

This introduction is not part of IEEE Std 1854-2025, IEEE Guide for Smart Distribution Applications.

Many smart distribution applications are integral to an Advanced Distribution Management System (ADMS). Some of these applications include:

- Supervisory control and data acquisition (SCADA)
- Outage management
- Demand response
- Asset management
- Fault location, isolation, and service restoration (FLISR)
- Volt-var optimization (VVO)
- Distributed energy resource management system (DERMS)
- Renewable generation integration

These applications are enabled by distribution line devices such as sensors, switches, reclosers, regulators, and capacitors. Automating these devices using advanced logic provides the foundation for distribution applications. Deploying two-way communications with automation enhances this foundation and enables smart distribution applications. Implementing these applications can support improvements to system reliability, power quality, system efficiency, and distribution system hosting capacity. This guide focuses on leveraging distribution line devices to enable smart distribution applications and may provide some of the following quantitative benefits (ignoring qualitative benefits that are difficult to monetize or calculate):

- System reliability, accelerating and facilitating the response to system disturbances and major storm events. This can reduce outage time and overall customer impact because of reduced outage costs. ([Clause 6](#))
- Power quality ([Clause 7](#))
- Efficiency of the electric distribution power system ([Clause 8](#))
- Hosting capacity of the distribution power system ([Clause 9](#))

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IEEE Guide for Smart Distribution Applications

1. Overview

1.1 Scope

This guide identifies and categorizes important smart distribution applications, develops descriptions of the critical functions involved, defines important components of these systems, and provides examples of the systems that can be considered as part of distribution management systems or other smart distribution systems. This guide includes discussion on control, communications, and cybersecurity considerations when deploying smart distribution applications.

1.2 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may equals is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can equals is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

There are no normative references for this guide.

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

advanced distribution automation: The integration of analytical decision making and supervision to execute decisions with distribution automation (DA) devices to improve the operation of the electric distribution system.

advanced distribution management system (ADMS): A software platform that includes utility systems and supports distributed energy resources (DER) integration. It also includes the controllability of legacy devices and implements different functionalities. These include fault location, isolation, and service restoration (FLISR); conservation voltage reduction (CVR); Volt-var optimization (VVO)/control (VVC); and demand response.

advanced metering infrastructure (AMI): The communications hardware and software and associated system and data management software that creates a network between advanced meters and utility business systems. Allows collection and distribution of information to customers and other parties, such as competitive retail providers, and provides it to the utility itself.

centralized control: A single location or system, either staffed or supervisory, that is responsible for controlling multiple connected devices.

combined heat and power (CHP): Cogeneration including technologies using a variety of fuels to produce electricity or power and heat.

conservation voltage reduction (CVR): The practice of using voltage reduction, within predefined parameters, whenever possible to promote energy conservation and during specific time periods to reduce demand load.

data warehouse: Provides data storage functions for future reference and can also provide a source of information to maintenance, work management, other programs and systems, and advanced system analysis.

decentralized control: Coordinated locations or systems that are responsible for independently controlling multiple groups of operating devices.

demand response (DR): Change in customer power consumption to better match the demand for power with the supply.

distributed energy resource (DER): A source of electric power that is not directly connected to a bulk power system, as defined in IEEE Std 1547™-2018 [B62].⁹ DER includes both generators and energy storage technologies capable of exporting active power to an electric power system (EPS). An interconnection system or a supplemental DER device that is necessary for compliance with IEEE Std 1547-2018 [B62] is part of a DER.

NOTE—Controllable loads used for demand response are not included in the definition of DER.¹⁰

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁹ The numbers in brackets correspond to those of the bibliography in Annex A.

