

IEEE Trial-Use 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 1854™, market, power, power quality, reliability, smart

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Introduction

This introduction is not part of IEEE Std 1854-2019, IEEE Trial-Use Guide for Smart Distribution Applications.

Many applications are being considered as part of smart distribution system development and distribution management systems. These applications can include advanced automation and supervisory control and data acquisition systems for reliability improvement, outage management systems, fault location and fault management, voltage and var management systems, distributed resource and renewable generation integration, demand response systems, advanced protection systems, equipment diagnostics and asset management, real time simulation for system optimization, microgrids, and many others. Terminology and descriptions of these systems are not standardized, which makes it difficult to develop specifications for these functions as part of planning and developing smart distribution systems. This guide categorizes important smart distribution applications, develops descriptions of the critical functions involved, defines important components of these systems, and provides examples of the systems. The guide is a reference for distribution planners and designers and will be a living document that can expand and grow as technology and the applications change over time.

Acknowledgments

Figure 14 is from Goel, Wu, and Wang, 2008 [B47]. Reprinted with permission from DTU Electrical Engineering.

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IEEE Trial-Use Guide for Smart Distribution Applications

1. Overview

1.1 Background

Modern distribution systems are not always passive systems. Maintaining integrity and operating the system requires reliable access to timely information and the ability to remotely control distribution grid elements through automated devices and their sensors.

Although the distribution system is the main connector and direct link between the transmission system and customer, for some utilities the integration of distribution automation (DA) and associated technologies is lagging those of generation and transmission systems. This could be partially attributed to the large number of components and significant investment needed to automate the system. However, with the increasing customer dependence on reliable power and expectations of quality of service, bi-directional power flow, social and regulatory drivers, and developments in communication technologies opportunities are emerging, and many utilities are moving toward the modernization of distribution systems using DA.

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 are not capable of supporting DA objectives. As utilities move toward smart distribution technologies, it is advantageous to install standalone line sensors in proximity to these older generation devices. While not affording any control ability, this could provide relevant status information such as current, conductor temperature, voltage (e.g., switch opened or closed), etc. Placing additional sensors throughout the system at key locations brings additional visibility to the operators (IEEE Std 1547.3™ [B60]). A smart distribution application incorporates:

- 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 made by the processor

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

1.2 Scope

This guide categorizes important smart distribution applications, develops descriptions of the critical functions involved, defines important components of these systems, and provides examples of the systems; however, it does not describe in detail what technologies and communications support what smart distribution applications, which can be found in widely available published literature (as shown in the bibliography).

2. 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.¹

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 metering infrastructure (AMI): The AMI-SEC taskforce defines AMI as the communications hardware and software and associated system and data management software that creates a network between advanced meters and utility business systems and which allow collection and distribution of information to customers and other parties such as competitive retail providers, in addition to providing it to the utility itself.

combined heat and power (CHP): CHP or cogeneration includes 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: A 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.

demand response (DR): A change in the power consumption of a customer to better match the demand for power with the supply.

distribution automation (DA): A technique used to limit the outage duration and/or customers interrupted and restore service to customers through fault location identification and automatic switching.

distributed energy resource (DER): Source of electric power that is not directly connected to a bulk power transmission system. DERs include both generators and energy storage technologies.

distributed generation (DG): Electric generation facilities connected to an area electric power system (EPS) through a point of common coupling (PCC); a subset of distributed energy resources (DERs).

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

fault location, isolation, and service restoration (FLISR): Application often used by utilities to improve reliability across their distribution systems as it manages outages and recovers from them quickly.

