DIGITAL

Schneider Electric's
Guide to Value-Driven
Grid Data Management

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Executive Summary

Electric Distribution Utilities Face a Serious Data Management Challenge

The rapid proliferation of distributed energy resources (DER) poses many operational, planning, and business challenges for electric distribution utilities. The scale of this shift is even more significant than the transition to advanced metering infrastructure. Over the next five years, data generation will more than quadruple. Compared to other enterprises, distribution utilities face a unique data management challenge because of the large number and broad dispersal of its assets and customers.

A Value-Driven Approach to Grid Data Uncovers Many Business Values

To rise to this data management challenge, electric distribution utilities must not waste resources searching for a needle of "truth" in a data haystack. As distribution utilities become data operators in addition to grid operators, they need a foundational, stepwise, and practical approach to grid data management. Only then can their data management practices realize significant business value, including enhanced safety, cost efficiency, reliability, resilience, flexibility, sustainability, asset utilization, customer empowerment, cybersecurity, and affordability.

This Reference Guide Explains How

Logically organized according to distribution utility functions, the in-depth content within this guide systematically examines how "value-driven" grid data management practices enhance distribution utility planning, design, analysis, construction, operations, maintenance, training, and demand-side management.

You Can Explore the Use Cases Most Relevant to Your Business

What does this reference guide cover? Here is a sample of the nine grid data management use cases described within:

- **Distribution planning and simulation.** Planning and simulation tools can now encompass DER and electric vehicle data, analyze connection requests, and incorporate data from many sources (e.g., real-time control systems, smart meters, behind-the-meter, and distributed sensors) in associated network models and dynamic models across multiple time horizons.

- **Asset performance management.** Asset management tools and methods now use geospatial and operational data from more sources to help distribution utilities balance risks vs. costs, CapEx vs. OpEx, and short-term vs. mid-term asset repair/replace decisions.

- **DER management.** DER can accelerate decarbonization, enhance reliability and resilience, empower utility customers, support grid flexibility, expand utility services, and defer system upgrades. Yet its variable nature and unpredictability complicate utility planning, operations, asset management, and other functions. Learn about leading practices for distribution-transmission coordination, demand-side management, and microgrids, and see examples of optimal DER management.

- **Cybersecurity.** Cybersecurity and data privacy practices and compliance should pervade grid data management across the entire landscape – from the field to enterprise level, and from the grid to the grid edge.

Executive Summary

You Can Gain Insights into Better Grid Data Management

What will you learn? Here is short selection of key insights found within this reference guide:

- **Standards: The Hidden Heroes.** Compliance to standards is a crucial element of efficient grid data management. They leverage collaborative intelligence to enable interoperability, reduce resource needs, and facilitate integration of applications, as described in the use cases within.

- **The Digital Twin: A Cross-Cutting Tool.** Today's digital twins continue expanding beyond core applications. Soon, digital twins will provide value across all domains and zones, enabling better informed and faster decision making.

- **Advanced Analytics: The Next Step.** With grid data management as a foundation, emerging advanced analytics provide greater depth of analysis and bridge traditionally separate analyses into integrated use cases. Higher-fidelity data availability, siloed data consolidation into integrated databases, and artificial intelligence (AI)-based applications facilitate this evolution.

- **A Data-Backed Strategy: Data Governance.** While data assume a central role in business decision making, focus on embedding data management into business projects, instead of executing "data projects." Execution of utility business strategy should be backed by trusted, available, and sustainable data that are validated across data production chains.

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Scott Koehler

Bertrand Lack

Alain Malot

Sebastien Michelin

Enrique Ramos

Jenny Roehm

Izabela Stefani

Nenad Tojagić

Kevin Walsh

Matthew Zimmerman

Hoffman Power Consulting

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Introduction

The Opportunity

Grid data management practices and solutions are one way that electric distribution utilities can realize significant value, including enhancing safety, cost efficiency, reliability, resilience, flexibility, sustainability, asset utilization, customer empowerment, cybersecurity, and affordability.

For this reason, these practices can be called “value-driven” grid data management practices. Of equal importance, these practices can produce value across many distribution utility functions, including operations, maintenance, planning, design, analysis, construction, training, and customer engagement.

For distribution utilities, these data management practices, which include digital twins and advanced analytics, are part of the broader digital transformation process. However, holistically gathering, processing, validating, managing, governing, and effectively using data is challenging. For an average-sized utility, for example, the annual data volume generated is in the petabytes (million gigabytes) range, and is forecasted to double over the 2021-2024 period.[1] Due to the increasing power system complexity of most distribution utilities and other challenges, change is difficult, even when the benefits of digital transformation are clear.

Successful digital transformation and grid data management represent the dividing line between distribution utilities that generate value, and utilities that fail to realize this value for their organization, their customers, and society. Hence, a “digital division” has arisen between forward-looking distribution utilities that seek business and operational resilience for a strong future, versus cautious utilities that may incur significant risks through inaction.

Purposes of this Guide

The purposes of this guide are:

- To explain how electric distribution utilities can overcome a broad range of challenges with a strong foundation of value-based grid data management across their organizations
- To demonstrate via specific use cases how leading practices enable distribution utilities to apply a foundational, stepwise, and practical approach to grid data management
- To provide a comprehensive reference source for Schneider Electric customers and prospects seeking to gradually enhance grid data management practices in agile, consistent, scalable, secure, and cost-effective ways

[1] IDC Research, “Address the Data Dilemma in Utilities,” IDC Analyst Brief, December 2020.

Scope of this Guide

This guide covers the broad array of data management challenges that distribution utilities face.

Although many examples of challenges, solutions, standards, and regulation in this guide are specific to North America, Europe, and Australia, the scope of this guide is global. Note that the guide focuses on the distribution grid, as well as loads, resources, standards, and regulation at the grid edge.

This document covers nine use cases, which Schneider Electric selected based on their relevance to data management, rapid evolution, and Schneider Electric expertise. The use cases are listed later in this section; this list is not intended to be comprehensive.

Utilities Face Multifaceted Data Disruption

Data are the lifeblood of the new digitalized distribution utility, the building block of grid data management, and the ultimate enabler of value.

These data come in many shapes and sizes, and originate from:

- Smart meters and various sensors
- Distributed energy resources, including renewables and electric vehicles (EVs), at the grid edge
- Network automation, including internet-of-things (IoT) devices, such as smart circuit breakers and smart transformers
- Substation automation and construction
- Asset condition monitoring
- Distribution grid analytics
- Vegetation management
- Customer engagement
- Energy forecasting and markets
- Geospatial information systems
- Archived time-series and other data
- Utility field personnel and engineers
- Many other sources

These sources are multiplying the amount of data that distribution utilities gather. At the same time, a growing ecosystem of stakeholders seeks to use these data, requiring efficient data exchange mechanisms. The data sharing ecosystem today includes distribution utilities, transmission system operators (TSOs) energy retailers, ISOs/RTOs, aggregators, regulatory agencies, and customers, and is expanding to include more players, such as energy markets or even data markets.

Overall Data Management Challenges

According to the former CEO of a large European distribution system operator, distribution utilities are rapidly becoming data operators in addition to asset managers and grid operators.

Compared with other businesses, the challenge of data management may be uniquely complex for distribution utilities because of the immense number and geographic dispersal of its assets and customers. However, the following generic data management issues cut across most industries and businesses:

- Management and storage of extremely large amounts of data
- Proliferation of electronic devices that can be uniquely identified
- Expanded use of the IP-based communications
- Availability of sufficient bandwidth to maintain connectivity
- Prioritization of data
- Minimization of data and connectivity losses
- Adaptation of existing infrastructure and business systems to handle the influx of data
- Assured cybersecurity and data privacy

The many functions within an electric distribution utility impose various data requirements, and therefore impose different grid data management challenges, across the data lifecycle (see the text box for definitions of various types of lifecycles).

"Lifecycles"

Data, assets, and models have lifecycles. In the context of the electric power industry and this guide:

- The **asset lifecycle** typically includes asset design, engineering, construction, implementation, operation, maintenance, upgrading, decommissioning, and disposal.
- The **data lifecycle** typically includes data generation, acquisition, storage/backup, and analytics and visualization.
- The **system model lifecycle** typically includes model specification, development, population with data, validation against the real-world, and ongoing refinement and enhancement.

In this context, the primary focus of this guide is **grid data lifecycle management**, as well as management of the models that use these data across the model's lifecycle. A secondary focus is use of data for asset management across the asset lifecycle. This guide discusses each of these in appropriate use cases.

Overall, utilities face the challenges of maintaining or improving the following:

- Data quality (accuracy, level of detail, and granularity)
- Data completeness and integrity
- Data latency (the need for up-to-date data)
- Data context (how data inter-relate)
- Data integration time
- Data accessibility
- Data relevance and usefulness to drive actions
- Data standardization (formats, protocols, etc.)
- Data scalability

Moreover, grid data needs vary across different time horizons. Real-time operations personnel have different data needs than operational planners or long-term planners.

One French grid operator estimates they spend 90% of their time understanding the meaning of the data, and 10% of the time actually using the data. This is not surprising, given the exponential increase in data flowing into utility databases. For example, consider the data explosion a single feature of the smart grid creates – the transition from traditional metering to the smart meter:

- With traditional metering, distribution utilities manually read and recorded one data point – kilowatt-hours (kwh) consumed – per month, for an annual total of 12 data points per customer.
- By comparison, a smart meter set for half-hour readings sends a utility 17,520 per year for a single customer.
- If the smart meter sends readings every 5 minutes, the annual total becomes 105,120 readings per customer.
- If smart meters also send the utility voltage, power factor, and other readings, a large utility may gather trillions of data points per year from smart meters.

Faced with a need for more and higher-fidelity data (i.e., more detailed, accurate data), as well as a blizzard of nearly unmanageable data, utilities are turning to various types of models to organize and interpret data. The text box defines the various types of models discussed in this guide.

"Models"

Models mean different things to different industries and people, and using a descriptive adjective with "model" is recommended. In the context of the electric power industry and this guide:

- A **physical model** is a three-dimensional representation of a real-world or proposed object, typically at a reduced scale, to help visualize complex structures.
- A **mathematical model**, which is a description of a system using mathematical concepts and language, can be used to analyze or forecast system behavior.
- A **software model** is a description of a physical model or mathematical model (or both) within a computer system.
- A **data model** is a description of the objects and their relationships within a software model. A data model provides the foundation for a description of the objects' behavior in order to simulate or predict system operation.
- A (power system) **asset network model** is a static description of the current power system, including the topology of power system assets and how they are connected through feeders and lines, etc.
- A **dynamic model** (aka an operational network model) is a real-time description of the current power system using field data, such as currents, voltages, switchgear positions, etc.
- The **Common Information Model (CIM)** is an internationally-recognized protocol for specifying the characteristics of power system assets using a standard lexicon.
- A **digital twin** is a general term for any software/model that emulates the as-built or as-operated state of a real-world system.
- An **energy model** is more generalized and includes a broader array of relationships that affect the power system, (e.g., represents end users' energy consumption or production).

This guide discusses each of these model types and their relevance to grid data management in appropriate use cases.

The Use Cases

The following set of use cases demonstrates the broad practicality and benefits of value-based grid data management.

The use cases reference applications within electric distribution utilities where grid data management can provide the greatest value. Some of these use cases consolidate utility functions due to their inter-related nature. For example, the DER Management use case consolidates functions related to the challenges, practices, and value associated with distribution and transmission coordination, distributed energy resource (DER) adoption, demand-side management, commercial/industrial buildings, and microgrids.

Each of these use cases is developed following the same logic:

- **Subject area overview**
- **Today's data management challenges,** objectives, and/or imperatives
- **Today's recommended practices** for value-driven grid data management
- **Value-producing business outcomes,** based primarily on Schneider Electric's "value pillars"
- **Schneider Electric solutions** to meet today's challenges

This guide covers the following nine use cases:

- Asset information management, network model management, and field work
- Distribution analysis and operations
- Planning and simulation
- Asset performance management and asset investment planning
- Substation automation, systems engineering and maintenance
- Augmented reality for system operations, maintenance, and personnel training
- DER management, including DSO-TSO coordination, a DER case study, demand-side management, and microgrids
- Smart metering
- Cybersecurity

Figure 1 shows how these use cases inter-relate in the broad definition of today's grid. Building on these nine use cases and extending grid data management to the near-term future, the digital twin merits special attention, because:

- Digital twins cut across and provide potential value across all nine of the use cases.
- Digital twins enable better informed, faster decision making using powerful simulators and analytics in a virtualized, software-defined environment.
- Digital twins provide a way to organize thinking on near-term enhancements to grid data management.
- Digital twins serve as a bridge to powerful families of advanced analytics that promise significant business benefits.

Hence, the end of this guide presents a section dedicated to digital twins and advanced analytics.

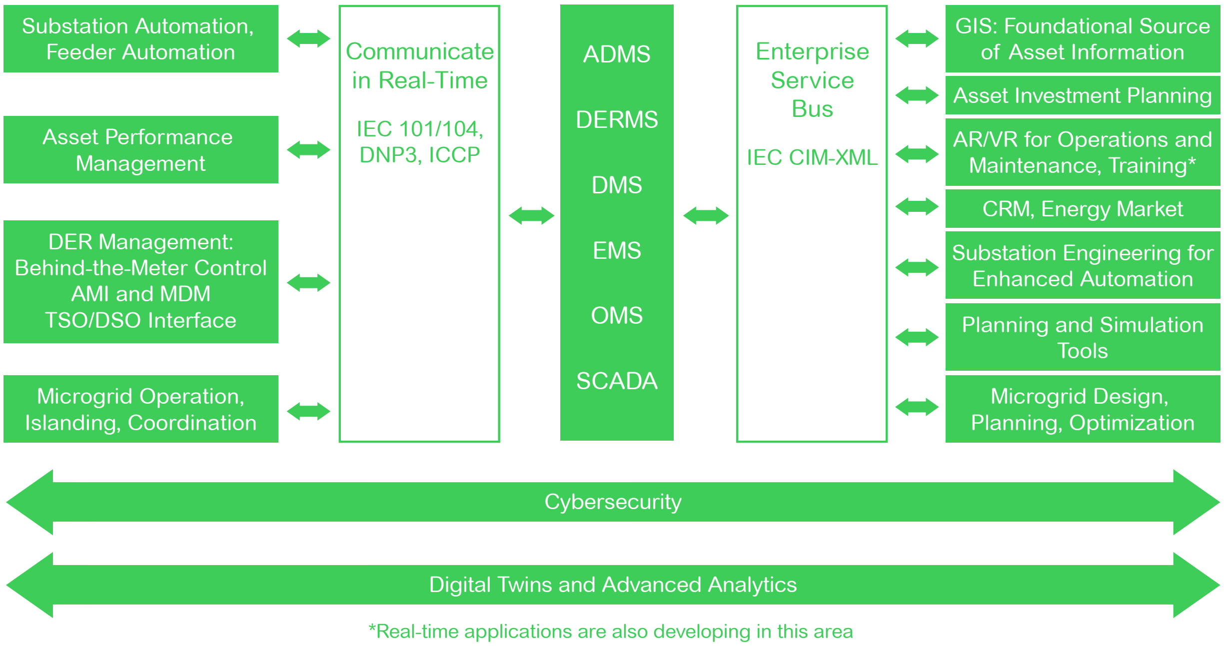

Figure 1. How it all fits together: Value-Driven Grid Data Management

Value Pillars

A digitalized grid will support the goals of major industry value pillars, which can be summarized concisely as follows (see Figure 2):

- **Sustainability** minimizes environmental footprint
- **Resilience and reliability** mitigate power disruptions
- **Efficiency** ensures affordable energy
- **Flexibility** maximizes grid adaptability

This guide describes how the various use cases support these value pillars.

	Sustainability	Resilience and Reliability	Efficiency	Flexibility
Grids of the future pillars	Minimize environmental footprint	Build grid resilience	Ensure affordable energy	Enable smart investment and decarbonization
Enablers/ examples	• Remove greenhouse gases (SF_6 free) • Deploy sustainable products and circular economy practices • Reduce energy losses	• Ensure reliability • Withstand stressful forces of climate change • Mitigate cyber risks	• Increase operational efficiency • Optimize asset management • Improve grid edge planning and operations	• Optimize network planning • Enable DER integration
	Interoperable grid digital twins			

Figure 2. Schneider Electric grids of the future pillars and enablers/examples

Sustainability and Data Management

Of the four value pillars, sustainability is a ubiquitous goal and offers “cross-cutting” value: Any technology deployed to enhance resilience, efficiency, or flexibility must also consider sustainability.

- Sustainability impacts from enhanced **maintenance** via improved grid data management include:
  - Extending the lifetime of assets, which avoids manufacturing new devices
  - Reducing maintenance interventions, thus avoiding crew dispatches and emissions from truck rolls
  - Improving crisis management (resiliency), for example, via more efficient use of field technicians
- Sustainability impacts of **operating** the grid with advanced data management tools include:
  - Increasing energy efficiency
  - Reducing non-technical losses
  - Improving sector coupling (i.e., bridging traditionally separate analyses)
  - Optimizing use of grid-edge resources
- Sustainability impacts of improved grid **O&M coordination** via enhanced data management include:
  - Improved risk analysis, based in part on more precise information about asset health, affects traditional tradeoffs between O&M, enabling more comprehensive inclusion of green criteria to support sustainability
- Facilitating a more **flexible grid** via data management enhances sustainability by:
  - Easing the integration of renewable generation and EVs
  - Optimizing the ability of EVs to absorb more energy from renewables when they are available and to support grid services when needed (the V2G or vehicle-to-grid concept)
  - Obtaining a clear model of a distribution utility’s hosting capacity, as well as visibility into grid-edge activities
  - Optimizing addition of new DER and data-driven grid automation by considering lifecycle cost and sustainability

Organization of this Guide

This guide offers distribution utilities an overview of the current status and leading practices for grid data management.

The overall organization of the main body of this report is as follows:

- Standards and the Digital Transformation of Distribution Utilities
- The Use Cases (nine sections)
- Future Vision: Digital Twins, Analytics and More
- How to Deploy Data Management Practices
- Conclusions

02 |

Standards and the Digital Transformation of Distribution Utilities

Overview

Standards are the hidden heroes of the digital transformation of the electric distribution grid.

Standards are voluntary rules or guidelines that specify technical information on equipment, services, and products. National standards organizations are composed of committees of various industry stakeholders that nominate experts. These committees and working groups typically consist of representatives from suppliers of products and services, as well as representatives from end-user groups. The power system industry is a global business, and many national standards are based on international standards. In some cases, standards become part of legislation and/or regulations as recommended or even mandatory requirements. Utilities require that their networks conform to some combination of international, national, or internal standards.