¹⁰ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

distribution automation (DA): A technique used to limit the outage duration and/or customers interrupted. It also is used to restore service to customers through fault location identification and automatic switching. A legacy term some in the industry still use is “smart distribution automation.” For the purposes of this guide, smart distribution automation is the same as DA.

distribution automation device (DA device): Any device incorporating one or more processors capable of data acquisition and/or control from or to an external source (e.g., electronic multifunction meters, digital relays, controllers).

distribution management system (DMS): A collection of applications designed to monitor and control a distribution network efficiently and reliably.

fault location, isolation, and service restoration (FLISR): An application utilities often use to improve reliability across their distribution systems. It manages outages and recovers from them quickly. FLISR has been used interchangeably with other industry terms including Fault Detection, Isolation, and Restoration (FDIR); Fault Isolation Service Restoration (FISR); and Fault Location, Isolation, and Restoration (FLIR). For the purposes of this guide, FLISR is used.

faulted circuit indicator (FCI): A single- or multi-phase device designed to sense fault current and provide an indication the fault current has passed through the power conductor(s) at the point where this sensor is installed.

remote terminal unit (RTU): A device/function that serves as the primary interface (the data concentrator function) between a protection and control system and a SCADA system to provide operational data visibility to, and perform command operations from, the SCADA control center. (IEEE Std C37.2™ [\[B56\]](#))

smart grid: The integration of power, communications, and information technologies for an improved electric power infrastructure serving loads while providing for an ongoing evolution of end-use applications.

smart meter: A microprocessor-based electronic device that records consumption of electric energy and provides two-way communications to report the meter data on a periodic basis to the utility for monitoring and billing purposes.

supervisory control and data acquisition (SCADA): A function used to indicate monitoring and controlling devices that are physically located remotely from a centralized computer. Some form of communication is implied between the central location and the outlying devices.

voltage regulator (transformer type): An induction device having one or more windings in shunt with and excited from the primary circuits and having one or more windings in series between the primary circuits and the regulated circuit, all suitably adapted and arranged for the control of the voltage, the phase angle, or both, of the regulated circuit.

volt-var control (VVC): A function that manages voltage and reactive power flow on the electric distribution system to achieve utility specified operating objectives that include maintaining acceptable conditions at all times and improving feeder efficiency and performance.

volt-var optimization (VVO): A function that manages voltage and reactive power flow on the electric distribution system to achieve optimal performance by minimizing energy consumption, electrical losses, and peak electrical demand.

3.2 Acronyms and abbreviations

ADMS	advanced distribution management system
AMI	advanced metering infrastructure
CHP	combined heat and power
COTS	commercial off-the-shelf
CVR	conservation voltage reduction
DOE	Department of Energy
DR	demand response
DA	distribution automation
DER	distributed energy resource
DERMS	distributed energy resource management system
DMS	distribution management system
EMS	energy management system
EPS	electric power system
FCI	faulted circuit indicator
FDIR	fault detection, isolation, and restoration
FISR	fault isolation service restoration
FLIR	fault location, isolation, and restoration
FLISR	fault location, isolation, and service restoration
LTC	load tap changer
LTE	long term evolution
MAS	multiple address system
ONR	optimal network reconfiguration
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
THD	total harmonic distortion
UPS	uninterruptible power supply
VVC	Volt-var control
VVO	Volt-var optimization

4. Introduction to smart distribution applications

Modern distribution systems are not always passive, simple distribution automation (DA) functions (e.g., auto transfer, main-tie-main, simple loop schemes) that rely on local sensing and control with no communication. However, further improving integrity and system reliability typically requires access to timely information and the ability to remotely control distribution grid elements through automated devices based on their sensor inputs and programmed logic.

Historically, smart distribution applications were not widely deployed due to several factors such as a large number of components and significant investment to automate the system. Today, many utilities are moving toward adopting smart distribution applications due to the following:

- Increasing customer dependence on reliable power and service quality
- Implementing bidirectional power flow
- Changing social and regulatory drivers
- Improving communication technologies

While new devices may have modern features, such as communications, remote control, and automation capabilities, much of the present infrastructure is composed of older, yet still very functional, devices that cannot support a utility's smart distribution applications. A smart distribution application is enabled by a distribution line device equipped with supervisory control and data acquisition (SCADA) capability and communications to the designated control authority. Some older distribution line devices, for example, gang operated switches, become available for smart distribution applications when retrofitting line post sensors for voltage and current monitoring.