¹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

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

intelligent electronic device (IED): Any device incorporating one or more processors with the capability to receive or send data/control from or to an external source (e.g., electronic multifunction meters, digital relays, controllers).

load tap changer (LTC): A selector switch device, which may include current interrupting contactors, used to change transformer taps with the transformer energized and carrying full load.

long-term evolution (LTE): Long-term evolution is cell phone terminology. Current phones run 4G LTE (i.e., the fourth generation or cell signal (4G) with LTE packets). The FCC spectrum bands for LTE are 700 MHz for commercial services, 1900 MHz for personal communications service, 2300 MHz for wireless communications services, and 600 MHz for broadcast television UHF band.

microgrid: A group of interconnected loads and distributed energy resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid connected or island mode.

multiple address system (MAS): The Federal Communication Commission designation for a set of frequency pairs in the 928 MHz to 952 MHz range.

remote terminal unit (RTU): A piece of equipment located at a distance from a master station to monitor and control the state of outlying power equipment and to communicate the information back to the master station or host. RTU is becoming an embedded function in distribution devices. *See:* **intelligent electronic device**.

smart distribution: The integration of power measurements, two-way communications, analytical decision making, and supervision to execute decisions to improve the delivery of electric energy.

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 generic term 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.

var: An abbreviation for volt-ampere reactive used to express reactive power in an ac electric power system. Reactive power exists in an ac circuit when the current and voltage are not in phase.

volt var control (VVC): A general term that encompasses the entire topic of managing voltage and reactive power flow on the electric distribution system to achieve utility-specified operating objectives, which include maintaining acceptable conditions at all times and improving feeder efficiency and performance.

volt-var optimization (VVO): A general term that encompasses the entire topic of managing voltage and reactive power flow on the electric distribution system to achieve optimal performance whose objectives include minimizing energy consumption, electrical losses, and peak electrical demand.

voltage regulator: A device that controls voltage output within a specific range when the voltage input and connected load are within specified ranges.

3. Needs of smart distribution applications

All smart distribution applications rely on 1) sensors that measure states or technical values of distribution components, 2) communications to and from either an RTU or an IED, 3) processing for analysis and decision making, and 4) supervision of the execution of decisions made by the processor.

Sensors can measure the following:

- Line currents
- Line to ground voltage
- Capacitor current
- Neutral current
- Real and reactive power
- States, such as switch position, LTC tap position
- Continuous voltage and current
- Load current (A)
- Instantaneous fault currents
- Conductor motion/vibration
- Time-stamp
- 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™ [B58])

Communication is an essential element of smart grid (IEEE Std 2030™ [B65]). It provides means for integration of intelligent electronic devices (IED) installed across the power system into the smart grid (IEEE Std C37.1™ [B66]). Some of the key objectives of smart grid communications network are as follows (Bavarian and Lampe [B9]):

- Reliable communication for data transmission.
- Affordability: due to the coverage area of a typical distribution system, the communication networks should be affordable.
- Compatibility with legacy (existing) systems to provide platforms for integration, interoperability, and interchangeability of legacy systems as well as new ones.
- Security of communications and privacy, which are especially important for data communications through public communications networks.

- Bandwidth and latency: depending on the device and application, various alternatives should be available. For example, for communication assisted protection, low latency with high probability of low latency is a prerequisite such that only fiber optic or dedicated spread-spectrum radio as a medium can fulfill that requirement. For other switching devices, cellular or satellite communications would be sufficient, but a typical wireless mesh network with high latency would not be a candidate for switching operation but rather, for example, for voltage regulator setting changes.
- Scalability.
- Remote management and fault tolerance.

Important elements to consider when selecting communications network are data classification in terms of characteristics (how data is created and how it is used in application) and data requirements (such as rate of occurrence and volume and time sensitivity (latency and processing time)) (Bavarian and Lampe [B9]).

There is a variety of communications media available today and most utilities are using a mix of media. The two broad categories of communications media are wired and wireless solutions.