Standards have important economic implications, because they specify preferred performance criteria, support interchangeability and interoperability between products and processes, and promote basic levels of quality and safety. According to the European Parliamentary Research Service,[2] these standards outcomes affect the economy in a number of positive ways, especially with regard to technology-related products:

- Improve competition and efficiency
- Exploit the beneficial impact of network effects (i.e., when the value to one user increases as the number of users increases)
- Contribute to the diffusion of innovation
- Reduce production costs

Standardization improves allocation of resources by offering equal information access to all producers, thus leveling the playing field and lowering barriers to entry. In particular, creating Interface standards (i.e., designating the functional or physical characteristics that allow systems or equipment to work together) decreases the ability of a supplier to "lock in" consumers to one product.

Standards are becoming increasingly important in the rapidly advancing digitalization of various industries, including electric distribution. Timely adoption and promotion of standards ensures interoperability and promotes innovation. Technologies and trends such as the internet-of-things (IoT), big data, and artificial intelligence (AI) create value as part of an interconnected world. One of the principles that the World Economic Forum identified to unlock AI potential in the energy industry is to "establish data standards, data-sharing mechanisms, and platforms to increase the availability and quality of data."[3] A report from the Organisation for Economic Co-operation and Development (OECD)[4] suggests that the digital transformation of various industries will demand a neutral standards-based architecture. The electric utility industry has formulated such an architecture and is developing standards in terms of that model.

[2] European Parliament, I. Zachariadis, "Standards and the digitalisation of EU industry; Economic implications and policy developments," PE 635.608, March 2019.
[3] World Economic Forum, "Harnessing Artificial Intelligence to Accelerate the Energy Transition," white paper, September 2021.
[4] Organisation for Economic Co-operation and Development (OECD), "Key issues for digital transformation in the G20," report prepared for a joint G20 German Presidency/OECD conference, January 12, 2017.

Smart Grid Architecture Model (SGAM)

The SGAM[5] emerged from a need to identify existing technical standards applicable to smart grids, as well as identify gaps in technology and standardization.

European standardization organizations, including the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI), formulated the SGAM.

The SGAM provides a three-dimensional visualization of a smart grid architecture (see Figure 3):

- **The domains** (i.e., generation, transmission, distribution, DER, and the customer premises) constitute a process and value chain.
- **The zones** (i.e., process, field, station, operation, enterprise, and market) denote a hierarchy of power system management, forming a potential automation pyramid.
- **Interoperability layers** include component, communication, information, service/function, and business layers.

Within this visual structure, use cases can be located in a three-dimensional system landscape to identify standards (or lack thereof) and develop interface specifications.

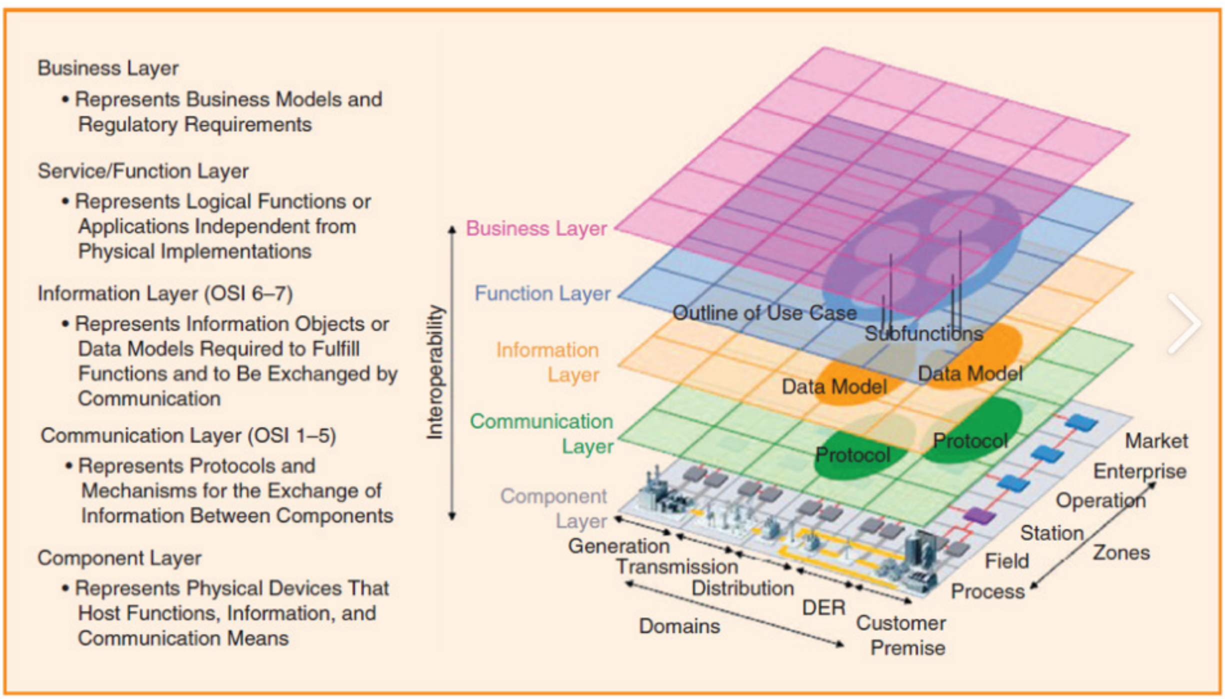

Figure 3. The Smart Grid Architecture Model (2012)[6]

Figure 4 shows the process by which new use cases sometimes expose gaps and lead to the development of new standards. After a new use case is identified, it is queued and then mapped into the SGAM to locate functions and requirements for standards. Then if gaps are identified, the finding passes to the appropriate IEC technical committee for study and standards development. Also, the existing applicable standards are verified.

[5] CEN-CENELEC-ETSI Smart Grid Coordination Group, "Smart Grid Reference Architecture," November 2012.
[6] CEN-CENELEC-ETSI Smart Grid Coordination Group, "Smart Grid Reference Architecture," November 2012.

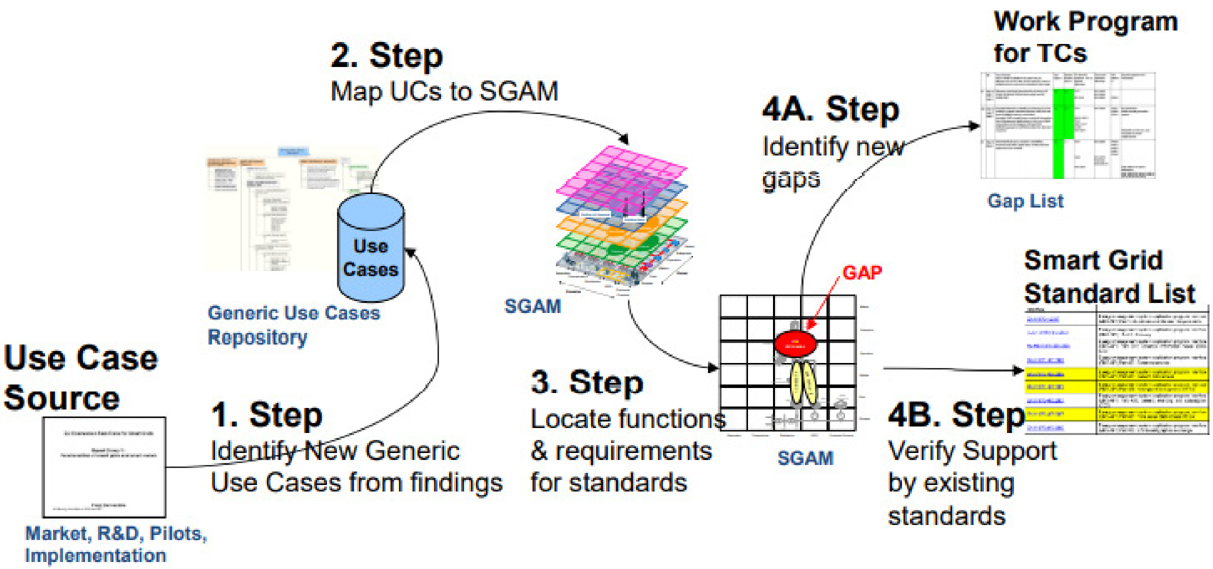

Figure 4. From use case through SGAM to new standards development[7]

Digital Standards for Electric Distribution Utilities

In most developed countries, designated organizations contribute to the development of country-specific standards.

However, international standards organizations are attempting to bring clarity and consistency to the development of world-wide standards. The goal is to create standards that can boost interoperability and interchangeability on an international scale.

In Europe, CEN and CENELEC, as well as ETSI, are officially recognized as European standardization organizations. CEN, CENELEC, and their national members initiate most of their standards work based on requests from businesses, and develop them with input from other stakeholders. According to the CENELEC website,[8] the European Commission mandates about 30% of the standards based on European Union legislation. After a European standard is published, each of the 34 CEN and/or CENELEC member countries is obligated to withdraw any national standard that conflicts with the European standard.

The left side of Figure 5 illustrates the most important interrelationships among independent national standards entities, the world-wide standards organizations, and local manufacturers and utilities. The right side of the figure lists various industry groups that provide input on regulations to the European Commission. In the center of the figure, CEN, CENELEC, and ETSI act as a bridge between government and world-wide standards organizations. The Frankfort and Vienna Agreement, signed in 1991, aims to prevent duplication of effort between the International Organization for Standardization (ISO) and CEN, and save time when preparing new standards through joint planning.

[7] CEN-CENELEC-ETSI Smart Grid Coordination Group, "CEN-CENELEC-ETSI Smart Grid Coordination Group – Sustainable Processes," page 32, Figure 8, November 2012.
[8] CEN CENELEC website, "European Standardization," accessed August 2021.

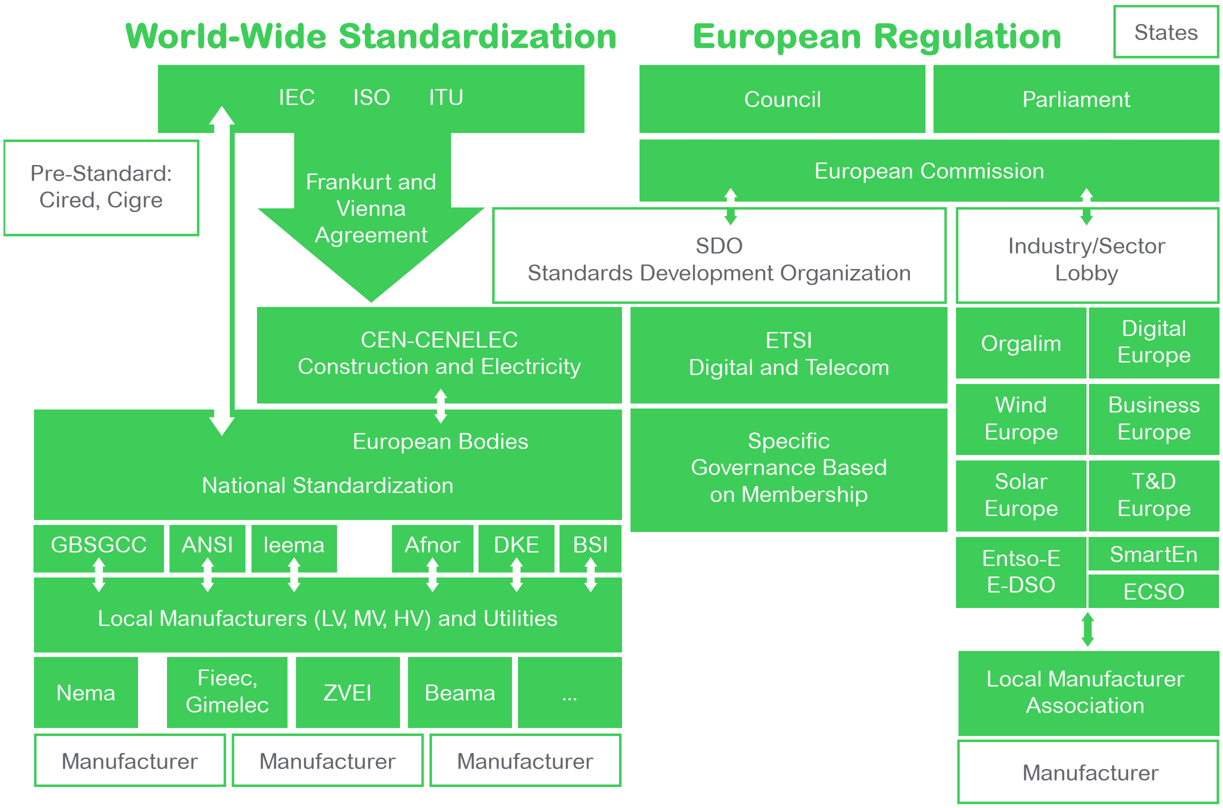

Figure 5. World-wide standardization and European regulation entities

In the U.S., the North American Electric Reliability Corporation (NERC), the National Institute of Standards and Technology (NIST), and the Institute of Electrical and Electronics Engineers (IEEE) are heavily involved in the production of electric utility standards. The Electric Power Research Institute (EPRI) conducts research that informs development of standards.

Like most countries with standards organizations, the U.S. organizations work closely with the International Electrotechnical Commission (IEC), which produces the most commonly used standards for electric utilities around the world. The IEC develops standards for, and receives feedback from, 36 participating countries and ten observer countries. Digital communications standards are developed under the guidance of Technical Committee 57 (TC 57). The IEC website describes the scope of TC 57 as:

> To prepare international standards for power systems control equipment and systems including EMS (Energy Management Systems), SCADA (Supervisory Control and Data Acquisition), distribution automation, teleprotection, and associated information exchange for real-time and non-real-time information, used in the planning, operation and maintenance of power systems.[9]

TC 57 has instituted Working Groups for some of the more relevant distribution utility data management standards (see Table 1).

[9] International Electrotechnical Commission (IEC) website, "TC57 Power systems management and associated information exchange," accessed August 2021.

Table 1. IEC Working Groups and Related Standards Relevant to Distribution Utility Grid Data Management[10]

Working Group	Responsibility	Principle Standards or Series	Description
WG 3	Telecontrol protocols	IEC 60870	Standardizes the communication between intelligent electronic devices (IEDs) and defines the related system requirements to be supported.
WG 10	Power system IED communications and associated data models	IEC 61850	Originally applied primarily to substation automation, expanded to include a wide variety of basic communications structures.
WG 13	Software interfaces for operation and planning of the electric grid	IEC 61970	The “wires” model and other information exchange profiles for energy scheduling, network analysis, and dynamic simulation.
WG 14	Enterprise business function interfaces for utility operations	IEC 61968	Information exchange profiles between systems to facilitate outage management, customer management, work management, etc.
WG 15	Data and communications security	IEC 62351	Undertakes the development of standards for the security of communication protocols including digital signatures and intrusion detection.
WG 16	Deregulated energy market communications	IEC 62325	Develops a set of standards for deregulated energy market communications based on the Common Information Model.
WG 17	Communications systems for DER	IEC 61850-7-420	Builds on the core IEC61850 standards defined by WG10, specifies information models to be used in the exchange of information with DER.

Now expanded to other areas, the substation standard, IEC 61850, demonstrates the usefulness of standards development to the successful acceleration of substation automation and interoperability. Based on this standard, various suppliers have demonstrated the interoperability of over 150,000 intelligent electronic devices (IEDs) at about 2,000 substation projects. (See the section on “Substation Engineering for Enhanced Automation” later in this document for a more complete discussion of IEC 61850.)

See the section on “Cybersecurity” later in this document for a discussion of standards in this area.

CIM and Semantic Standards

As they evolve over time and become “siloes” and outdated “legacy systems,” information technologies can exacerbate rather than facilitate the management of data.

Separate protocols, data structures, and semantics can lead to systems that literally cannot understand each other’s languages. Rather than focusing on customer service, cost efficiency, reliability, sustainability, and flexibility, grid managers need to spend time and effort trying to find the needle of “truth” in a data haystack.

[10] T. Lefebvre and H. Eglert, “Current and future smart grid standardization activities of IEC TC57 ‘Power system management and associated information exchange,’” 2013.

In the electric utility arena, the Common Information Model (CIM) has proven its value as an interface between information siloes. The CIM facilitates the interoperability of a broad range of utility applications and information systems primarily by standardizing the semantics (the precise specifications) of electric system equipment, data, and processes.

As shown in Figure 6, the CIM – which includes IEC standards 61968, 61970, and 62325 – defines domain semantics for the operation, enterprise, and market zones of the SGAM. The IEC 61850 series covers the process and field zones. Together, these standards define the semantics of power system management.

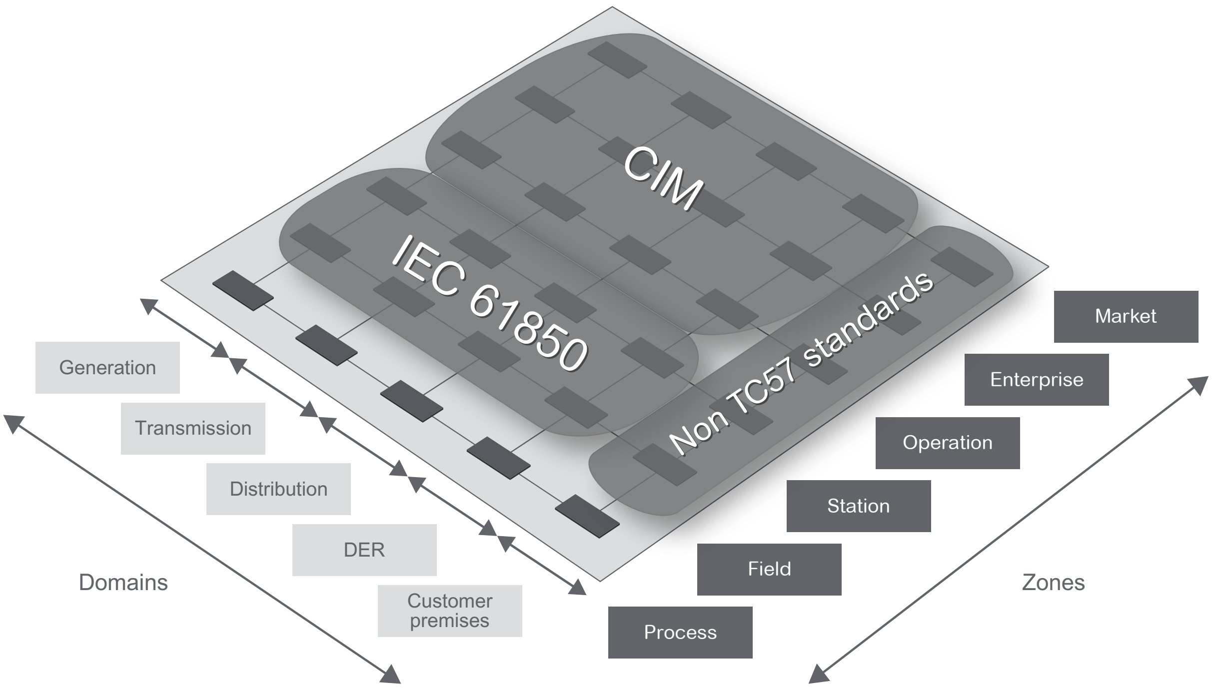

Figure 6. Semantic Domains in SGAM[11]

According to the IEC TC57 leadership, decoupling communications protocols and technologies from data models is key to achieving long-term interoperability. As communications technologies evolve, an adaptation layer between the data model and communications services assures the long-term stability of the data model. This concept[12] forms the basis for the current business plan.[13]

Figure 6 also shows where coordination with other IEC technical committees and groups (see the green oval – non-TC57 standards) is needed to crossover from the power system to customer domains. For example, TC57 shares responsibility for developing semantic profiles for demand response with three other IEC committees.