As utilities move toward smart distribution applications, it is advantageous for utilities to develop objectives that will guide them through efficient implementation of smart distribution applications by evaluating short-term, mid-term, and long-term objectives to meet the utility's needs. For example, a short-term objective may be to install standalone line sensors in proximity to older generation devices. While not affording any control ability, this could provide relevant operating information, such as current, conductor temperature, voltage, etc.

Placing additional sensors throughout the system at key locations brings additional visibility to the operators. However, for one example, mid-range and long-range plans may be to replace these older generation devices as they approach end of life with devices that support smart distribution applications. While DA objectives are critical to effective and efficient implementation of smart distribution applications, the focus of this guide is on the implementation of smart distribution applications and not on the development of DA objectives. (IEEE Std 1547.3™-2007 [B64], US. Dept. of Energy "Distribution Automation..." [B105])

A smart distribution application incorporates the following:

- Measurement of distribution component states or values
- Communication to and from a processor
- Analysis and decision-making by the processor
- Supervision to execute the decisions the processor makes

These items are discussed for smart distribution applications in general, and some sample applications [e.g., Volt-var optimization (VVO)] are described in some detail within this guide.

5. Needs of smart distribution applications

All smart distribution applications can leverage sensors that measure states or technical values of distribution components, communications to and from DA devices, processing for analysis and decision-making, and supervision of the execution of decisions made by the processor.

5.1 Sensor measurements and controls

Sensors can measure the following:

- Line currents
- Line-to-ground voltage
- Capacitor current
- Neutral current
- Real and reactive power
- States, such as switch position, load tap changer (LTC) tap position
- Continuous voltage and current
- Load current (Amps)
- Instantaneous fault currents
- Conductor motion/vibration
- Timestamp
- Gas content
- Phase current
- Temperature
- Frequency

Sensor data can be post event processed into the following:

- Estimated fault location
- Fault waveform signature
- Power factor
- Perceptibility of short-term flicker (Pst)
- Perceptibility of long-term flicker (Plt) IEEE Std 1453-2015 [B61]

The following monitoring and control capabilities are recommended at each DA site:

- Power measurements (e.g., per phase basis: Volts, Amps, MW, Mvar, MVA, and power factor)
- Remote control
- Fault detection
- Power quality (harmonics up to 30th) and % total harmonic distortion (THD)
- Asset health monitoring (e.g., contact wear, oil/gas measurements, oil level, liquid level, temperature)
- Device and equipment status (e.g., open/closed state, control blocked/unblocked state, failed to operate, pump status)
- Smart distribution device health monitoring

The capability to externalize the SCADA data provides benefits that continue to be realized. As an example, a substation maintenance engineer can review the SCADA event data to perform preliminary diagnostics in preparation for routine maintenance and equipment repair. Another example would be where a distribution engineer may use SCADA event data to research system disturbances affecting system reliability.

The ability to collect data from multiple sites along the distribution feeder and to synchronize the event data has been invaluable in expediting the identification of the problem or disturbance as well as its remediation (Forte, Pires and Warren [B44]). In recent years, DA systems have reported the magnitude of major storm events before customers begin reporting service outages. This capability provides the service restoration engineers and teams advance notice in planning and implementing the response to system disturbances. The distribution planning engineer can use the ability to determine the real time voltage profile along the distribution feeder to maintain acceptable voltage levels within prescribed regulatory limits.