Wire and cable-based communication solutions include the following:

- Power line carriers (PLC): data is transmitted over the existing power lines. This is an old and proven concept used widely. Some of the main advantages are: use of existing infrastructure, coverage is provided where power lines exist, and cost is comparable with wireless technologies. Some of the main disadvantages are electromagnetic interference, distorted signals, and reliability issues, since connection may be lost when the phase they utilize is faulted.
- Telephone lines: dedicated leased lines or dial up can be used to provide connectivity to DA devices. The main advantage is that technology is well-known and widely available in urban areas. The disadvantages are similar to those of power line carriers; low reliability, interference, and poor latency (dial-ups can have long delays just to establish the connection).
- 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 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 security of data packets, and resistance to EMI and other similar electromagnetic phenomenon, which makes them good candidates for installation along power lines as well. The key disadvantages of fiber are cost of installation and vulnerability to vehicle accidents and damage in storm scenarios (in overhead circuits). Acquisition of rights-of-way (ROW) due to strict environmental regulations (in overhead and underground circuits) may also be a problem.

In general, wireless solutions allow for quick installation and cost savings for new infrastructure and flexibility for growth to accommodate more devices. These communications networks include the following:

- Radio networks were used as one of the first communications media in the early days of DA deployments using mesh and multiple address system radios. The investments and costs are low and these networks present robust communications (Green and Wilson [B52]). A disadvantage is the typical need for 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.
- Cellular communication systems are widely available, and many utilities utilize cellular networks as a standard for communication solution for overhead automated devices. The cellular modem may be powered by either a local ac supply or a local dc power supply and is connected to the control

using Ethernet or serial ports. The main advantage of these systems is that wireless infrastructure is provided and maintained by a service provider. Therefore, operations costs may be reasonably low and predictable. Some of the main disadvantages are that the infrastructure (3G, 4G, LTE, 5G) 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.

- Satellite communication systems: in many remote areas (usually away from major population centers), satellite is the only (economically viable) form of communication. There are many commercially available options for satellite data and voice services. The main advantage is that the technology offers extensive coverage and may be a cost-effective solution for connecting remote assets where other communications infrastructure is not available. However, where other forms of communications are available, satellite communications may be higher cost compared to other technology solutions.
- Wireless mesh network (Bavarian and Lampe [B9]): may provide cost-effective connectivity over a selected geographic area. Typically, the network is based on a radio-based network supplied by the vendor and enables a variety of DA applications. These networks are being deployed as part of larger metering infrastructure programs undertaken by utilities that are deploying smart meters. The main advantages may include low cost, a level of resilience 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). This needs to be considered for the communications application.

Communication protocols and overall smart grid architecture should be in place to take advantage of smart grid applications that utilize DA devices. There are a number of communications protocols that enable communication between DA devices and a central control system or between each other (peer to peer communication systems or decentralized control). These include Area Network System Segmentation (PAN, LAN, MAN, etc.), other protocols behind-the-meter (SunSpec, IEEE 2030.5, Open Field Message Bus (OpenFMB), etc.), and the convergence of operations technology (OT) and information technology (IT). Some of these protocols are proprietary and are very likely to limit communication to devices of the same manufacturer. In the last two decades or so, there has been a larger industry push toward the use of standardized protocols such as DNP3 (IEEE Std 1815™) [B64] and IEC 61850 [B54].

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

Empowered by IEDs, sensors, and the communications network, DA is a foundational technology that can help facilitate the attainment of the smart distribution goals based upon many benefits (offset by associated costs), which are generic in nature and are inclusive to the described DA technology/techniques. Both goals and benefits are briefly covered in the guide but are widely available in published literature (Wang, et al. [B97], EPRI “Guidebook...” [B40], and NRECA [B75]). The transition to a next-generation smart grid operating system leverages the DA deployment, utilizes the components of the smart distribution system, and provides improved operating capabilities using advanced applications. DA technology is deployed throughout a utility’s service territory to achieve a wide-area deployment strategy.