[11] T. Lefebvre and H. Eglert, "Current and future smart grid standardization activities of IEC TC57 'Power system management and associated information exchange,'" 2013.
[12] T. Lefebvre and H. Eglert, "Current and future smart grid standardization activities of IEC TC57 'Power system management and associated information exchange,'" 2013.
[13] International Electrotechnical Commission (IEC), "SMB/7253/R; Strategic Business Plan for TC57," April 3, 2020.

From Simple Metering to Smart Building Interfaces

Standards are evolving in a variety of distribution utility areas, including the following:

- **Smart metering.** In the past, the primary interfaces between utilities and customers facilitated billing. The standards for automatic meter reading have been extended to become smart meter standards, which creates additional interfaces. These market-oriented interfaces include the exchange of tariff and pricing information to help prosumers optimize their energy costs, potentially via third-party aggregators.

- **DER.** The widespread deployment of renewable DER is leading to development of additional types of communication and information exchange. Distribution utilities face challenges from the rapid evolution and increased adoption of DER, which includes renewables, energy storage, and demand response. One of these challenges is the lack of well-defined holistic standards that would facilitate improved DER management on the distribution grid. Standards related to DER exist in focused areas, but the industry lacks standards on how to establish the power system model needed to analyze the effect of DERs.

- **Home automation.** Another rapidly evolving area with inadequate standardization to date is home automation (i.e., smart homes). Vendors are supplying home energy management devices, but these may not communicate readily with – or meet the needs of – distribution utilities as they operate the power system. While the communications protocols of these devices could become de facto standards, the lack of open standards may strand some consumers with devices that do not interoperate with new technologies or cannot be replaced by new technologies (interchangeability).

The continuing development of communication and information standards for the grid edge will help utilities operate the grid more efficiently, resiliently, sustainably, and safely, especially during abnormal and emergency conditions, for example due to extreme weather.

Schneider Electric and Standards

Schneider Electric affirms the importance of standards to speed the evolution of the grid of the future.

Schneider Electric underwrites that affirmation by encouraging the active participation of more 170 of its employees in standards working groups around the world. For many years, Schneider Electric employees have actively helped shape existing standards, and continue this tradition today.

Schneider Electric also publishes applications guides to help those who design power systems to design according to IEC standards. Schneider Electric's Network Protection & Automation Guide[14] is the standard reference book in the electrical protection field. It provides detailed analysis on the application of protection relays and automation solutions within electrical energy management. In the latest edition, Schneider Electric has introduced new concepts to encompass distributed generation, arc protection, design for safety, and the impacts of IEC 61850 standards in electrical solutions. Schneider Electric also publishes the Electrical Installation Guide.[15] This technical document helps electrical designers and contractors design electrical installations according to standards such as the IEC 60364 or other relevant standards.

CIM standards are quite robust, but without compliance and/or interoperability testing, they remain open to interpretation. By aligning interpretations of specific standard profiles, utilities can obtain implementations from different vendors in a uniform way, potentially reducing implementation costs.

In October 2017, Schneider Electric participated in the CIM Compliance Test Workshop in Knoxville, organized by EPRI in conjunction with the CIM Compliance Testing Task Force. The goal was to test compliance of the IEC standard 61968-100:2013 for Utility Application Integration, and DER group management functions enterprise integration against the then draft IEC 61968-5 Distribution Energy Optimization. Schneider Electric is the first company with the Certificate of Compliance for both the client and the server side.

In November 2019, Schneider Electric participated in another series of interoperability testing for several interfaces defined in accordance with IEC 61968-100:2013 and IEC 61968-5 and organized by the National Renewable Energy Lab (NREL) in Denver. Throughout the interoperability tests, Schneider Electric's EcoStruxure™ ADMS successfully exchanged messages with EPRI's TestHarness and OpenDERMS software, thus confirming the Schneider Electric commitment to the CIM standards that contribute to easier, more efficient, and reliable integration of enterprise systems.

[14] Schneider Electric website, "Network Protection & Automation Guide," accessed August 2021.
[15] Schneider Electric website, "Electrical Installation Guide," accessed August 2021.

03 |

Asset Information Management, Network Model Management, and Field Work

Overview: The Integration of Field Work and Network Models

Today, many electric distribution utilities view the geographic information system (GIS) as the foundational or "master" source of its asset information.

As the utility's system of record, the GIS is a repository with the most accurate network information. A state-of-the-art GIS:

- Contains detailed maps with data layers
- Stores geospatial and meta-data about assets
- Calculates location-based analytics
- Provides a platform for apps and geospatial services
- Integrates readily with utility network models such as an advanced distribution management system (ADMS)
- Acts as a data depository of physical assets for other utility data models

However, the GIS is not the sole source of asset information. Other data sources are emerging, including network automation (via internet-of-things devices), smart meters, DER, and others. Increasingly, electric utilities will view GIS as a foundational system that will facilitate various types of analyses using many sources of high-fidelity data.

The "G" in GIS is evolving from a "geographic" program to a "geospatial" platform that accommodates a multidimensional approach to decision making, while accounting for natural systems (e.g., vegetation) and human-built infrastructure. Geospatial thinking allows an in-depth view of neighborhoods, as well as local and service territory-wide implications of a wide range of data types. It can also encourage more efficient use of existing resources – by using higher fidelity data to defer capital investment.

By providing visualization of assets at specific locations, GIS data can facilitate insights into patterns and trends, and improve operational awareness. During emergencies, GIS data can reveal areas with outages and provide other critical data to improve performance during a crisis. With its ability to handle more detailed data, newer GIS systems (e.g., ArcGIS) can provide a foundation for improved data management.

New GIS systems provide a platform with an application programming interface (API) to accommodate web-based apps. This feature enables field crews to access network and operational status, improving efficiency and safety. Many utilities use the ESRI ArcGIS and its Utility Network platform, and Schneider Electric offers apps (see below) that enhance ArcGIS.

Today's Opportunities and Challenges

Opportunities

A utility's GIS and the data it contains can help support the company's mission, enable more informed business decision making, and help meet the needs of:

- Customers
- Owners (investors, governments, or co-op members)
- Employees, contractors, and suppliers
- The larger stakeholder community (e.g., federal regulators and utility commissions, environmental groups, engaged citizens, and others)

Viewing utility stakeholders through a geospatial lens can reveal a rich set of connections. The modern GIS provides so much more than network documentation; it reveals a rich set of patterns and trends. A utility's GIS and its data can help a utility answer many location-based questions, including but not limited to the following:

- Where are excessive energy losses or thefts?
- Where are accidents occurring most frequently?
- Where is the power system most vulnerable to storms, flooding, heat waves, other severe weather, and physical attacks?
- Where are customers satisfied or not satisfied, and why?
- Where are environmental issues occurring?
- Where is the network infrastructure most vulnerable to a single event?

Locational analytics can gather data from vegetation management programs, assets involved in personnel injuries, crime data from the police department, and more, to help identify potential problem spots for crews. With this insight, a utility's operations team can then create risk management plans.

Challenges

An often-underestimated challenge of data management is the need to "create" higher fidelity data in the field and upload the data to the GIS. Engineers, linemen, and foremen are at the headwaters of gathering, authoring, and correcting data that are fed into the utility's GIS.

Utilities understand that the digital transformation encompasses many areas of their business. However, the pace and success of that transformation depends largely on providing engineers and field workers the tools, training, and incentive to capture more accurate and granular data. A network model is only as good as its data.

Today, utilities seek high-fidelity data to match their higher-fidelity operational models and systems, such as an ADMS, a DER management system (DERMS), and others. How can utilities obtain more detailed data about their numerous and varied installed assets?

In most circumstances, the data must originate from engineers and field workers, when they observe differences between what they see in the field and what the GIS predicted they would find. These front-line personnel need to take photographs, record nameplate information, install internet-of-things (IoT) devices and sensors, and use other means to digitally capture the corrected, more detailed data. These corrections may include more accurate pole locations, corrected phase information attributed to a feeder, and many others. The corrections have implications for personnel safety, reliability, cost efficiency, and service restoration. Nearly every member of the utility field workforce can help improve the quality of GIS data by gathering and sharing information about the assets they encounter in the field.

When engineers and field personnel install new equipment in the field, and change existing equipment to accommodate new equipment, they should also submit these data for upload to the GIS.

The method and timing of capturing and uploading this more detailed data also presents challenges. Manual data entry and paper-based processes are inefficient, time consuming, prone to error, and may not meet the demands of higher-fidelity systems, digital devices, new regulations, and safety protocols. Prompt, direct field personnel input of images and digital data on field-hardened smart tablets can significantly enhance the efficiency, timeliness, and accuracy of the data updating process.

Today's Recommended Practices

Utilities can minimize the number and size of databases by utilizing geospatial data – data about a utility's assets including geospatial location and network connectivity.

These data can form the basis for nearly every aspect of asset management. A utility can use an enterprise GIS as a data foundation for analysis, design, construction, maintenance, and customer service departments.

Because it models network connectivity, a geospatial database provides insight into the as-built state of the network, unlike the traditional hierarchical format of an enterprise asset management (EAM) system. For example, normal switch position defines the network infrastructure and connectivity – data that the EAM system does not reflect. A GIS also is much more flexible and data-rich than computer-aided design (CAD) systems and paper files, and provides better quality-control capabilities. An enterprise GIS further enables an accurate ADMS network model by:

- **Reducing the lag** between work order and database update, even eliminating the lag when designs and as-built changes are performed within the GIS
- **Providing actionable information** for use at any time for storm response and restoration, including fault location and isolation, dispatch, and service restoration, and crew management within ADMS
- **Hosting data** that are readily accessible in the field and within the utility, from the designer's desk to the board room, for operations, analytics, planning, and training
- **Facilitating incorporation and tracking** of new and intelligent devices and DER, including renewables, storage systems, EV locations, and microgrids
- **Modeling connectivity** for demand management, including switching; voltage reduction and volt-VAR optimization; load shedding; and customer energy efficiency programs for residential, commercial, and industrial customers

While digital transformation is the goal, the process requires commitment from operators, field crews, and any employees who are the main users of digital solutions. The use cases generally involve how to author data appropriately and efficiently. Existing digital tools enable engineers and construction workers to shift from paper-based, manual entry systems to streamlined, digitized data authoring and entry.

Following are key recommended practices to accelerate the digital transformation process by capturing design and field work data more rapidly and accurately:

- **Establish a change management team**. This team should develop recommendations for needed resources, communications, and scope of work for the digital transformation. Include construction and line crew representatives on the team.

- **Digitize everything**. Digitization reduces time-consuming use of paper, prevents data loss, and, with the proper tools, avoids the expensive data-crunching process known as ETL (extract, transform, load).

- **Communicate value across the organization**. Data maintenance is a prime example of the convergence of people, process, and technology. People enter and maintain data, and they function at a high level only if the process ensures quality and the technology solution simplifies data authoring and validation. Clearly communicating the benefits of continuous data quality maintenance and improvement across the organization maximizes value and achieves desired business outcomes.

- **Use digital design, mobile, and as-built tools**. Engage engineers and construction workers as full participants in the digital transformation. This involves leveraging apps that communicate seamlessly with the GIS. With these tools:

  - **Upload higher fidelity data**. Engineers can design network additions or changes and seamlessly upload these changes to the utility's network models for immediate analysis. Higher fidelity data, such as detailed transformer data from a built-in catalog, can be automatically incorporated. Similarly, field workers can send information to the GIS. The information flow can be bi-directional, with each iteration resulting in more detailed data.

  - **Enable model promotion**. Engineers can access analytical tools to quickly evaluate the effect of a new feeder or a new low-voltage substation on the overall electrical system. This implies that the GIS can "talk" directly to the utility's ADMS to analyze how the new design element affects power flows and to perform contingency analyses. This process is known as "model promotion."

  - **Access construction information**. Foremen, linemen, and other construction personnel can use their smart phone or tablet to receive detailed information about the relevant line or substation, along with situational data such as any emergencies, weather, traffic events, potential criminal activities, or environmental sensitivities.

  - **Access topology and task sequencing**. Field technicians can access from their tablet or smart phone the topology of the relevant circuits, and the sequence of operational or maintenance steps to perform on the equipment. They can then collect data to feed into and enrich the GIS and ADMS models. Contractors can also more securely access information flows similar to those described above to perform their work. Especially when crews from other states aid in emergency power restoration, secure access to offline data is a critical element of recovering from a severe event.

Value-Producing Business Outcomes

Embracing the digital transformation for asset information management, network model management, and field work can produce the following outcomes:

- **Enhanced safety**. Ensuring personnel and customer safety is the number one priority. High-fidelity data – resulting in improved switching management, enhanced situational awareness, and work procedures performed with the latest data – leads to a safer working environment. If a field technician has not recently updated their network data, GIS administrators are alerted because that situation alone can present a safety issue.

- **Increased cost efficiency**. The ability to quickly provide digital data to an engineer, a GIS technician, and a field crew, as well as to access the analytical power of an ADMS digitally, increases cost efficiency.

- **Enhanced resilience/reliability**. More accurate data can accelerate service restoration in an outage or severe event.

- **Improved flexibility**. A more accurate digitally modeled grid enables the utility to use its existing assets more efficiently, thus delaying the need for new infrastructure and improving grid flexibility.

- **Enhanced sustainability**. An advanced and higher-fidelity GIS leads to improvements in asset modeling and lifecycle management, which in turn can reduce the physical resources required to serve customers. Better data can lead to improved risk analysis—especially with more precise information about asset health. Better information can alter the traditional tradeoffs between operations and maintenance by including more green criteria to support sustainability.

Schneider Electric Solutions

Schneider Electric is in a partnership with Esri, an international supplier of GIS software, to provide solutions that extend the capabilities of Esri's ArcGIS in specific sectors such as the electric, gas, and water industries.

Schneider Electric offers a suite of products known as the ArcFM Solution XI Series, which is built for the Esri Utility Network or the Geometric Network platforms. While utilities can use the apps individually, the XI series enables digital data movement through the entire equipment design, construction, and as-built process, eliminating paper-based approaches. The suite facilitates digital movement of designs and map corrections, digitally verifies corrections from the field, and automatically validates the design as part of the network. The core XI suite includes:

- Designer XI, the cornerstone of the XI series, is a digital design tool that integrates with the ADMS. It can create a digital design, a bill of materials, and a construction print. The design can be sent to the field for construction notes, to a work management system to keep inventory and asset management up-to-date, and to the GIS.

- Editor XI is a tool for the GIS technician. Editor XI can significantly reduce the time required to perform GIS data edits, and its validation tools can significantly reduce the time required to evaluate and resolve data anomalies.

- Mobile XI for field crews is a utility-scale mobile GIS system, built with an open design.

04 |

Distribution Analysis and Operations using Network Model Management

Overview of Advanced Distribution Management Systems

Electric distribution utilities are striving to create a modern grid that can reduce peak demand, optimize use of DER, improve outage response, and enhance asset management to minimize capital expenditures.

To do this, utilities need higher-fidelity data and real-time analytical tools to manage bi-directional flow in the distribution network. However, utilities' existing operational systems cannot adequately process and analyze sufficient data to enable a smart, reliable, and self-healing grid. For example, many utility legacy systems cannot recognize, much less analyze and predict, bi-directional power flows from prosumers.

In response, many utilities are implementing an Advanced Distribution Management System (ADMS). This sophisticated software tool can monitor and operate their network to enhance planning, analysis, construction, operations, maintenance, and customer engagement processes. Schneider Electric describes ADMS as "an integrated software system for control, analysis, and optimization of electricity network operations."

ADMS provides electric distribution system operators powerful analytical tools for improving analysis and operations processes, and is state-of-the-art software for monitoring, managing, and optimizing an electricity distribution network.

Figure 7 depicts a typical ADMS high-level architecture:

- The ADMS is interfaced to real-time systems that process operations data (from substation and feeder automation, and transmission systems) via various protocols (e.g., IEC 101/104, DNP3, and ICCP to account for cybersecurity).
- In an optimal arrangement, the ADMS can be tightly integrated with an energy management system (EMS), and includes the following complementary modules/subsystems:
  - Supervisory control and data acquisition (SCADA) system
  - Distribution management system (DMS)
  - Outage management system (OMS)
  - DER management system (DERMS)
- Via an enterprise service bus (ESB) using IEC 61968-100-compliant messages and CIM-XML files, the ADMS also interfaces with off-line and near-real-time systems that process equipment or accounting data:
  - Enterprise resource planning (ERP)
  - Customer relationship management (CRM)
  - Geographic information system (GIS)
  - Advanced metering infrastructure (AMI)
  - Meter data management (MDM)
  - Mobile workforce management (MWFM)
  - Weather forecasts
  - Energy markets
  - Others

Note that the GIS is only one source of data in the list above. As mentioned in the section on "Asset Information Management," other sources are emerging to complement GIS data and enable various applications, including functions that the ADMS provides.

Overall, the ADMS presents an "intelligence center," where data are processed and analyzed, and new functionality and value are produced (see Figure 7).