The DA system provides invaluable self-diagnostics to improve system availability. System data is used to monitor system health and to detect and manage disturbances to improve the continued availability of the DA system's monitoring, reporting, and controlling capabilities. Additionally, web-based tools or DA system integration interfaces can provide the DA data to the enterprise without creating an undue burden on the host system.

This means the distribution engineer, the planning engineer, the maintenance engineer, etc., all have access to the same views and data as the operating engineer. Thus, an enterprise-wide distribution team has the necessary real time data to facilitate coordinated and efficient responses to system disturbances and maintenance requirements as well as historical data to review larger scale asset optimization and potential impacts of future system changes.

5.2 Communications technologies

Communication is a key element of smart grids and enhances smart distribution applications (IEEE Std 2030™-2011 [B70]). It provides a means for integration of DA devices installed across the power system into the smart grid (IEEE Std C37.1-1994 [B55]). Some of the key objectives for smart grid communications networks are as follows (Bavarian and Lampe [B9]):

- *Reliability*: Uninterrupted and failure free communication for data transmission is necessary to support DA applications.
- *Affordability*: The communications network needs to be affordable to provide a positive return on investment and justify the cost benefit analysis.
- *Compatibility*: The communications network needs to be compatible with existing systems to provide platforms for integration, interoperability, and interchangeability of all systems involved in DA applications.
- *Security*: Secure communications and data privacy are important considerations for data communications through both public and private communications networks. A risk based approach should be used to determine what physical and cyber security are required for the smart distribution applications. Communications network capabilities should also be assessed to help ensure it can support the necessary security controls and the overhead it may introduce (e.g., data encryption).
- *Availability*: Sufficient bandwidth and latency are important for smart distribution applications to help ensure they can provide the desired functionality and responses.
- *Scalability*: The communications network must be scalable to support hundreds to thousands of DA devices across an entire utility distribution system.
- *Other objectives*: Some of the other key objectives for the communications networks include the ability to provide remote connectivity to the DA devices because SCADA operators remotely monitor and manage them. Also, the communications network needs to be fault tolerant (e.g., redundant communications routes) when there are communication network impairments so the DA applications can continue to function and provide the operational improvements they are designed to provide.

There are also other important elements to consider when selecting a communications network, such as data classification. These include data characteristics (how data is created and how the information is used in application) and data requirements (such as rate of occurrence and volume, time sensitivity (latency and processing time) (Bavarian and Lampe [B9]). Data classifications are based on ensuring information is securely and effectively transferred, and each communications interface should be assessed for providing the necessary data characteristics it must support (IEEE Std 1453-2015 [B61]). Table 5–1 from IEEE Std 2030-2011 [B70] is a good reference to use when assessing data classifications and data characteristics.

IEEE Std 2030-2011 [B70] establishes two broad categories of communications media available for DA applications: wireline and wireless solutions. The following communication solution descriptions provide additional detail behind the different communication media and describe how they support the key smart grid communication network objectives that enable the smart distribution applications mentioned within this guide.

Wireline communication technologies include the following:

- *Power line communications (PLC)*: Data is transmitted over the existing power lines using PLC devices attached to the conductors. Some of the main advantages are use of existing infrastructure, coverage is provided where power lines exist, and cost is comparable with wireless communication solutions. Some of the main disadvantages are electromagnetic interference and signal attenuation/distortion.

Faults on the coupled phase may cause additional signal attenuation. PLC system designers must consider these cases when analyzing channel performance and worst-case signal-to-noise ratio. PLC can typically meet the key objectives for smart grid communications mentioned above, but designers must determine whether the reliability objectives of the particular smart distribution application can be met.

- *Telephone lines*: These dedicated leased lines or utility owned lines over traditional copper telephone lines can be used to provide connectivity to DA devices. The main advantage is the technology is well known and can be at a lower cost than other alternatives. The disadvantages are similar to those of power line carriers: low reliability, interference, and higher latency.