Some DA systems are built off the operational foundation that supervisory control and data acquisition (SCADA) systems provide (IEEE Std 1815™ [B64]). 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 de-centralized 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 and, through communications links to centralized SCADA systems, 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. No matter the level of sophistication employed, each new DA site can also expand the SCADA system capabilities to remotely monitor and control the electric distribution system. Each DA site is also capable of performing multi-disciplined automation tasks. The fundamental task of a DA site is the device-specific functional capability to perform remote automation including monitoring and control in concert with other such devices impacting the same portion of the distribution system. DA sites support operational requirements such as providing system reconfiguration and sectionalizing as the need arises. Fault detection is implemented in the DA sites to support enhanced response during system disturbances and wide-area storm events such as Super Storm Sandy. Measurements of the power system can also be used from each DA site to facilitate planning, providing the ability to create real-time voltage and load profiles along the distribution feeder. Also, if power quality measurements are reported by the DA site, such as %THD (Total Harmonic Distortion) (IEEE Std 519™ [B55]) for voltage and current on a per-phase basis, these can be used to detect power quality issues on the distribution feeders. These power quality measurements can be reported on the same periodicity as the real time operational power measurements or reported less often to keep real time operating data flowing at a higher and faster priority level.

Remote terminal units (RTUs) can also facilitate the DA deployment strategy. While supporting remote monitoring and control capabilities, an RTU supports the expansion of the SCADA capabilities along the distribution feeder when used in concert with other RTU-enabled devices or with centralized logic schemes. Programmable logic capability within an RTU supports the development of automated switching schemes between DA sites, including returning the system to its normal configuration without operator intervention after the distribution system returns to normal. Automated switching schemes that use embedded or centralized logic can also perform the tasks as they continuously monitor the state of the system and can return it to its normal configured state when necessary. An RTU can also simultaneously support dynamic system reactive requirements by enabling switching capacitors either on a three-phase basis or on an independent per-phase basis, as well as monitoring and reporting fault detection on a per-phase basis. The versatility of the modern RTU has enhanced and improved DA deployment strategies.

The components of DA are multi-disciplined and dissimilar. The multi-functional nature of each DA site can support specific functionalities for operations, fault detection, planning, power quality, etc. A deployment strategy typically enables the development of dissimilar technologies. For instance, an RTU or similar device can be used to facilitate communications between dissimilar technologies and provide a seamless system-wide solution. Deployed DA technologies include the following:

- Distribution line monitoring
- Distribution line reclosers and other distribution line fault interrupters
- Sectionalizing and other switches
- Automatic transfer switchgear
- Underground network protectors
- Underground switchgear
- Standby generators
- Power circuit breakers
- Faulted circuit indicators
- Meters
- Regulators
- Switched capacitors

The central theme contributing to the success of the DA deployment strategy is the integration of automation technologies. The strengths of dissimilar technologies, as well as different and dissimilar automation products,

are enhanced in the integration concept. The integration concept is embraced to achieve the utility's DA deployment goals. Typically the integration efforts involve the use of distribution line sensors (either stand-alone or embedded within a device) and an RTU, or similar device, to support the monitoring requirements for the automated distribution line device. The DA communication infrastructure then supports the wide-area deployment of distribution line monitoring capability.

The following system parameters and control capabilities are typically supported at each DA site:

- Measurements (per-phase basis: MW, Mvar, V, A, calculate MVA, and power factor)
- Remote control
- Fault detection and isolation
- Sectionalizing
- Power quality (harmonics up to 30th) and % THD (Total Harmonic Distortion)

DA applications improve distribution system efficiency and operation, reduce outage time, and improve customer service, and thus directly address many customer satisfaction issues. 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 that are 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 [B43]). In recent years, DA systems have reported the magnitude of major storm events before the customers begin reporting service outage. This capability provides the service restoration engineers and teams advance notice in planning and implementing the response to system disturbances. The ability to determine the real-time voltage profile along the distribution feeder can be used by the distribution planning engineer to maintain acceptable voltage levels within prescribed regulatory limits.

The DA system provides invaluable self-diagnostics to improve the availability of the system. System data is utilized to monitor the health of the system 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.