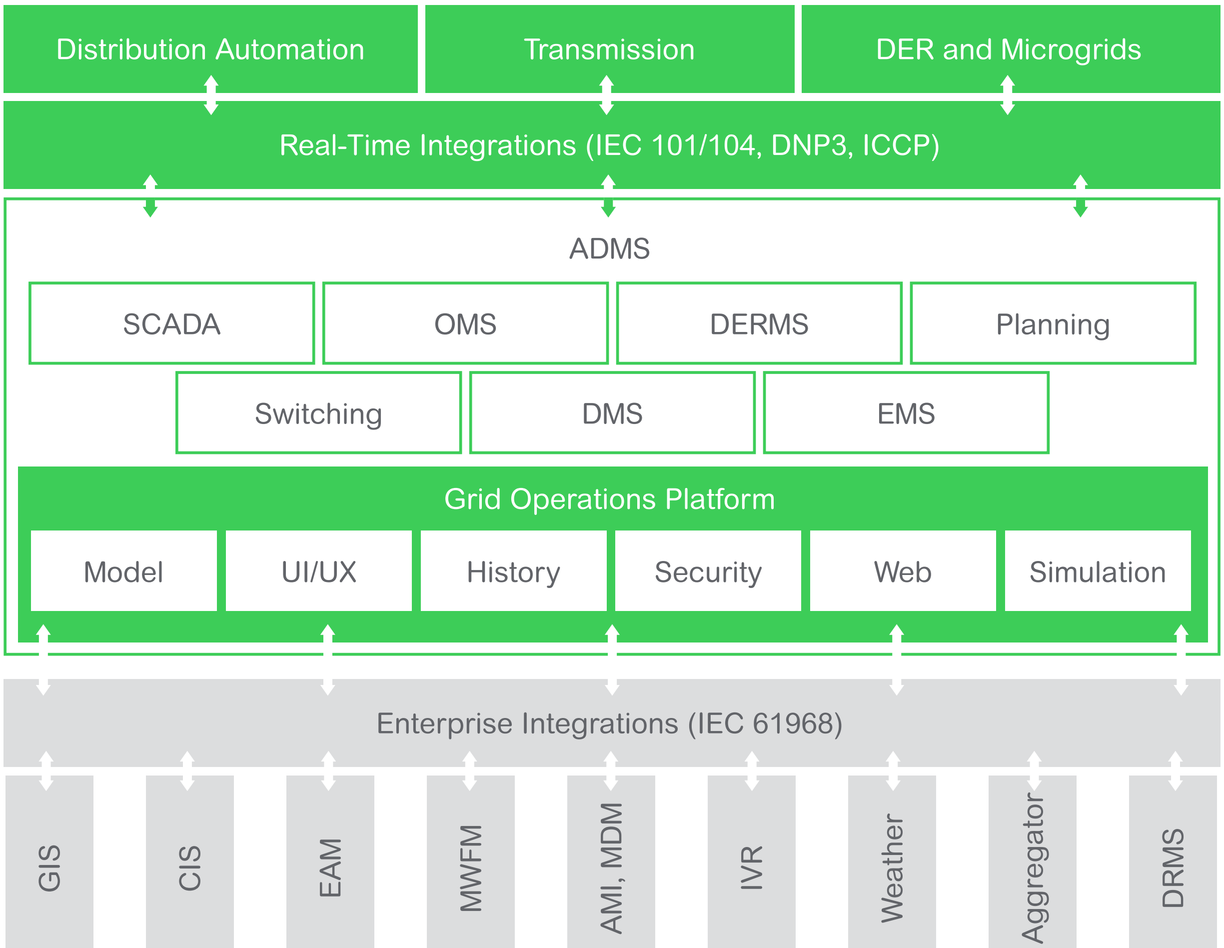

Figure 7. Typical ADMS high-level architecture showing interactions with real-time data and utility data management systems

Today's Challenges and Objectives

The ADMS system uses a combination of a static network model and dynamic network models to perform its functions and provide value.

These models need high-fidelity data, especially for advanced functions such as power flow analysis, DER support, and volt/var optimization.

To gather the data needed to produce the basis for these models, the ADMS typically imports geospatial data from a utility's GIS. However, the granularity of data in the GIS (or in other data sources) may be insufficient, the quality of these data may vary significantly across the utility's service territory, and data errors or deficiencies my not be uncovered until ADMS implementation begins.

Hence, ADMS implementation typically becomes a broader, and more complex, data management and model management challenge.

In addition to validated GIS data, a fully functional ADMS needs data from various other sources (see Figure 8), including:

- Detailed equipment data with electrical characteristics such as impedances, rated voltage, failure rates, etc.
- Load and critical customer data typically from a CRM, AMI, or MDM system
- SCADA monitoring and control points
- Substation internals, such as single-line diagrams
- Weather forecast data for load and DER forecasting

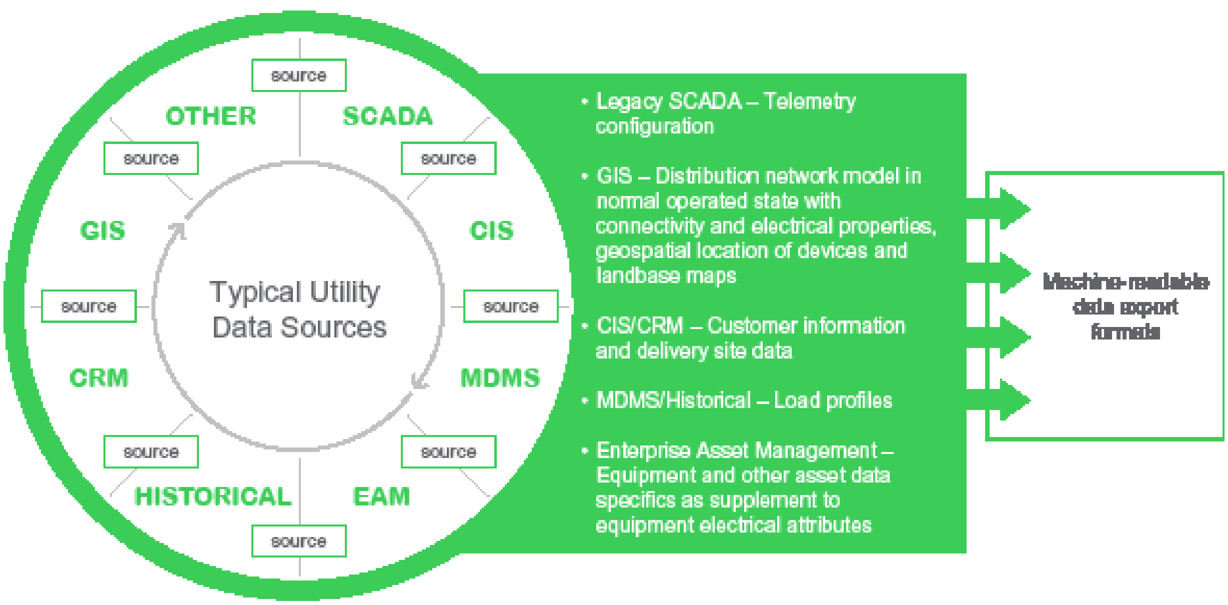

Figure 8. Typical data sources for an ADMS

Today's Recommended Practices

Model Integration

Utilities can accelerate the process of integrating existing utility models by importing data on geospatial location and network connectivity from a GIS. However, Schneider Electric recommends that the utility import GIS data through the Common Information Model (CIM), which uses an internationally-recognized standard model for specifying the power system characteristics of assets using an ontology defined as a CIM profile. The integration should also adhere to the following standards:

- IEC 61968, which details standards for exchanging information between independent systems and applications concerned with distribution management and market operations
- IEC 61970, which details standards for exchanging power system network models used in energy management systems and market systems

In addition to GIS integration, following is a selected subset of considerations when deploying an ADMS:

- **AMI/MDM Integration.** In AMI-based distribution networks, smart meters can help report outages and faults. In addition to the information collected from the AMI head-end system, such as power down and power up, an ADMS can work with the SCADA system and reported trouble tickets to proactively discover, predict, and identify outages, and to help narrow the predicted fault location. Besides the ability to ping meters in order to obtain their status, the ADMS can poll voltages for appropriate meters. The ADMS can use these voltage readings, in turn, to verify voltage values on a smart meter. The ADMS can also use voltage sag/swell event information for various DMS applications (e.g., conservation voltage reduction).

- **The Important Role of DER.** Understanding, analyzing, and optimizing the effect of DER ranks high among the data management functions that utilities need. DERMS provides real-time monitoring, near-term forecasting, and user-friendly control of DERs in a distribution network. DERMS increases an operator's visibility into DER capabilities. It also avoids potential problems in real time or near-real time by constantly monitoring and analyzing the types of DER currently installed on the network. A primary goal of the DERMS is to enhance the existing grid's capability to absorb large amounts of distributed energy assets, and to meet regulatory mandates while avoiding technical constraints. An ADMS can provide CIM-compliant integration with third-party systems on DER groups provided through the IEC 61968-5 standard.

- **Incorporation of Customer Data.** Because an ADMS includes an OMS in an optimal arrangement, import of customer data (e.g., typically from a corporate customer information system) is needed.

- **Automated Vehicle Location (AVL) Integration.** A utility with visibility on vehicles in its fleet can improve productivity and efficiency. Accurate location data means more accurate dispatching. The ADMS AVL integration can be designed as an interface used to transfer vehicle coordinates data from various client-owned systems to an ADMS. This increases operational awareness of ADMS users, and crews can be optimally dispatched. Through the AVL Interface, the ADMS can allow external systems to update vehicles' coordinates in near-real time.

Model and Data Validation

High data quality is needed to achieve the maximum benefits of ADMS implementation, including network optimization, reliability and resilience improvement, and others. Aligning ADMS model data with real field information is necessary to ensure that the decisions made based on the ADMS operational model reflect the reality in the field. For example, more thorough feeder surveys may need to be conducted to ensure that source feeder data are correct, accurate, and complete.

The ADMS can be used to provide quality control of the imported data. Errors can be detected during data import or by running ADMS applications to analyze the imported and calculated data. Data validation can include an iterative process with a bi-directional feedback loop that accounts for ADMS functional results. In a recommended approach:

- The ADMS system evaluates and validates data quality from the GIS during the importing of network model data.

- The ADMS enhances GIS data with additional attributes, such as electrical equipment data (or even use standard or "default" data when precise information is not available).

- ADMS results can be used for data corrections in the GIS.

C-Suite Support

The process of integrating a utility's existing legacy systems into ADMS can be challenging. Implementing ADMS has a major impact on both distribution analysis and operations, and eventually on many business aspects of a distribution utility. Demonstrating corporate commitment (via strong CEO and CIO support) by describing anticipated business benefits can help break down the silos of corporate departments.

Implementing an ADMS essentially urges the distribution utility to rethink how one corporate entity hands off information to another. High-level commitment to developing needed business processes will help sustain the integrity of data once the network model is built. (See the section, "Asset Information Management, Network Model Management, and Field Work," for more information on digitizing the "hand off" process.)

Value-Producing Business Outcomes

Efficient data management with streamlined model integration, static and dynamic data validation, and C-suite support can reduce the time, expense, and business disruption resulting from implementing an ADMS.

Additional benefits can include improved business processes to ensure data integrity and greater cooperation among business units.

Utilities can expect a broad variety of value-enhancing results from implementing a state-of-the-art ADMS, including:

- **Enhanced safety.** An ADMS can enhance safety by providing greater situational awareness and improved functions, such as enhanced switching management.

- **Greater flexibility.** Utilities can experience enhanced flexibility via an improved ability to incorporate DER (increase hosting capacity), optimize DER performance (e.g., to reduce network peak load), minimize grid constraints, and potentially defer capital investments.

- **Increased cost efficiency.** Utilities can improve cost efficiency through better operations and asset management, closer linkage between planning and operations, easier network optimization via system automation and remote capabilities.

- **Enhanced resilience/reliability.** Faster and more efficient mitigation of power disruptions can improve resilience. With fault location, isolation, and service restoration (FLISR) seamlessly integrated in its OMS, an ADMS can more accurately predict incident locations and reduce restoration times, improving customer satisfaction. Using historical analysis, the ADMS can also enhance near-term forecasting of load and storm impact.

- **Improved sustainability.** Reduced energy losses – via advanced optimization algorithms – can promote sustainability. Voltage and var profiling can help deliver higher power quality and optimal voltage levels. The ADMS can also support optimization of demand-side management programs and grid-edge resources, which are typically cleaner than traditional resources. ADMS provides a clearer picture of a distribution utility's grid-hosting capacity. With this information, ADMS can optimize addition of new DER, improving sustainability by considering lifecycle costs.

For example, one Australian utility prepared a detailed case study analyzing the impact of replacing its legacy network management system with an ADMS. The study examined a wide range of benefits, which can be summarized in two broad categories:

- **Reductions in capital expenditures.** Operators gain insight into and control over the network with ADMS functions, such as power flow analysis, load forecasting solutions, and dynamic ratings. These and other capabilities provide greater certainty about peak load and improved asset management, thus allowing delay of expensive network upgrades.

- **Operational and safety improvements.** An ADMS can offer greater efficiency and accuracy in writing and checking line switching instructions, thus avoiding safety or network operating violations, while enhancing efficiency and reliability.

The Australian utility also pinpointed the functions of its legacy systems and compared those with the enhanced capabilities of an ADMS.[16] The red entries constitute the functionality of the utility's existing systems, and the black entries indicate the additional functions of an ADMS.

Schneider Electric Solutions

Schneider Electric's EcoStruxure™ ADMS (Advanced Distribution Management System) provides a comprehensive network management solution, including monitoring, analysis, control, optimization, planning, and training tools that function on a common representation of the electric distribution network.

By merging a utility's DMS, OMS, and SCADA systems into one security-focused, unified solution with more than 50 advanced functions, Schneider Electric's EcoStruxure™ ADMS can provide value from a growing foundation of advanced metering, intelligent grid devices, and distributed renewable energy. EcoStruxure™ ADMS and its data analytics capabilities is a centralized solution for consolidation of independent models dispersed across various utility silos. This solution significantly improves transparency and decision making.

EcoStruxure™ ADMS offers utilities:

- A modular and flexible platform with a single pane of glass across all modules

- Common network models for all voltage levels, geographies, and network configurations

- A data model integration framework

- A security-focused infrastructure (supporting IEC 62443 and NERC CIP)

It integrates energy efficiency, demand response, and DER technologies to enable synchronized and automated approaches to demand management. EcoStruxure™ ADMS also provides automation through closed loop control, advanced apps for volt/VAR optimization (VVO), demand management/ peak shaving, and FLISR.

[16] Ausgrid, "Revised Proposal, Attachment 5.13.N.1, ADMS Business Case," page 8, January 2019.

A Schneider Electric EcoStruxure™ ADMS enhances cost efficiency by consolidating platforms, offers a common user experience, can be deployed in a modular fashion, and promotes standards-based CIM integration with external systems such as GIS, AMI, CIS, weather services, DER aggregators, etc. Schneider Electric EcoStruxure™ ADMS is the only system that received the Certificate of Compliance with IEC 61968-5 (Distributed Energy Optimization) and 61968-100:2013 (Implementation Profiles) by the UCA International Users Group (as verified by an EPRI test laboratory on October 13, 2017) for both server and client sides. The certificate supports GetDerGroupStatus, GetDerGroupForecast, and ExecuteDerGroupDispatch interfaces. Through these interfaces, EcoStruxure™ ADMS can be integrated with various aggregators, thus improving grid management. It can observe, orchestrate, and coordinate DER to benefit customers and resource owners, while improving grid safety, reliability, resilience, and flexibility.

In addition, Schneider Electric has developed a product interface between EcoStruxure™ ADMS and the system of record – ArcFM (a specific utility application built on the ESRI ArcGIS to support utility operations and maintenance). This interface accelerates the process and improves the accuracy of model integration and data validation. Analysts enter network extensions, rework, and repair – planned and in process – into the GIS/ArcFM, and the updates are automatically promoted to the EcoStruxure™ ADMS. The latter checks the data quality and complements the data if needed with additional attributes (such as electrical equipment data, or even standard or “default” data when precise information is not available) using an advanced defaulting engine.

05 |

Planning and Simulation

Overview: The Evolution of Utility Distribution Planning

The traditional utility distribution planning process primarily used an analysis focus to ensure power system reliability and safety at least cost.

Typically performed with little coordination with other utility departments, a small planning team used deterministic, static, relatively simple power system and (one-way) power flow modeling. Planners examined only conventional solutions to meet load, treated DER as a change in net load, and rarely examined alternatives to grid expansion. Power system simulation typically mirrored these approaches and the relatively simple power systems they emulated.

Figure 9 shows that both traditional and today's planning functions cover the spectrum of real-time planning, near-term operational planning (e.g., 1 day to 1 month), mid-term planning (e.g., 1-5 years), and long-term planning (e.g., 10-30 years). However, the similarity between traditional and today's planning ends there.

Today, distribution utilities are in various stages of performing advanced, proactive (and consequently, more complex) planning:

- Planning goals now also include least-cost DER integration and enhanced resilience using DER, microgrids, and other resources and approaches. DER has become an active grid contributor in planning processes.
- Distribution planners now need to coordinate with transmission and DER planners and operations teams, as well as provide online information for customers (e.g., a "heat map," which shows color-coded hosting capacity).
- Planners are increasingly merging economics and analysis, linking with asset management and investment planning, and examining a broader set of solutions.
- Planners now use more complex probabilistic modeling to address more uncertain load and DER forecasts.

Power system simulation needs mirror these planning challenges, while the need for enhanced training of planners to address these challenges grows more acute.

Today's Challenges and Objectives

Planning Challenges

These challenges lead to the following pain points for distribution utilities:

- Increasing number of new DER connection (aka registration) requests, and the need to automate the responses to these requests whenever possible
- The fact that much existing DER is not registered, except in countries with a systematic process of DER registration,[17] leaving some utilities "blind" to these resources

[17] One example is the Distributed Energy Resource (DER) Register of the Australian Energy Market Operator (AEMO), accessed August 2021.

- The need to maintain and align network models with many applications and tools
- Weak integration between planning tools and power production and asset data sources
- Uncertainty due to an evolving regulatory environment, increasing DER penetration, and the need for decarbonization to address climate change
- The need to construct investment plans to improve network performance and obtain regulatory approval
- The need for multiple dynamic short-term plans, rather than the traditional single long-term strategy

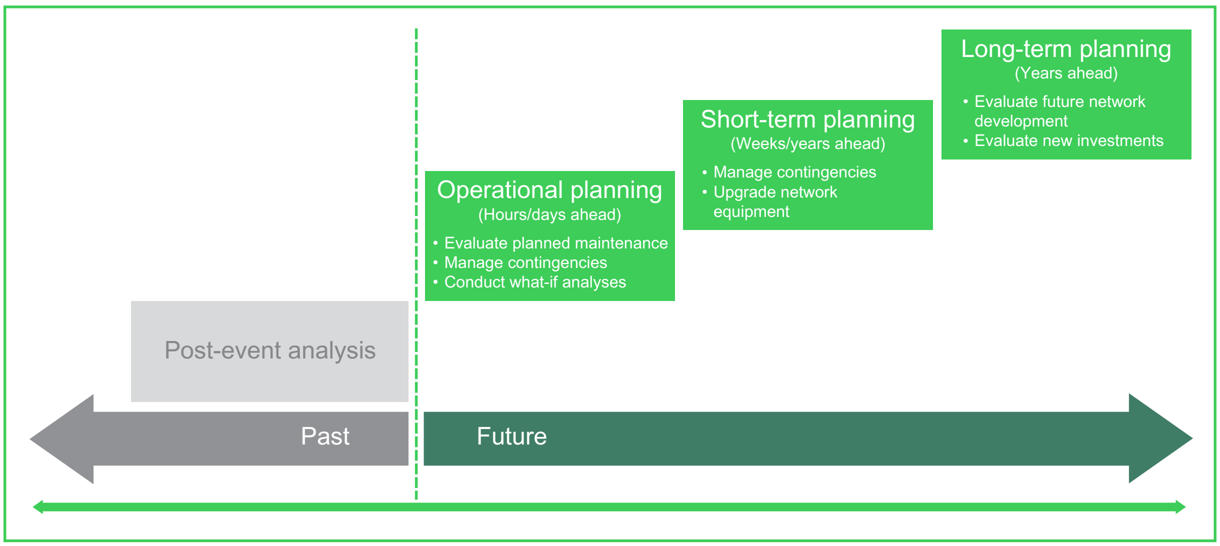

Figure 9. Time horizons for various types of planning

Data Management Challenges

In traditional distribution planning, data sources included GIS data, relatively predictable forecasts of load growth and use patterns, and data on a small number of centralized generation sources, which enabled development of relatively simple network models.