In many areas, there are additional requirements for more electric isolation of these telephone lines, and this typically increases their cost. Also, many telecommunications providers are removing these and replacing them with newer communications solutions, so their availability has become more limited. Telephone lines can meet some of the key objectives for a smart grid communications network but again may not be able to meet the reliability objectives depending on the smart distribution application used.

- *Fiber-optic communication systems*: These are expected to be more widely deployed to accommodate demanding high speed, reliability, and overall data requirements in smart grid applications (Bavarian and Lampe [B9]). Fiber-optic cables are commonly used in underground DA and are the only communications media that can help ensure high speed and required latency that could be required by some smart distribution applications.

The main advantages are extremely high bandwidth to support increasing data transmission, high data packet security, and resistance to EMI and other similar electromagnetic phenomenon that makes them good candidates for installation along power lines as well. The key disadvantages of fiber are cost of installation, vulnerability to vehicle accidents, and damage in storm scenarios (in overhead circuits).

Storm damage ranges from a single outage during an extreme weather event ranging from a pole mounted transformer to wide-area damage involving large numbers of customers. The most extreme examples of wide-area damage include tornadoes, hurricanes, and icing events. Fiber-optic communications attached to overhead lines are subjected to the same level of damage experienced by the distribution line. Fiber-optic communications, while costly, can meet all the other key objectives mentioned for a smart grid communications network that supports the smart distribution applications mentioned in this guide.

Wireless communications technologies include the following:

- *Radio networks:* Radio networks were used as one of the first communications media in early days of DA deployments, using mesh and multiple address system radios. These networks present robust communications (Northcote-Green and Wilson [B81]). A disadvantage is the typical need for a line of sight between radios. Terrains with mountains and obstructions may require more radios, and in some areas regulatory restrictions of communication pole or tower height may limit cost effective deployments.

Radio networks come in two types: licensed and unlicensed. Licensed radio networks are those that have a license to operate in a certain frequency band and are protected from interference from other users, so they generally provide higher reliability and lower latency than unlicensed radio networks (US. Department of Energy “Communications Requirements...” [B104]). Unlicensed radio networks do not require a license to operate but must accept interference from other radios using the same spectrum, so they can reduce the reliability of the communications and increase the overall latency (US. Department of Energy “Communications Requirements...” [B104]). Because of these differences, use careful consideration when selecting a radio network for smart distribution applications to help ensure the key communication objectives can be supported.

- *Public carrier cellular communication systems:* Public carrier cellular communication systems are widely available, and many utilities use cellular networks for a communications solution for overhead DA devices and smart distribution applications. The main advantage of these systems is that wireless infrastructure is provided and maintained by a service provider, so the upfront costs may be lower. Some of the main disadvantages are that the infrastructure is not controlled by a utility, and a utility may have to change the modems if the provider discontinues the support on legacy technology or devices. Also, the service level agreements for cellular communications may vary and could impact service reliability during congested times on the cellular network or in storm situations where priority across the cellular network may be given to first responders over utility communications needs.

In general, public carrier cellular communications can meet the key objectives for smart grid communications, but the overall reliability may be less than what some smart distribution applications require.

- *Private long term evolution (LTE) cellular communications systems:* Private LTE cellular communications systems are becoming available, and some utilities are deploying these networks to support their DA devices and smart distribution applications. The utility typically owns and operates these systems, or it can pay other public cellular carriers to install and maintain the network for them.

The main advantages of these systems are the ability for the utility to design the system to meet its communications needs and requirements, the ability to separate its communications from public cellular spectrums, and to help ensure the utility has priority for its communications needs. The main disadvantages are the upfront cost is typically higher than the public carrier cellular communication option, the ability to acquire cellular radios that support a utility’s spectrum may be limited, and the coverage area may be limited.

In general, private LTE communications can meet the key objectives for smart grid communications, but the overall reliability may be less than what some smart distribution applications require.