Some DA technology deployments include some of the following qualitative benefits (ignoring qualitative benefits that are difficult to monetize or calculate):

- Improvement in the efficiency of the electric distribution power system.
- Reduced cost of daily system maintenance activities.
- Improvement in system resiliency, accelerating and facilitating the response to system disturbances and major storm events. This can reduce outage time and overall customer impact due to reduced outage costs.
- Optimization of the capital expenditures for improvements in the electric distribution power system.

4. Reliability

4.1 Introduction

4.1.1 Description of the challenge

Ensuring the reliability of the electric system has always been a primary responsibility for utilities and a main driver for regulatory authorities. In recent years, several factors are also making it a challenging duty. Society's increased reliance on the electric grid has created a bigger impact from each outage, and lack of redundant sources has impacted the outage duration and frequency. The customer value of each kWh has increased due to the proliferation of computers, smart phones, and plug-in vehicles combined with the significant improvement in end-use energy efficiency. In response to these, utilities are looking into system enhancements such as new configuration schemata and automatic devices that could improve the reliability of the system.

4.1.2 Application to smart distribution

Smart distribution applications for reliability combine technology advances in communications, measurement, computing, and control to reduce the number and duration of power service interruptions to customers or to improve the efficiency of power delivery. Measurements may include fault currents; load currents; voltages; and other parameters observed at the substation, protective and switching devices, other points on the distribution system, and even at customers' meters. Computer systems or processors to make recommendations to operators or actually command operations may be located at central control facilities, in substations, on poles, in vaults, or at other points on the distribution system.

4.2 Description of components

4.2.1 Service restoration

Whenever there is a fault in any section of the feeder, there is a need to identify the faulted section and isolate it. Since most distribution feeders operate in a radial configuration, the sections beyond the faulted section are left without supply. Therefore, reconfiguration needs to restore supply to the healthy sections when possible, such as when they are tied to a second source through an open point. While reconfiguring the network, it is important to make sure that the operational constraints such as capacity constraints and voltage constraints are still satisfied. DA applications that perform these functions are called FDIR (fault detection, isolation, and restoration) or FLISR (fault location, isolation, and service restoration) (these terms can be interchanged, however the term FLISR will be used in this guide) and are most often used by utilities to improve their reliability across their distribution systems as it relates to managing outages and recovering from them quickly.

As an example, consider a distribution system as shown in [Figure 1](#). There are two substations that are interconnected by the open switch SW15 between Feeder 1 and Feeder 2. Feeder 1 has several sections (Section 11, Section 12, Section 13, Section 14, and Section 15) separated by the sectionalizing switches SW11, SW12, SW13, and SW14. Switch SW15 is a normally open switch – a tie point between Feeder 1 and Feeder 2. Similarly, Feeder 2 has several sections (Section 21, Section 22, Section 23, and Section 24) separated by the sectionalizing switches SW21, SW22, and SW23. Assume there is a temporary fault on Section 13 as shown in [Figure 1](#). Because of this temporary fault, the circuit breaker CB1 for this Feeder 1 would sense the fault and open, de-energizing the complete feeder. The sectionalizing switches are configured in this example such that, when there is no power for a certain amount of time, they would automatically open. Therefore, all switches of Feeder 1 would be open some configured time period after CB1 was opened (different schemes have different configurations and other schemes can also be implemented). Then CB1 would go through its reclosing cycle to determine that it no longer detected the fault and remain closed. Since Section 11 has power again, switches SW11 and SW12 would close restoring power to Section 12 and Section 13. After Section 13 has power, switch SW13 would close trying to restore power to Section 14. Since the temporary fault is gone, it would restore supply to this section, followed by switch SW14 closing to restore power to Section 15, thus restoring power to the complete feeder. In some schemes, the sectionalizing switches are timed such that they do not open unless the CB fully locks out. This reduces unnecessary operations.