Many Timescales. But today, the significant evolution in distribution planning brings myriad data management challenges. Distribution planning and simulation require more granular historical, real-time, and forecasted load and generation resource data (see Figure 9).

DER Data. The data needed on DERs increases complexity due to the variable nature of renewable DER, uncertain generation and load profiles, and the uncertain pace and location of DER adoption. The data needed on EVs and their growth rates is even more complex and difficult to forecast. At uncertain times of day, EVs can shift from a resource (storage discharging) at an uncertain location (home, work, shopping center) to a load (charging). Mass adoption of vehicle-to-x (where “x” can be a building, the grid, etc.) is predicted in the next few years.

Connection Requests. The large number of new connection requests for these DERs and EVs, as well as new structures, etc., further complicates matters; planners need to be able to analyze the impacts on the distribution system of the requested new connections and identify solutions.

Data Sources. These data needs require planners to gather more granular data from a broader array of sources, including real-time control systems, smart meters, behind-the-meter data, and distributed sensors.

Today's Recommended Practices

To perform distribution planning tasks, Schneider Electric recommends associating the utility's network model with its dynamic model (see Figure 10):

- The **network model** is a static description of all network elements (equipment, feeders, lines, etc.) in its normal operating topology.
- The **dynamic model** is a description of the power system state, including status of devices, tap changer positions, measurements such as voltages and currents, temporary elements such as jumpers, cuts, mobile generation, etc.

Planning Using Network Models

Planners can use various "snapshots" of the network model for various planning analyses, including:

- Archived past network configurations to analyze various network models with different resources available, and to perform post mortem analysis of past network models
- The current network configuration for short-term operational planning (e.g., planned outages due to maintenance work)
- Prospective or planned network configurations to account for upcoming changes in order to plan future network development or upgrades

For the *current* network configuration, Schneider Electric recommends using the same configuration that the ADMS uses for real-time operations as a starting point for simulation purposes and also for short-term operational planning. This approach provides synchronization of operations and network planning and enables planners to perform studies on the current network configuration. The simulation can run simultaneously in operations and network planning environments, without affecting real-time operations (see Figure 10).

	Real-time Context	Simulation Context
Network Model	• Current model	• Past from history • Current • Future (planned)
Dynamic Model	• "As-operated" state of network • Feeds from SCADA	• Real-time snapshot • Historical snapshot • Save case • Forecasted state • Extreme network state • Initial – "as-built"

Figure 10. Planning using network models and dynamic models in real-time and simulation contexts

Planning Using Dynamic Models

Using real-time data feeds from the SCADA system (which gathers data through field devices), the dynamic model provides as-operated snapshots-in-time of the network topology. Over time, the utility can build up a repository of these snapshots – each leveraging the high-fidelity data from the GIS, SCADA, and ADMS – for a variety of future analyses. This is an important way to address the data management challenge for planning and simulation – leverage operations data.

Schneider Electric recommends the capability to select various snapshots of network states as a starting point for planning purposes, as well as "what-if" analysis, including the following:

- **Real-time snapshot**. In this snapshot, all dynamic data are aligned with real-time, which is an important synchronization between operations and planning. However, when the planner makes a change to a switching device, for example, the effects of that change are not reflected in the real-time operation environment.

- **Historical snapshot**. This loads dynamic data from a past snapshot in time (a form of playback). So, for example, if a different state of a device is needed for a planning analysis, a past snapshot can be loaded and examined.

- **Saved case**. This can be a dynamic model that was examined earlier, with perhaps some dynamic states changed.

- **Forecasted state**. This consists of a dynamic model using specified, forecasted load and generation data.

- **Extreme network state**. This consists of a dynamic model where the planner can specify an extreme state such as maximum loading, minimum loading, maximum generation, minimum generation, maximum generation with minimum loading, etc., and the system will locate the dynamic data for an instant in time that best meets the desired criteria.

- **Initial as-built state**. This is the dynamic model defined in GIS for the normal status of devices (topology).

An Array of Planning and Simulation Activities

Capabilities like these enable a broad array of distribution planning and simulation activities related to network operation, network analysis, network planning, and network optimization (see Figure 11).

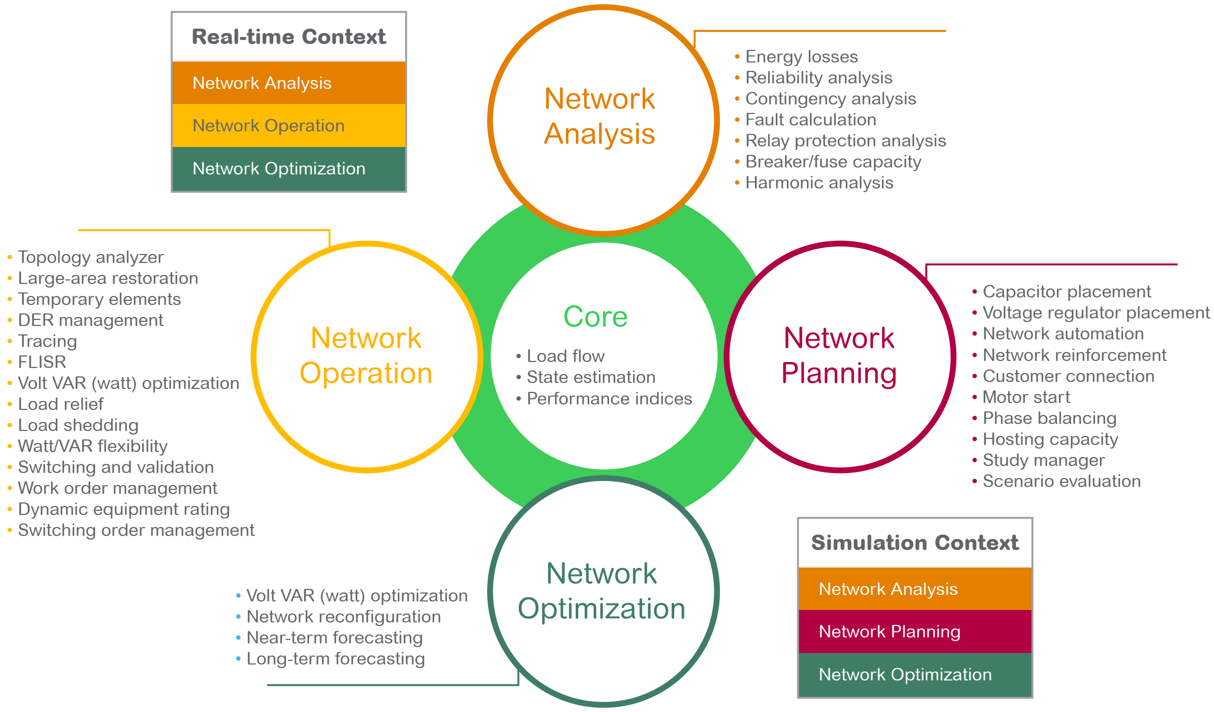

Figure 11. The variety of planning and simulation activities required in a real-time context and simulation context

Value-Producing Business Outcomes

Implementation of advanced distribution planning and simulation approaches, driven by effective data management practices, are likely to produce the following business outcomes:

- **Efficiency**. Utilities can reduce the total cost of ownership of planning tools, and improve personnel efficiency via tight integration with the ADMS and data sources.
- **Efficiency**. Convergence of planning and operation using a common platform, common data, baseline model, security, and user interface also enhances efficiency.
- **Flexibility**. Advanced planning and simulation can enable more rapid and extensive DER adoption, while minimizing grid constraints.
- **Flexibility**. Utilities can also connect DER more quickly and at lower cost via more efficient host capacity planning.

- **Sustainability**. Advanced distribution planning and simulation can maximize the benefit of equipment investments, since the same intelligence is embedded in the software that plans and utilizes equipment. It can enable a utility to defer capital investment through implementation of various resources, such as generation, storage, demand response, and energy efficiency, identified via scenario evaluation and high-fidelity data. The flexibility enhancements just described – more rapid and extensive use of DER – also contribute to a greener, more sustainable grid.

- **Regulatory**. Advanced planning and simulation can also facilitate compliance with regulatory and government targets and requirements.

- **Risk and corporate goals**. Reduced risk, while working toward achieving corporate goals, via careful, extensive scenario planning and simulation driven by high-fidelity data.

Schneider Electric Solutions

Schneider Electric provides a holistic approach to distribution planning and simulation that considers forecasted load and generation, DER and EV penetration, technical constraints, and regulatory and government requirements.

The Schneider Electric planning and simulation capability enables development and comparison of multiple network planning scenarios and multi-year planning studies from a performance perspective.

To maximize planning and simulation capabilities, Schneider Electric's approach associates the network model with the appropriate dynamic model. Schneider Electric then provides a tight interface and integration between the ADMS and simulation and planning tools. Schneider Electric's system enables planners to simultaneously run simulations in operations and network planning environments. Both the Schneider Electric network planning capability and Schneider Electric real-time ADMS rely on the same database, rather than unintegrated processes linked via an interface. This integration enables centralized maintenance of network models and out-of-the-box access to operational data history. This enables distribution utilities to efficiently conduct a wide range of planning and simulation analyses.

In fact, this integration is a key part of data management in the planning and simulation context. Using the same high-fidelity, high-quality, granular data gathered from field data, stored in the GIS, and used in the SCADA and ADMS (and DERMS), *in planning and simulation functions* is crucial to the effectiveness of these functions. This synchronization is a must-have to realize maximum value from planning and simulation activities.

A key capability here is the ability to provide detailed insight into the capability of the distribution network to accommodate (host) additional DER and EVs, considering potential voltage violations, overloads, voltage dips, relay protections settings, etc. This information helps utilities create and post online a hosting capacity "heat map," which shows how much new generation can be installed in an area of the distribution system with no significant system parameter violations.


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06 |

Asset Performance Management and Asset Investment Planning

Overview: Asset Management Trends

Leading utilities are now realizing the value of enhanced asset management.

With risk-based maintenance, Hydro One tripled vegetation treatment in 2018 compared to 2017, with only a marginal increase in cost.[18] Ofgem has defined a risk-based approach for asset management decisions to be applied by all UK distribution network operators (DNOs).[19] The ISO 55000 standard for asset management is gaining momentum and promotes risk monetization in asset management decisions. Over 70 electric utilities are now ISO 55000 certified worldwide.[20]

Asset management is a balancing act for utilities that involves the following questions:

- **Risks versus costs.** What do we need to do with our assets to meet objectives at optimum cost?
- **CapEx versus OpEx.** How do we decide between repair (maintenance) and replacement (new investments) to preserve value?
- **Short-term versus mid-term.** When do we need to repair (maintain) or replace assets?

Today's Challenges and Objectives

In the areas of asset performance management (APM) and asset investment planning (AIP), the primary challenge is to understand, correlate, integrate, and synchronize data from many sources to form a seamless exchange of data between applications.

Data sources include the following:

- Asset (equipment and system) **inspection data** from utilities' enterprise asset management (EAM), computerized maintenance management system (CMMS), or mobile workforce management (MWM) system, including off-line (entered manually to these systems after the field crew work) or online (automatically entered to these systems) data
- Off-line or on-line asset **testing data** from EAM, CMMS, and MWM systems, and laboratory tests (e.g., periodic samples of transformer oil and laboratory analysis results)
- Real-time **measurements and indications** from assets that originate in the field (e.g., from IoT sensors, the ADMS, the SCADA system, etc.)
- Off-line **catalog databases** of static asset data (e.g., nameplate data) from the network model, GIS, ADMS, and EAM system

Data are needed to support asset management analyses across multiple timeframes, spanning the asset lifecycle (see Figure 12).

[18] Hydro One, "Hydro One Limited 2018 Annual Report; Powering economics, connecting communities," 2019.
[19] Ofgem, "DNO Common Network Asset Indices Methodology; Health & Criticality, Version 1.1," January 30, 2017.
[20] International Organization for Standardization (ISO) website, "Known Certified Organizations," accessed August 2021.

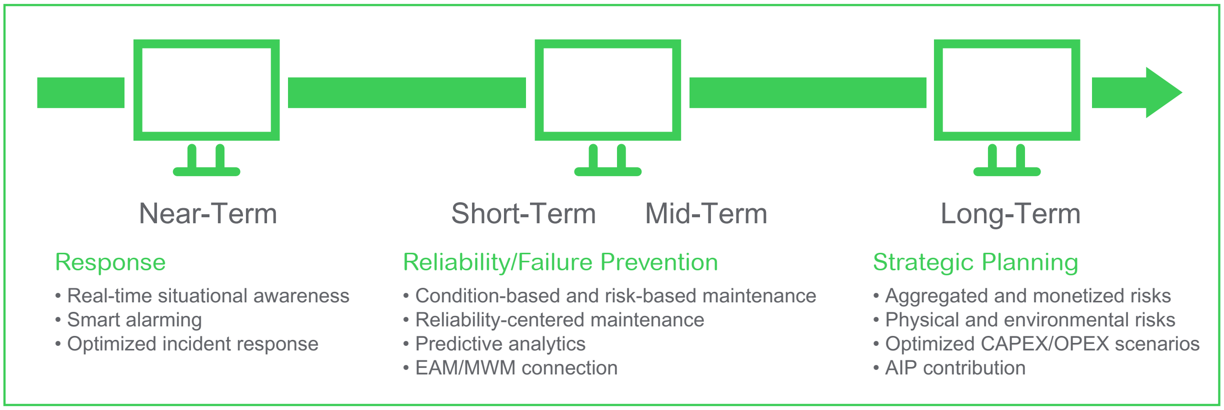


Figure 12. Asset management is needed across the entire continuum of asset life

Today's Recommended Practices

Schneider Electric recommends shifting:

From the scheduled approach:

- Time-based maintenance
- Expert knowledge and home-grown, rudimentary internal tools

To an evidence-based approach:

- Risk-based decisions combine asset health, reliability, and criticality
- Advanced analytics based on geospatial and operational data, including IoT
- Advanced risk models configured with utility-specific information and experience

Schneider Electric recommends tightly integrating the range of data described above (using standard methodologies) for seamless entry into a master asset database and asset analysis tool. For example, these data can be used to develop insights, such as an assessment of asset health, the effects of asset failure, and the criticality of each asset. (Ideally, these key performance indicators [KPIs] can also be monetized to aid decision making.)

In turn, this information can help utilities identify needed maintenance actions. To maximize value and provide an end-to-end process, those maintenance actions need to be exported to customer IT tools that schedule, dispatch, and execute maintenance tasks. This requires pertinent data to flow between tools.

This process not only inputs data, but also exposes data for other use cases and functions.
The master asset database and tool can then use this dynamic data to estimate asset health and criticality, and then feedback this information to the ADMS system, for example, in another type of closed loop. Information on asset health and criticality can enable the ADMS and network operational personnel to make better informed decisions on alternative operational scenarios to mitigate failure risks (e.g., switching sequences, which change the network topology and use assets with now known asset health).

Value-Producing Business Outcomes

This approach provides a grid-driven approach to asset management based on the active topology.

From a data perspective, it values existing data, while providing comprehensive grid asset visibility with de-siloed data. Compared to existing time-based maintenance practices, expected utility outcomes from implementing asset performance management and asset investment planning systems include the following:

Cost efficiency

- Condition-based maintenance (aka predictive maintenance or risk-based maintenance) implementation can yield up to 15% cost savings, compared to time-based maintenance, which can lead to costly premature or too-late asset repair/replacement.
- Condition-based maintenance can also aid maintenance prioritization, clearly identify needed actions, and extend asset useful life.

Resilience/Reliability

- Operations and maintenance improvements can reduce the risk of failure by up to 80%.
- The availability of operating assets can increase by up to 15% by reducing the risk of asset failure.

Sustainability

- Utilities can realize up to 25% CapEx deferral gains.
- This process can facilitate evidence-based decision making to optimize CapEx versus OpEx.
- This process can align financial and operational objectives within the utility's strategic asset management plan, supporting compliance to ISO55001:2014.

Schneider Electric Solutions

Schneider Electric offers an EcoStruxure™ Grid Asset Advisor system that works with utility EAM, MWM, and digital automation systems, as well as its network model, GIS and ADMS, to provide the following capabilities (see Figure 13):

- Assesses asset health and risk, provides predictive analytics, and provides decision support
- Aids capital investment decisions, financial modeling, and portfolio planning
- Works with CIM, network model, and active topological data, as well as advanced ADMS and GIS functions with APM data
- Enables native integration of an asset performance management and asset investment planning capability with ADMS and ArcFM for rapid implementation, maximum use of data, and facilitated workflows with field applications
- Facilitates grid-wise risk management that considers physical and environmental risks in a single system
- Provides a balance of asset decision support across asset lifecycles and timeframes, including near-term response, short-term and medium-term reliability and failure prevention, and long-term strategic planning

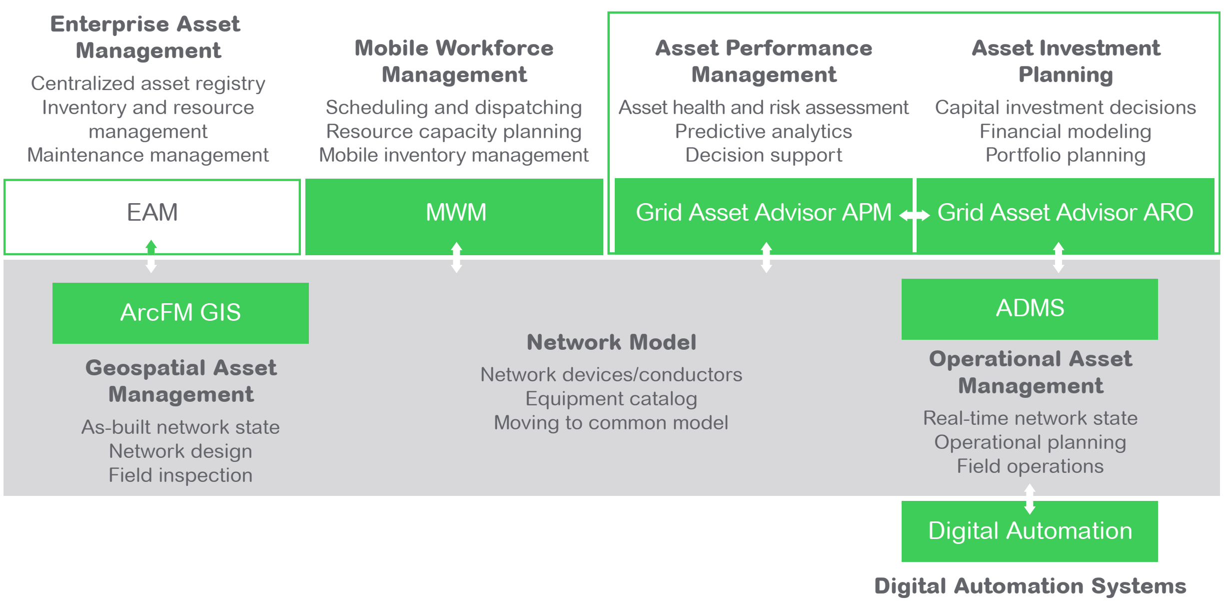


Figure 13. One potential configuration of grid asset tools with utility EAM, MWM, ADMS, GIS, and digital automation systems

07 |

Substation Automation, Systems Engineering, and Maintenance

Overview

Utilities tell Schneider Electric that they seek interoperability and interchangeability across all vendors that supply digital equipment in the substation automation market in order to design future-proof, vendor-agnostic systems.