- *Satellite communication systems:* In many remote areas (usually away from major population centers), satellite is the only (economically viable) form of communication and may be a solution to consider for connecting remote assets where other communications infrastructure is not available. There are many commercially available options for satellite data and voice services, and there are some recent developments where new low orbit satellite options are becoming available to increase the availability of these solutions.

The main advantages of satellite communications are the extensive coverage area and the overall high reliability. The main disadvantage is satellite communications typically have higher latency and lower bandwidth than the other wireless technologies mentioned. Therefore, satellite communications can meet some of the key objectives for a smart grid communications network but may not be capable of meeting the ones necessary to support a given smart distribution application.

- *Wireless mesh networks* (Bavarian and Lampe [B9]): These may provide connectivity over a selected geographic area. Typically, the network is based on a radio based network supplied by a vendor and enables a variety of smart distribution applications. These networks are being deployed as part of larger metering infrastructure programs utilities undertake to deploy smart meters.

The main advantages include a level of resilience (e.g., redundant communications routes) for localized disturbances, such as communication faults or in storm conditions, and growth and expansion completely under utility control. The main disadvantages are lower bandwidth (kbps to single digit Mbps) and a higher latency (1 –1.5 s). They also may cost more upfront than some of the other wireless media mentioned here. Therefore, wireless mesh networks may not be able to meet all key objectives for a smart grid communications network or some of the requirements for smart distribution applications.

Communication protocols and overall smart grid architecture should be in place to take advantage of smart grid applications that use DA devices. A number of communications protocols enable communication between DA devices and a central control system or between each other (peer-to-peer communication systems or decentralized control).

Some of these protocols are proprietary and are very likely to limit communication to devices of a same manufacturer. In the last two decades or so, there has been a larger industry push toward the use of standards such as IEEE Std 1815™-2012 (DNP3) [B69] and IEC 61850 Manufacturing Message Specification (MMS) and Generic Object Oriented System Event (GOOSE) [B54] to overcome the lack of interoperability between different DA device suppliers. For more information on typical communication protocols used in DA devices see Annex B of IEEE Std 1615™-2019 [B68].

When smart distribution applications connect to distributed energy resource (DER) systems, IEEE Std 1547.1™-2020 [B63] requires devices to support at least one of the following three protocols: SunSpec Modbus, IEEE Std 2030.5™-2018 [B71], and IEEE Std 1815-2012 (DNP3) [B69].

5.3 Analysis and decision making

A decision on centralized versus decentralized control can significantly impact the overall system architecture. These decisions are based on a utility's size, service territory, and overall operating environment. Many utilities are, however, deploying hybrid systems, such as decentralized control, for areas where high reliability is required along with minimization of restoration times and centralized control for normal operation. Some areas typically requiring high reliability are portions of the distribution circuit serving emergency services (e.g., hospitals, police and fire services, and other critical services).

Empowered by DA devices, sensors, and the communications network, DA helps facilitate attaining smart distribution goals to achieve many qualitative benefits (offset by associated costs). Both goals and benefits are both briefly covered in the guide but are widely available in published literature (Wang, Martino, Reilly and Lu [B108], EPRI "Guidebook for Cost/Benefit Analysis..." [B40], NRECA [B82]. The transition to a next generation smart grid leverages the DA system architecture using distribution line devices and provides improved operating capabilities using advanced applications. DA technologies are deployed throughout a utility's service territory to achieve a wide-area deployment strategy.

Some DA systems are built off the operational foundation SCADA systems provide (IEEE Std 1815-2012 [B69]). However, other DA systems can operate independently from SCADA, with or without reporting key information and operations back to a central SCADA control/operator. Indeed, both centralized and decentralized automation can be established to work together in a coordinated way.

Decentralized DA systems can be created to operate independently as a first level of automation. Through communication links to centralized SCADA systems, they can achieve the second level of automation that expands the range of alternative automated remediation actions from the original few substations and associated feeders to a broader portion of the system.