With regards to interoperability, they want various equipment vendors to operate using common data in a common language using common behavior. They want interchangeability from specifications, not from vendor blueprints, to enable competition between vendors that fosters innovation. Utilities also understand that this system-based, standards-based approach usually involves a higher upfront cost (CapEx), but enables significant lifecycle OpEx savings, reducing long-term total cost of ownership and maintenance (see Figure 14). Compared to traditional systems, this CapEx can be further reduced by an amount directly proportional to the number of new rollouts and upgrades completed, as well as the number of standardizations of system and application requirements achieved.

Evolving technology in the field of data modeling and communication has opened pathways to exchange of data and their semantics across:

- Multiple levels of the grid
- Across asset lifecycle phases (i.e., specification, engineering, operation, maintenance, and upgrading)

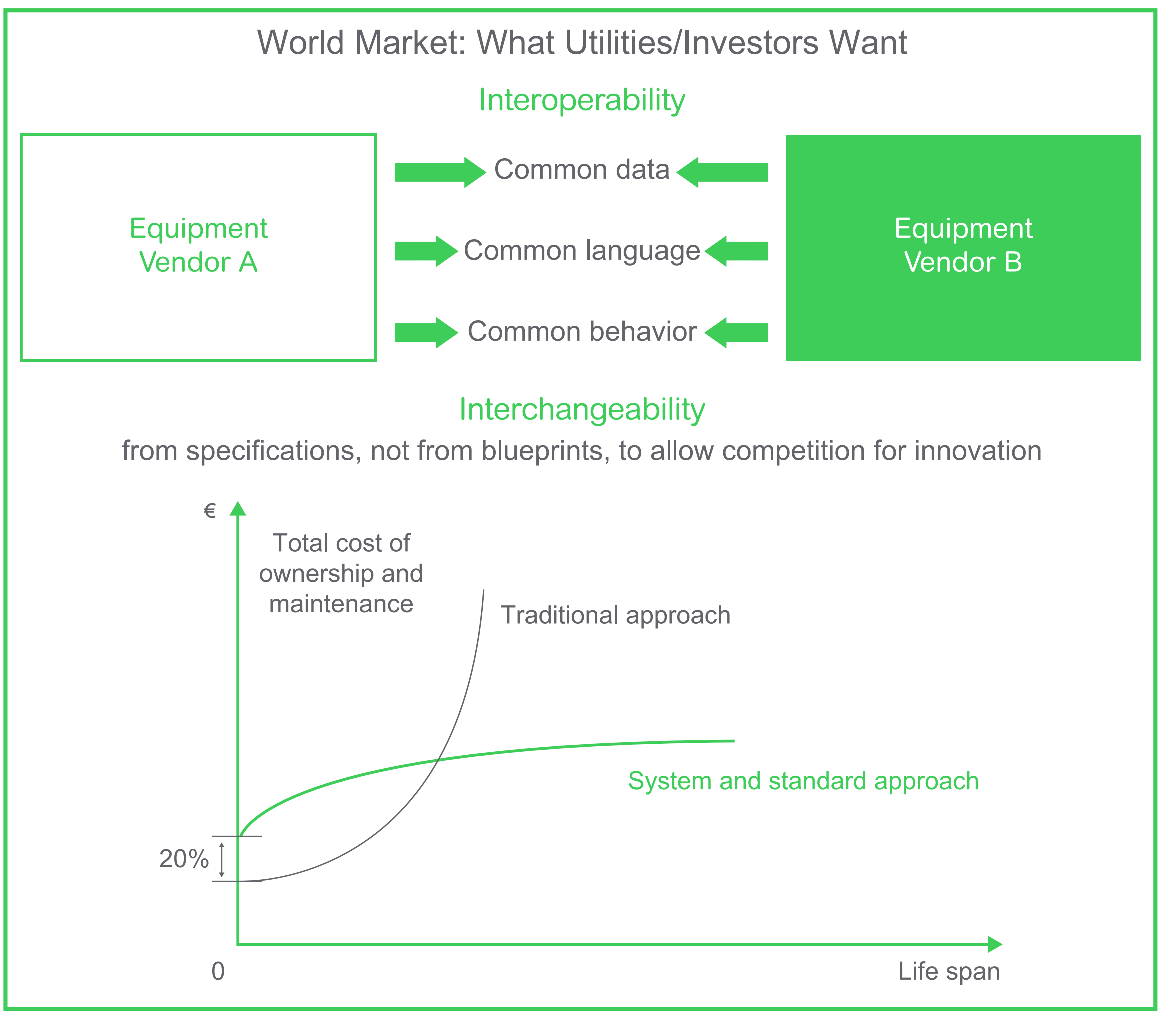


Figure 14. Utilities seek interoperability and interchangeability, while realizing that this requires a higher upfront cost that reduces long-term total cost of ownership and maintenance

Leveraging these state-of-the-art concepts and latest technological trends, the International Electrotechnical Commission (IEC) Technical Committee 57's IEC 61850 has become a well-established standard for the design, configuration, communication, and testing of electrical substation automation systems. IEC 61850:

- Leverages a data-driven approach based on machine-processable languages that facilitates digitalization
- Improves the efficiency and quality of the entire engineering lifecycle of the substation
- Enables a vendor-agnostic approach across the lifecycle
- Enables interoperability of the core substation automation system with other IT/OT systems in the smart grid

IEC 61850 has become a cornerstone technology for the substation automation world. This standard has made possible the vision of truly multi-vendor power utility automation solutions. An estimated 2,000 projects with over 150,000 IEDs from different suppliers are demonstrating interoperability on real projects.

The next step in interoperability is to specify the large amount of diverse data involved in utility requirements for substation automation projects, as well as supplier/vendor tenders for these projects, in a standard, implementation-agnostic way at an early stage of system engineering using machine processable language – substation configuration language (SCL). This will help utilities realize the benefits of IEC61850 for the end-to-end lifecycle of substation automation systems:

- **Digitalization and automation** of the substation automation procurement process
- **Minimization** of the gap between customer expectations and vendor responses
- **Standardization** at each phase of the project lifecycle, which in turn helps control TotEx (the sum of capital and operational expenditures, see Figure 15)

Utilities are increasingly embracing digitalization across their processes and an engineering workflow powered by machine-processable language.

Up to 25% of Savings on the Overall Lifecycle Costs (TOTEX) for a Power Automation System

Prescription	Project Launch	Specification	Design and Engineering	FAT	SAT	Operate and Maintain	Upgrade
Pre-tested and standardized bay templates	IEC61850-based project specification • Vendor agnostic • Machine processable by vendors • Reusable (.SSD file)		Future proof System configuration Single source of truth (SCD file)	Faster FAT and SAT		Pre-test and standardize	Pre-test and standardize

Figure 15.
Standardization enables TotEx reduction throughout the project lifecycle

Today’s Challenges and Objectives

Utilities are facing challenges as digitization produces large amounts of data.

To use this data, they need to define a global and harmonized information technology (IT) framework, and more specifically, a data management framework that:

- Facilitates easy data exchange and interoperability
- Leverages the IEC 61850 standards suite
- Connects industrial operational technology (OT) systems (e.g., smart grid and smart metering systems) with legacy systems
- Incorporates data that originates from various sources (e.g., sensors, IEDs, SCADA, work management systems, and others)
- Facilitates use across various stakeholder groups (e.g., utility operations, utility enterprise users, third parties, and others)

Today’s Recommended Practices

Today, most utilities do not view all of their substations from a single pane of glass.

Utility operations departments view operating substations, and utility network planning departments view planned substations. Over time, these two substation views can be combined.

For new substations, detailed data can be compiled in the specification, configuration, testing, and commissioning phases. Using IEC 61850 and related standards, this data, and a data management system for substation automation system, that data and semantic can penetrate each later phase of the substation’s lifecycle (i.e., operation, maintenance, upgrading/retrofit/refurbishment, and decommissioning).

For existing substations, Schneider Electric views two data management aspects of substation automation:

- Gathering design and architecture data, by digitizing existing design, specification, configuration, and construction data
- Gathering real-time operating data by retrofitting enhanced data collection (e.g., via sensors)

These measures provide a baseline for the evolution of a substation that is operating today, but not yet modernized. Later, these steps facilitate better identification of needed retrofits, effectively future-proofing the substation.

The goal is to enhance asset management of existing substations so they are more maintainable, cost-efficient to operate, upgradeable in the future, and can operate across a longer service life. Utilities can now accomplish this in a vendor-agnostic manner (to provide the utility peace of mind, going forward) by following international standards.

Schneider Electric Case Study: The Vendor Tendering Process for Substation Automation Projects

Utility Challenge

In the area of substation engineering, the process for automating a substation is one example of data management challenges that most utilities worldwide face. Traditionally, incorporating automation into a substation involves utility development of a vendor-agnostic concept and specification, so that manufacturers can then tender proposals in response to this specification. The tendering process includes:

- The asynchronous part, in which utilities develop standardized application concepts and schemes in a vendor-agnostic manner
- The synchronous part, in which multiple vendors qualify their products against those concepts, and the winning vendor creates configuration templates, etc.
- Project execution

Today, the utility typically prepares the concept and specification as a large MS Word document. The tenders that vendors submit typically consist of hundreds of documents, spreadsheets, AutoCAD (computer-aided design and drafting), and documents in vendor proprietary formats, which lead to the following challenges:

- The tendering process is lengthy.
- The utility's concept and specification documents are non-machine readable, so they cannot be re-used in further steps in the tendering and execution process.
- Process automation and efficiency is limited due to manual creation of documents.
- Version and definition traceability is limited.
- Many documents need to be managed, and updates are entered manually – time-consuming processes.
- The process poses a high risk of data entry errors and interpretation errors between various project participants.

Many stakeholders in this process face these challenges, including:

- Designers (engineers)
- Software interface teams
- Manufacturers of bay controllers
- Asset management teams (e.g., to set IED protection setting and protection cubicle factory assessment testing [FAT])
- Maintenance and commissioning teams (e.g., that perform site acceptance testing [SAT])

Utility Solution

To streamline the process and improve efficiency, utilities need to evolve from a multiple document and spreadsheet-based tendering process to a fully digitized, machine-readable, automated, IEC 61850-compliant digital tendering process. To help achieve this, the single common XML-based file format (substation configuration language [SCL] specified in IEC 61850) can be used for the entire tendering process on both the utility side and the vendor side.

OSMOSE IEC 61850 Engineering Process

The Optimal System Mix of Flexibility Solutions for European Electricity (OSMOSE) recently formed a work package to facilitate and standardize this process, based on IEC 61850.

Schneider Electric and 32 other European partners (TSOs, research centers, universities, electricity producers, manufacturers-integrators, and others) formed OSMOSE in 2018 as an H2020 EU-funded project to "explored the technical and economic feasibility of innovative flexibility services and providers" [OSMOSE website]. The OSMOSE IEC 61850 engineering process creates a top-down approach that covers project steps across concept and specification, selection and procurement, system configuration, and IED configuration. Information exchange between these steps using SCL files increases efficiency, quality, and transparency of user requirements and IED capabilities.

Value-Producing Business Outcomes

This process can yield the following business outcomes:

- Facilitates supplier/vendor choice for substation automation projects
- Minimizes the effort to proceed from vendor-independent specifications to application templates (with indirect benefits on the synchronous part of the process)
- Enables automated updates of application templates and project files when specifications are updated, which maximizes concept traceability
- Limits the manual tailoring effort by using smart engineering tools
- Centralizes documentation, which limits the number of documents, files, and tools that the team needs to learn and manage
- Maximizes automation of construction and testing (e.g., FAT and SAT)

More generally, use of IEC 61850 in this way provides value in the following areas:

- **Cost Efficiency**
  - Reduces project costs and delivery time
  - Enhances project efficiency via a top-down engineering approach

- **Sustainability**
  - Facilitates the process of substation automation, enhancing utilization of these important assets and potentially allowing delay of new construction
  - Reduces project risks via improved communication during the tendering process, potentially enabling inclusion of more green criteria and improving project outcomes
  - Creates solutions that are fully documented and future-proof:
    - The capabilities of the deployed products can be matched and easily compared with the ones to be replaced in future.
    - A single-source-of-truth configuration file enables low-risk system evolution without causing inconsistency among other system components.
    - Data integrity is maintained due to the standardized engineering process and single-source-of-truth configuration file – the-substation configuration description (SCD).

Schneider Electric Solutions

Schneider Electric understands these data challenges, is at heart of (and enables) digitization, and understands how to use the data to solve problems at different phases of the grid management lifecycle.

For example, Schneider Electric is an OSMOSE partner and has successfully worked with multiple utilities to implement the IEC 61850-compliant digital tendering process described above.

Schneider Electric also provides “vertical integration” between the ADMS and substation configuration. More specifically, the CIM model at the ADMS level can almost automatically generate the IEC 61850 substation configuration. Conversely, after completing the IEC 61850 engineering at the substation, it can be exported in the CIM.

To support the latter capability, Schneider Electric offers an EcoStruxure™ Power Automation System (EPAS) platform of products, which include a human-machine interface (HMI), gateway, bay control unit (BCU), and engineering and maintenance tools.

EPAS engineering – a vendor-independent engineering workbench – helps utilities design and configure a future-proof protection automation and control system that is IEC 61850-compliant and enables application standardization and engineering efficiency. This solution incorporates a system specification tool, design, and a system configuration tool. Utilities can use these to specify all data in the substation engineering process in the SCL of IEC 61850 and share it across all vendors (vendor-agnostic process).

08 |

Augmented Reality for System Operation, Maintenance, and Personnel Training

Overview

The dedication of electric distribution utilities to safety stems from the potentially hazardous task of operating and maintaining a complex electrical network.

Even a momentary mistake or careless act can lead to an instantaneous and potentially tragic event. For this reason, utilities devote significant time and resources training employees to perform safely in field.

Fortunately, emerging digitally-enabled tools can accelerate an employee's progress up the learning curve by empowering operations and maintenance (O&M) personnel with near-real-time information and detailed procedures. Some of the most revelatory of these tools, augmented reality (AR) and virtual reality features, are available now that can:

- Reduce human errors to increase safety
- Provide training to build skill sets
- Accelerate O&M tasks
- Reduce outage time

Today's Challenges and Objectives

Electric distribution networks pose safety hazards, are complex, and are constantly changing.

Invisible to the naked eye, electric power equipment is inherently dangerous. Distribution network equipment consists of many separate devices, typically available in different sizes and models, from different manufacturers, with differences in appearance and capability. Troubleshooting or replacing a single piece of equipment can involve many procedures and steps.

Under these challenging circumstances, utility technicians are expected to maintain reliability while also working safely, sometimes on unfamiliar equipment, under stressful conditions, and sometimes in challenging weather conditions. They must master operational, maintenance, and safety practices – many of which are specified in manufacturer's technical manuals and procedures.

Consider the technician who travels from the dispatch center or home to investigate a potential fault and determines that the correct manual for the unfamiliar equipment is not available in the field. This limits the efficiency of the field technician, who is under pressure to promptly restore power. During extreme events, this situation many occur many times, as workers from neighboring or remote utilities provide aid through mutual assistance programs. Equipment and procedures can vary significantly from utility to utility.

In the past, as utility systems and procedures evolved slowly and employees benefitted from decades of experience, distribution system O&M challenges were substantial but manageable. However, today's utility personnel encounter a rapidly changing technical environment, whose underlying structure is becoming more automated and uses more complex digital technology.

At the same time, many utilities face attrition through retirement of their most experienced workers. As a result, utilities confront the reality of needing to rapidly train new workers on the O&M of more complex systems and procedures.

Figure 16 shows the range of challenges facing electric distribution utilities in four broad areas: people, system, equipment, and operation.

- **People:** Experiencing an aging workforce and headcount reductions, utilities face the challenge of transferring competency to less experienced workers, the need to enhance training processes, and the need to safely operate a vast network of diverse equipment.
- **System:** Challenges include ever-changing demand that requires an agile, robust system; aging networks that pose safety challenges; outmoded designs that complicate regulation compliance; and lack of redundancy and flexibility for continuous operations.
- **Equipment:** Challenges include stressed equipment due to continuous operation, equipment degradation from grid disturbances, and a higher probability of failure for the aging assets.
- **Operation:** Heavy demand, market expectations, and pressure to reduce operational expenses and maintain business continuity can dilute operational safety emphasis.

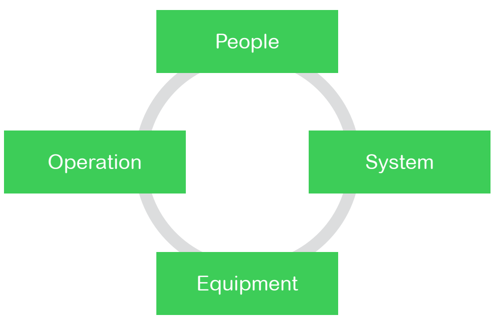
These challenges point to a need for digital solutions that can place real-time operational data, digital equipment manuals, and online procedures directly in the hand of field crews to facilitate safe and efficient O&M.

Adapt safety competencies to an evolving environment

- How can we transfer competency between newcomers and retirees?
- The vast power network and diversity of equipment requires regular enhancement of expertise for day-to-day operations.
- Technology evolution requires enhancement of competencies.
- Challenges include an aging workforce of experts, inexperienced newcomers, and reduced headcount.
- The need for 24/7 monitoring presents challenges.
- Internal training centers and trainers need to adapt their training programs and approaches (via digitalization), with manufacturer support.

Operations under 24/7 stressful conditions

- Heavy demand and market expectations place major stress on operations.
- High pressure to decrease operational expenses and maintain business continuity can lead to unsafe practices.
- The drive for improved performance and profitability may dilute safety considerations.
- Lack of a common repository and digital documentation results in an over-reliance on the aging workforce.



Evolving demand requires reconsideration of distribution and may create fragility

- Evolving demand requires agile and robust systems, forecasting, and action plans.
- Aging networks pose a greater threat to safe operation.
- Outdated system and equipment design complicates compliance with today's regulations.
- Lack of redundancy and flexibility limits the ability to ensure continuous operations.

Stressed equipment

- Equipment is heavily stressed due to continuous operation.
- Equipment condition degrades due to frequent, significant grid disturbances.
- The aging of assets increases the probability of failure.

Figure 16. Summary of O&M challenges facing distribution utilities

Today's Recommended Practices

"Mixed reality" (i.e., the combination of AR and VR) for O&M and training provides utilities a powerful tool for tackling the dual challenges of an increasingly complex network and the loss of highly skilled employees, especially O&M staff.

The broad set of distribution utility use cases for AR technology include:

- **Enhancing the competence and flexibility of O&M personnel.** Using sophisticated AR technology can reduce power system downtime, accelerate O&M, and reduce human errors, the latter of which are the cause of most accidents. Technicians can locate information faster with immediate online access to real-time data, as well as digital user manuals, procedures, and diagrams. AR technology can also enable technicians to move easily from one type of equipment with one complex scenario, to another type of equipment with a totally different scenario.

- **Accelerating training with tailored virtual reality (VR) exercises.** PCs or tablets can display a digital twin disconnected from the real-time network and used in virtual, highly realistic training sessions. Demonstrations have confirmed that personnel learn quickly in these kinds of simulations. Accelerated learning is advantageous because most utilities seek to reduce training time, despite their loss of experienced individuals available for mentoring.

- **Providing remote assistance that combines AR and expert assistance solutions.** A full complement of AR solutions can include remote expert assistance, which supplements the digital solution with online advice from experts.

Using AR technology, utilities can organize relevant data (e.g., equipment, procedures, and network status) and enable its field access on mobile devices (e.g., tablets, smart phones, and digital glasses or headgear). When a technician points a tablet's camera at field equipment (or wears digital glasses), the mobile device can accurately recognize the type, model, and specific piece of equipment requiring attention. This reduces the potential for human error due to equipment misidentification. The AR solution can then overlay circuit diagrams and/or step-by-step procedures to analyze or correct a situation. The field device can also virtually "open" the equipment to reveal internal components.

Today's state-of-the-art AR solutions can access a vast amount of data from various utility data management systems. As a result, the technician can gain access to the current state of the specific equipment, as well as manufacturer documentation. Links to the geographic information system (GIS) can provide physical location, as well as situational and environmental information (e.g., outage data and weather). Technicians can also interact with the utility's work order system. If parts are needed, the technician can photograph the equipment and submit it to the service desk. The device can determine whether the required parts are available, and if they are not, can automatically enter the supply chain for ordering.

This end-to-end task of repair assessment, parts ordering, and replacement scheduling may only take several minutes. By contrast, traditional maintenance methods could require hours or even more than one day. The result is faster and more accurate repair, reduced potential for error, and enhanced safety. When multiplied by hundreds or thousands of such improvements each year, the potential cost efficiencies and safety improvements can be significant.

Value-Producing Business Outcomes

Effective use of a state-of-the-art mixed reality solution can produce the following expected outcomes for electric distribution utilities:

- **Enhanced safety.** Enhanced safety ranks highest among the benefits of AR technology for utility O&M. The ability to verify the identity of a piece of equipment, retrieve detailed information about it, and access step-by-step procedures tied to a visual image of the equipment greatly reduces the potential for human error and unsafe practices. In addition, 3D geo-positioning can check the safety level of worker positioning in the field. In a world where work boundaries are fundamental, this key feature can warn the operator in case of area crossing.

- **Improved cost efficiency.** Before going to the field, operators can view on AR system the action to be performed. This enables them to identify all needed tools and be more efficient in the field, since they have already virtually performed the task. By enabling access to accurate information on a technician's smart device, AR technology can reduce O&M costs by saving personnel time and reducing human error. The availability of digital guidance in the field avoids return trips to the dispatch center to obtain information, saving time and money.

- **Enhanced resilience/reliability.** AR-aided service restoration can enhance resilience during extreme events. Local utility crews can restore service more rapidly, and mutual assistance workers from other utilities can work with increased confidence on unfamiliar equipment when supplied with AR technology that supplies technical specifications and procedures. Compared to a simple smartphone call with video sharing, the AR image with a laser pointer provides more accurate identification, including screen captures and notes. The opportunity to "see" live data provides improved context.

- **Training efficiency.** The effectiveness of skills transfer increases as the training context and case are closer to reality. Repetition is another positive mechanism that reinforces training. Another benefit is that a trainee need not wait for an in-class event to be organized; at home, they have the tool to discover step-by-step operations and fundamental procedures, as well as assets diversity.

- **Greater flexibility and sustainability.** As AR becomes widely adopted, and maintenance and restoration activities are carried out more efficiently, distribution operators (especially of large systems) will have more options for keeping DERs on line, hence improving flexibility and sustainability with fewer greenhouse emissions. Fewer troubleshooting and maintenance trips will boost sustainability by reducing vehicle emissions.

European Utility Finds Value in AR

A large European electric distribution utility analyzed the potential impact of SE's AR solution on its maintenance work load. The utility found that the solution would reduce the number of troubleshooting incidents by 1200 per year, and the number of preventive maintenance activities by 3500 per year. The utility and SE will launch a pilot project in a large Mediterranean city to test the effectiveness of the AR solution under real-world conditions.

Schneider Electric Solutions

Development of customized AR/VR solutions requires many hours of 3D developer labor – at high cost.

Schneider Electric's solution replaces this expensive approach with a solution that provides (at the customer's choice) either a ready-to-use application, or provides an authoring tool that enables non-IT users to architect and build their own applications.

Schneider Electric's mixed reality solution for O&M and training is EcoStruxure™ Augmented Operator Advisor 3D (EAOA 3D). In AR mode, EAOA 3D overlays reality – the real device or object – with a diagram, internal view, or set of procedures and live data (see Figure 17). In VR mode, EAOA 3D provides a simulation of the equipment or plant with real-time data originating from the operating equipment. For training purposes, the EAOA 3D solution disconnects from real-time operation and can be used either in AR or VR mode.

This product provides a variety of real-time and equipment information to O&M crews whenever and wherever it is needed. EAOA 3D is a customized solution tuned to the equipment and processes of each distribution utility. Each application, in turn, is customized and adapted to the environment and the machines (regardless of equipment manufacturer) to suit utility needs.

Developed in partnership with Microsoft and Capgemini, EAOA 3D improves operational efficiency by employing AR, enabling operators and maintenance personnel to superimpose virtual data and objects onto an electrical cabinet or a piece of equipment. These personnel can download at no cost and use the app on a smart phone, tablet, or computerized headgear. The latter enables "heads up" O&M activities.

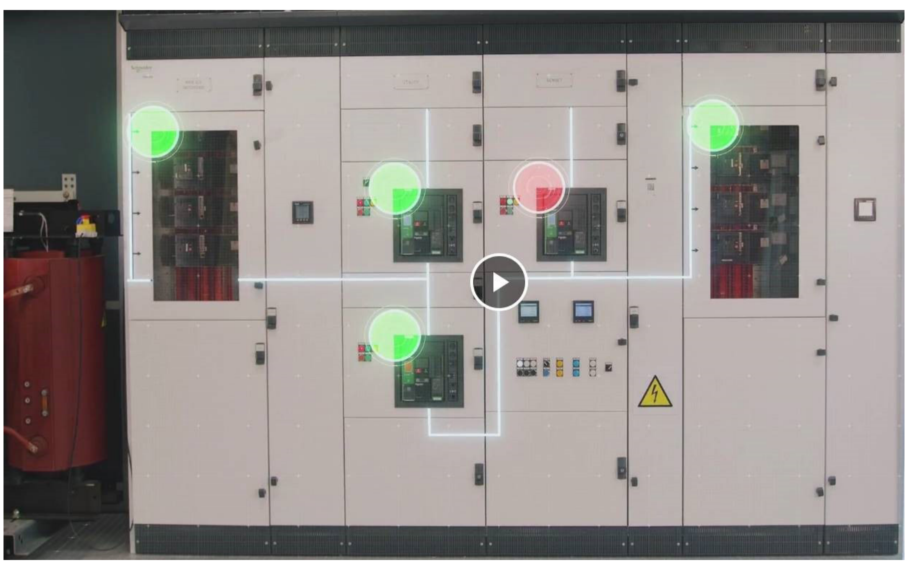


Figure 17. Schneider Electric's EcoStruxure™ Augmented Operator Advisor 3D (EAOA 3D) overlays an internal view of the equipment atop the real external image of the equipment

EAOA 3D provides access to a wide selection of asset-specific, real-time data from programmable logic controllers (PLCs), as well as documents, images, web pages, notes, labels, and data from an SQL database. The solution enables an operator or maintenance technician to review PDF files with electrical diagrams, images, and videos, and it can virtually reveal internal components of a cabinet, machine, or device. The utility can specify adjustment of the app to allow varying levels of access, depending on user roles and responsibilities. The EAOA 3D can also guide O&M personnel through step-by-step procedures by providing on-screen instructions superimposed on the equipment.

09 |

DER Management

Overview

DER is unique in that it simultaneously represents an opportunity and a challenge that electric distribution utilities face.

As Schneider Electric's Alain Malot explains in his LinkedIn post, DER means different things to different people. Adopting Alain's definition (which reflects a bit of a convergency among "think tanks") for the purposes of this guide, DER includes "supply-side or demand-side connected distributed generation, storage, and controllable loads, embedding EVs," but not energy efficiency (although it is closely related), nor microgrids (although many utilize DER). Using this definition, DER can include demand response (DR, aka load relief), although it does not necessarily include DR, depending on the context.[21] Note also that a virtual power plant (VPP) is a network of independent DER systems using a control system to perform like a single energy source (e.g., Schneider Electric partner AutoGrid).

DERs present the opportunity to accelerate decarbonization, enhance reliability and resilience, empower utility customers, help support the utility grid via flexibility, expand utility services, and defer distribution system upgrades. Yet their variable nature and unpredictability simultaneously present challenges to distribution utility planning, operations, asset management, and other functions. They present data management challenges in these functional areas of distribution utilities, as well as distribution utility interaction with:

- Transmission owner/operators
- Utility customers that own and operate DER
- Third parties, such as load aggregators, regulatory agencies, and others

This section covers the following:

- Challenges: Diverse and evolving DER-relevant utility regulation and market designs
- Challenges: DSO-TSO coordination and relevance to DER
- Practices: DER integration and DSO-TSO coordination
- Practices: Data exchange for DER
- Solutions: A Schneider Electric case study on DER
- Solutions: Maximizing DER value using microgrids
- Demand-side management: Challenges, solutions, and value

[21] In the U.S., demand response (DR) is usually considered separately from DER.

Challenges: Diverse, Evolving DER-Relevant Utility Regulation and Market Designs

Integrating DER into Wholesale Markets

In Europe, the trigger for integration of DER into wholesale markets was the implementation of feed-in-premiums/contracts for difference (FiP/CfD) for renewables larger than 100 kW, with a portfolio balancing obligation.

In the U.S., FERC Order 2222 (issued September 2020 and amended with Order 2222-A in March 2021) is an example of the opportunity and challenge of DERs. The original order promotes "competition in electric markets by removing the barriers preventing distributed energy resources (DERs) from competing on a level playing field in the organized capacity, energy and ancillary services markets run by regional grid operators."[22]

The different regulatory processes significantly impact the way that data are exchanged between distribution operators, transmission operators, aggregators, and other stakeholders (see Figure 18).

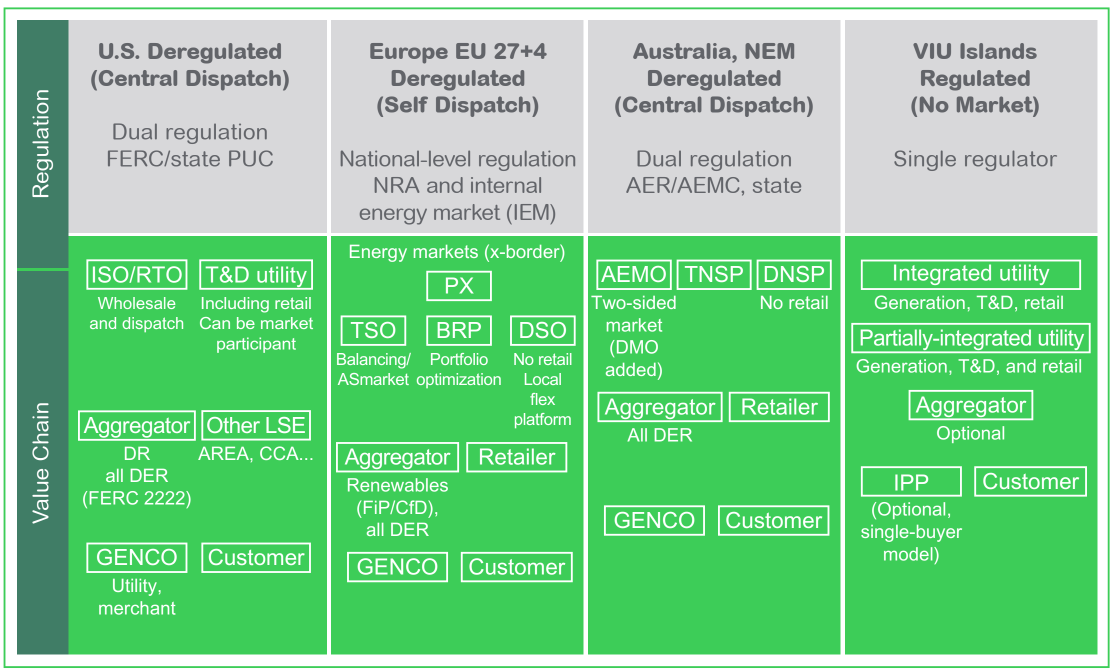


Figure 18. Utility regulation and market designs in selected regions of the world

Figure 18 Legend

AEMC	Australian Energy Market Commission
AER	Australian Energy Regulator
ARES	alternative retail electricity supplier
AS	ancillary services
BRP	balance responsible party
CCA	community choice aggregator
DNSP	distribution network service provider
DR	demand response
DSO	distribution system operator
FERC	Federal Energy Regulatory Commission
FiP/CfD	feed-in-premium/contract for difference
GENCO	generation company
IEM	internal energy market
ISO	independent system operator
LSE	load serving entity
NEM	National Electricity Market
NRA	National Regulatory Authority
PUC	public utility commission
PX	power exchange
RTO	regional transmission operator
TNSP	transmission network service provider
TSO	transmission system operator

[22] Federal Energy Regulatory Commission (FERC), "FERC Order No. 2222: Fact Sheet," September 17, 2020.

- **FERC 2222**. In the U.S., relevant regulation includes FERC 2222, the unique position of the electricity business in the state of Texas (which is not under FERC jurisdiction because Texas is a separate Interconnection), potential future regulation (e.g., California CPUC activities), the proposed Southeast Energy Exchange Market (SEEM), and discussion of a distribution system operator model in a handful of U.S. states.

- **Article 32**. In the European Union (27+4), key relevant regulation is Article 32 of the Clean Energy Package involving DSO use of flexibility. EU DSOs are wires-only companies and are implementing unique "local flexibility platforms."

- **Australia**. In Australia, regulatory uncertainty involves the timeline for the new DSO and distribution market operator (DMO) model. Australia follows a similar model to the EU for its distribution network service provider (DNSP), but the way that aggregators and retailers act is totally different than the EU due to its proposed two-sided market approach.

Challenges: DSO-TSO Coordination and Relevance to DER

DER Penetration Correlates with DSO-TSO Coordination

Across the world, higher DER penetration correlates with more intensive discussions of coordination between distribution operators (and hereafter called distribution system operators or DSOs) and transmission system operators (TSOs). The reason for this is that with low DER penetration, distribution operators can adjust resources without impacting balancing. However, complexities occur if distribution operators make large adjustments to resources without informing TSOs, or if TSOs significantly adjust frequency regulation using distribution-connected assets without informing distribution operators.

According to the European TSO association ENTSO-E (the European Network of Transmission System Operators for Electricity), "Flexibility, which is the prime response to variable renewables, can only be used efficiently for balancing and congestion management purposes if the appropriate data and information are exchanged between TSOs, DSOs and market players."[23]

Data Exchange Complexity: DSOs, TSOs, and Others

EPRI infographics presented at an EPRI Europe Conference in 2018 illustrate the complexity of data exchange needed, and show that more stakeholders than TSOs and DSOs must be involved. The graphics shows the flows and estimated magnitude of data exchange between various stakeholders, with emphasis on the European context (TSOs, DSOs, DER owner/operators, Power Exchange, and balance responsible party [BRP]) for various applications/functions across three different time horizons (real-time operations, operational planning, and long-term planning). For example, for long-term planning, major data exchange is needed between DER owner/operators (specification and investment) with TSOs for transmission adequacy, transmission forecasting, and other functions. For operational planning, more stakeholders and functions are involved, increasing complexity. For real-time operations, the single largest data exchange occurs to address congestion management between DSOs and TSOs, but many other interactions occur.[24]

[23] ENTSO-E, CEDEC, GEODE, EURELECTRIC, and EDSO,"TSO – DSO Data Management Report," July 27, 2016.
[24] EPRI, A. O'Connell, "EPRI Transmission and Distribution Coordination Initiatives," presented at the 8th International Conference on Integration of Renewable and Distributed Energy Resources (IRED), Vienna, Austria, October 18, 2018.

Practices: DER Integration and DSO-TSO Coordination

Traditional Approach

Figure 19 shows the basic logic (region-agnostic) of the traditional policy- and regulation-driven approach to DER integration. Here, DER-friendly policy drives regulation and market design, which in turn drives DER network integration (distribution side) and DER wholesale integration (transmission and wholesale market side). The distribution utility conducts the traditional activities of network planning, network operation, and asset management.

Non-Traditional Approach

In a non-traditional approach to DER integration on the distribution side, innovative regulation (e.g., FERC 2222) drives the need to coordinate between advanced transmission planning and operations, and advanced distribution planning and operations. At the distribution level, the DER integration process itself consists of operation within technical limits to provide static DER hosting capacity via DER monitoring, and enables various applications (e.g., locational planning, shared reinforcement costs, etc.). Alternatively, operation beyond technical limits to provide dynamic DER hosting capacity enhances flexibility.

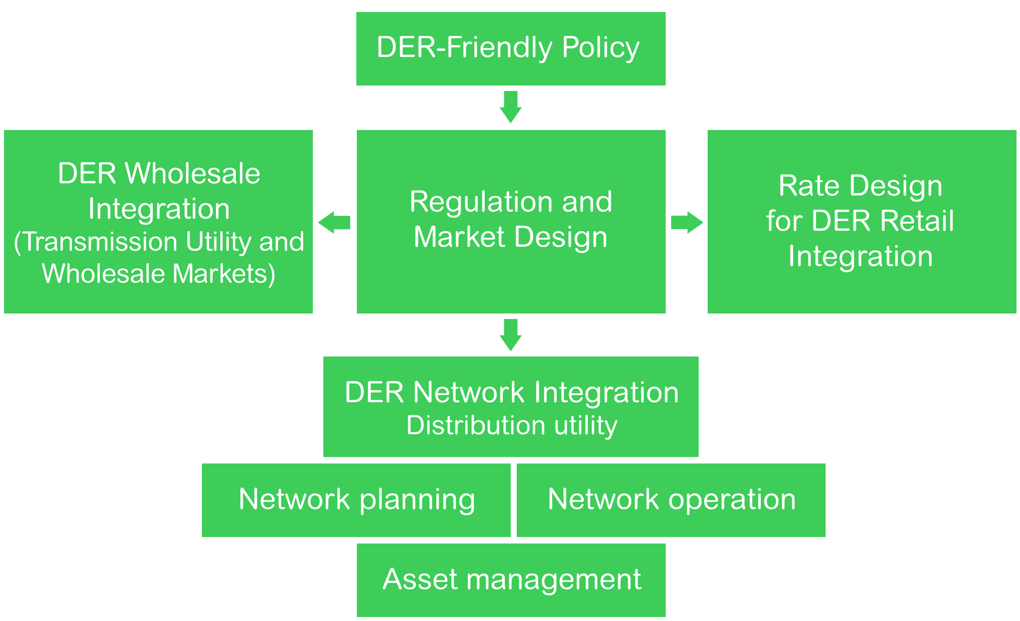


Figure 19.
Policy/regulation driven approach to DER integration

Practices: Data Exchange for DER

Several international and European organizations are carefully examining data exchange and data management considerations and practices for DER.

This section provides a brief summary of selected recent reports on this topic.

IRENA Data Exchange Platform

The International Renewable Energy Agency (IRENA) emphasizes the importance of a data exchange platform that enables DSOs and TSOs equal access to real-time DER information (see Figure 20).[25]

SmartNet Project in Europe

Funded by the Horizon 2020 project,[26] the 3-year SmartNet project aims to "provide optimised instruments and modalities to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs) and the exchange of information for monitoring and for the acquisition of ancillary services...in the distribution segment."[27] One of its three national pilot projects involves DSO area data monitoring in Italy.

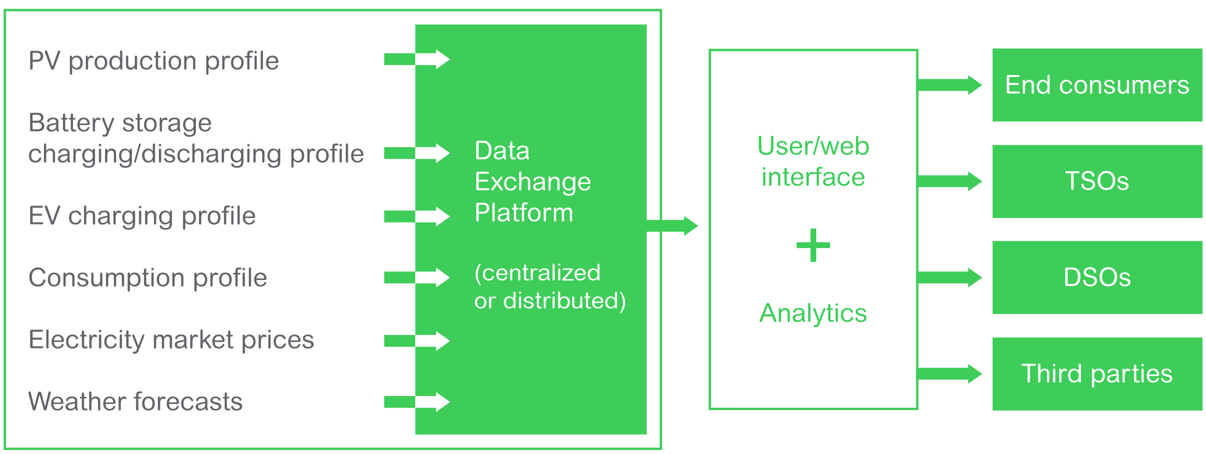


Figure 20. IRENA illustration of a data exchange platform for TSOs, DSOs, and other parties[28]

[25] International Renewable Energy Agency (IRENA), "Co-operation between Transmission and Distribution System Operators," Innovation Landscape Brief," 2020.
[26] European Commission website, "What is Horizon 2020?" accessed August 2021.
[27] SmartNet website, "About SmartNet," accessed August 2021.
[28] International Renewable Energy Agency (IRENA), "Co-operation between Transmission and Distribution System Operators," Innovation Landscape Brief," p 15, 2020.

UK National Grid DER Integration

In the UK, an ambitious project in progress is preparing for very large DER integration in the UK and aims to maintain power system integrity and stability based on the appropriate set of data to be exchanged at planning and operating levels. The UK National Grid ESO recently published a workgroup document that "seeks to increase the scope and detail of planning-data exchange between DNOs [distribution network operators] and National Grid ESO to help facilitate the transition to a smart, flexible energy system by aligning certain data exchange processes, providing greater granularity of data at a wider range of operating conditions."[29]

ENTSO-E Data Management Goals

In the ENTSO-E report on data management, TSOs and DSOs documented the following data management goals:[30]

- Aim for harmonized standards
- Ensure fairness via greater data transparency
- Ensure equal data access
- Maintain data integrity
- Eliminate discriminatory processing
- Aim for simplicity in processes
- Support competition
- Enable cost efficiency
- Maintain open access to data to encourage innovation
- Ensure data security and privacy

Two Data Exchange Principles in Europe

In Europe, two different data exchange principles are under consideration. One initiative uses a TSO-centric centralized data hub (that includes T&D grid, meter, DG, and flexibility data), which places the primary data management responsibility with the TSO. A second initiative is primarily the DSO-centric, cascade data flow approach, which places the primary data management responsibility with the DSO. Key considerations for this choice include data exchange requirements, communications and IT hardware, data protection and cybersecurity, business models, and data types.

European Commission DG Energy

A European Commission DG Energy report expands on this: "Data management can be done through different technical solutions, such as decentralized or centralized data hubs, with the majority of the Member States having already deployed or intending to deploy a data hub. Some countries have opted for centralized systems where an independent third party is responsible for managing the data and the respective flows (e.g., United Kingdom, Estonia), whereas others have opted for a decentralized system (where DSOs or suppliers are responsible), or a combination."[31]

A report that ENTSO-E commissioned places data for DSO-TSO cooperation into the broader perspective of data types and processes needed in an electricity market model.[32]

[29] National Grid ESO website, "GC0139: Enhanced Planning-Data Exchange to Facilitate Whole System Planning," March 16, 2021.
[30] ENTSO-E, CEDEC, GEODE, EURELECTRIC, and EDSO, "TSO – DSO Data Management Report," July 27, 2016.
[31] European Commission DG Energy, "European smart metering benchmark," June 27, 2019.
[32] THEMA Consulting Group, commissioned by ENTSO-E, "Data Exchange in Electric Power Systems: European State of Play and Perspectives," THEMA Report 2017-03, page 39, June 2017.

Solutions: A Schneider Electric Case Study on DER

General Industry Challenge

One of the most significant challenges that distribution utilities face is operational constraints due to DER, which can exceed network limits and potentially impair system stability. Resolving the impacts of DER shown in Figure 21 requires data and capabilities to use that data to form analytics and intelligence. Ultimately, this intelligence helps mitigate the impacts to maintain high reliability.

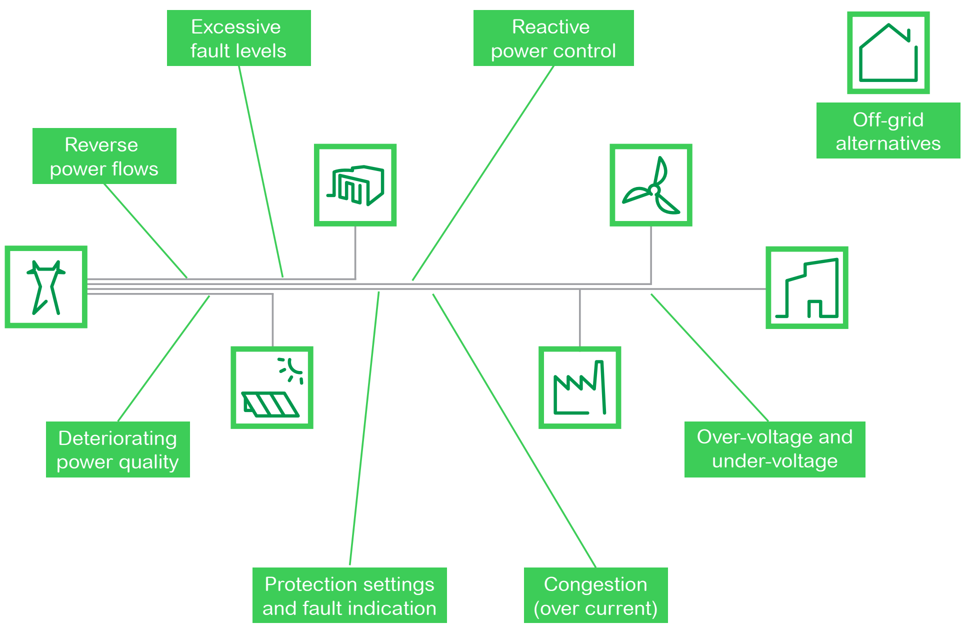


Figure 21. DER can impose operational constraints on distribution systems

The Challenge at a Specific Utility

One utility posed the following questions regarding DER:

- How can we procure flexibility in a flexibility market?
- How do DERs affect our network?
- How do we optimize DERs to enhance flexibility?

Traditional distribution networks operate using ADMS, and sometimes DERMS, but do not coordinate behind-the-meter (BTM) assets (and their associated data) such as solar PV, batteries, and EVs, including demand response.

General Industry Solution

A virtual power plant (VPP) system (e.g., AutoGrid) enables flexibility via visibility into and dispatch of BTM assets. AutoGrid, a Schneider Electric partner, also enables a third-party (e.g., aggregator) to tie-in to these assets. For example, a VPP system such as AutoGrid can help provide a distribution network platform where aggregators can bid for capacity or control. It can also manage microgrid capabilities.

The Solution and Value at a Specific Utility

After installing an ADMS, the utility sought to address its DER management challenges. To do so, the following data-related needs emerged:

- Enable BTM visibility via data from smart meters, low-voltage network monitoring, data from transformers, power quality data, power flows, voltages, and other metrics
- Map the network model to the low-voltage level
- Establish a core data platform (e.g., OSIsoft)

Using these data, the following combined DERMS-VPP use cases were examined, in order of increasing capability:

- **Data monitoring (DER real-time data)**
  - **Solution:** Gather BTM data to improve DER awareness and visibility to assess DER impact on the network and identify "hidden load"
  - **Value:** Improve operational efficiency, grid reliability, and customer satisfaction
- **Data usage to manage demand on the system level**
  - **Solution:** Gather low-voltage network data and use it to manage system demand (e.g., peak-load low production, low-load high production, and the duck curve effect) using DER program flexibility and production curtailment
  - **Value:** Support TSO grid management, avoid high-cost peak spinning reserves, maximize renewable production, and adopt more renewable generation
- **Data gathering to calculate and use "dynamic operating envelopes"**
  - **Solution:** Gather data on DER forecasts, real-time network conditions, and forecasted power flow, and use it to enhance the network's capacity to host new customer connections by recalculating DER limits based on network conditions (rather than static restrictions)
  - **Value:** Maintain grid reliability and power quality, increase DER hosting capacity, defer grid investments, enable DER to participate in wholesale markets, and provide customer broad network access
- **Avoid network congestion**
  - **Solution:** Enhance grid DERMS capability to schedule DER flexibility to avoid predicted network constraints
  - **Value:** Improve grid DER hosting capacity, enable new customer connections, maximize renewable and EV connections
- **Data from a flexibility market to actively manage the network**
  - **Solution:** Gather data on DER bids and merit order lists from a flexibility market, and use flexible connection and flexible services to manage network constraints
  - **Value:** Enhance network constraint management and facilitate flexibility market

Maximizing DER Value Using Microgrids

Among other capabilities and benefits, microgrids provide a way to enhance flexibility for both end customers and the utility grid:

- **Local optimization.** Microgrids can help to optimize DER use for the benefit of customers within the microgrid.

- **Grid benefits.** Microgrids can also aggregate DER to provide flexibility benefits to the grid.

Microgrid Leading Practices

Microgrids are another way to maximize the value of DER in three primary ways:

- **Artificial intelligence (AI)-based solutions** can better manage energy use and cost, while reducing emissions (increasing sustainability) – at a one-minute timescale. Data implications here involve efficiently gathering a highly complex and extensive set of data on energy user constraints, weather forecasts, electricity tariffs, energy market pricing, and demand response requests. Optimization algorithms enable the microgrid to leverage the electricity contract and optimize the energy bill, while decreasing the carbon footprint due to onsite available and forecasted flexibility.

- **Advanced real-time microgrid/grid control systems** can help ensure business continuity and power system stability during off-grid periods.

- **In the microgrid design phase (off-line)**, a digital twin can help optimize the sizing of DER in the microgrid, including present and forecasted future solar PV, stationary battery energy storage, and storage via electric vehicle-to-building (V2B) and vehicle-to-grid (V2G). Data implications here involve AI-based solutions using real-time data on building and grid operation in a feedback loop to enhance microgrid design.

These solutions provide value, regardless of grid configuration:

- **Grid-tied** (always connected, cannot island) microgrid, in which one or more energy users focus on energy optimization (could be considered a virtual microgrid, or a form of load aggregation)

- **Islandable** microgrid, which can operate on local resources as needed, to enhance the resilience of one or more energy users

- **Off-grid** (always islanded) microgrid, which serves remote energy users or situations where extension of the distribution grid to the area is problematic

Schneider Electric Microgrid Solutions

Schneider Electric provides two primary microgrid solutions:

- EcoStruxure™ Microgrid Advisor (EMA) forecasts and optimizes hourly when to consume, produce, store, or sell energy; forecasts and economically optimizes and dispatches DER hourly.
- EcoStruxure™ Microgrid Operation (EMO) helps ensure resilience and stability of energy supply in real-time under all grid conditions. EMO gathers relevant data by connecting with Schneider Electric or third-party EMS, ADMS, and SCADA systems using various communication protocols (Modbus TCP IP, IEC 61850, DNP3, IEC 101, and IEC 104).
- Working in concert, these two solutions can help energy users develop the business case for a microgrid, including estimating potential outage costs.

Building on its delivery of over 300 microgrid and control projects, Schneider Electric has entered into two joint ventures to advance microgrids using energy-as-a-service solutions:

- With Huck Capital, **GreenStruxure™** uses an energy-as-a-service (EaaS) contract for projects with modular and standardized renewable microgrids that serve medium-sized commercial, industrial, and government buildings.[33]
- With The Carlyle Group, **AlphaStruxure™** uses an EaaS contract for projects with larger microgrids that serve airports, university campuses, and industrial complexes.[34]

Schneider Electric Microgrid Case Studies

Energy Efficiency and Frequency Support in Finland. At the Lidl Finland Logistics Center, Schneider Electric delivered an integrated Schneider Electric EcoStruxure™ Microgrid and Ecostruxure™ Building Operation solution for a state-of-the-art, carbon-neutral, net-positive-energy distribution center, with up to 70% energy cost savings, that includes the following:[35]

- An integrated solution that combines a comprehensive building management system with a microgrid
- An advanced management system for cooling and heating
- A microgrid solution with energy storage that collects data, forecasts, and optimizes the operation of on-site resources

As one part of the solution at the Logistics Center, EMA controls a battery energy storage system and a generator set in a microgrid to provide frequency support to the grid. When the grid frequency deviates from defined limits, EMA charges the battery to lower the frequency, or discharges the battery to increase frequency, providing a new source of revenue for Lidl.

Exporting to the National Electricity Market in Australia. The South Australian Produce Market Limited (SAPML) selected Schneider Electric as a major supplier to achieve Australia's first energy microgrid connected to the spot market, which not only supplies the site's entire energy demand, but also exports power to the National Electricity Market (see Figure 22).

Figure 22. Using SE's EMA, the South Australian Produce Market is able to export power to the National Electricity Market

[33] Schneider Electric GreenStruxure™ website, "GreenStruxure," accessed August 2021.
[34] AlphaStruxure website, "Energy as a Service," accessed August 2021.
[35] Schneider Electric, "Lidl Finland: Customer Story Key Figures," webpage accessed September 2021.

The $10.5 million microgrid, which includes more than 6,400 solar panels and 25 Tesla power pack battery energy storage systems (BESS), uses Schneider Electric EMA technology in its control system. This enables the forecasting of demand and electricity spot market pricing 24 hours in advance. Using data analytics from the software, SAPML can determine the most economically beneficial times to charge or discharge the BESS. The microgrid will reduce annual greenhouse gas emissions by 32%, reduce the maximum demand on the South Australian electricity grid by 3.8 MWh per year, and produce a net savings of $4.3 million over 10 years.

Demand-Side Management: Challenges, Solutions, and Value

Business (Use) Cases

Demand-side management (DSM) encompasses the following four business use cases:

- **Utility customer engagement and data access.** To provide utility customers information on their usage, and to encourage changes in utility customer behavior for energy efficiency or demand response, customers need specific data, which is challenging.
- **Improving energy efficiency (utility and utility customer).** Identifying opportunities for energy efficiency and actually shifting energy use to reduce costs is the logical extension of the first use case above.
- **Demand response.** Helping utilities actively manage load by physically controlling utility customer assets at the customer's request (via automated DR or contractual agreement) to change how energy is used on the power system (e.g., increase load due to solar generation availability, or decreasing load to reduce peak usage).
- **Distributed electric energy storage,** including distributed stationary and mobile (EV) batteries pose challenges because the utility customer purchased the battery or EV asset primarily for backup power in a building or process, or for transportation purposes. This imposes additional constraints on utility control of these assets.

Data Challenges

The goal of DSM is to encourage or discourage certain behaviors of utility customers to change load shapes via energy efficiency and/or time of use – it's all about "the when." Utilities can do this most effectively by gathering and using the following types of customer-facing data:

- **Interval data.** Utilities need usage interval data to some level of granularity (hourly, half-hourly, every 5 minutes, or even more granular for some purpose).
- **Data context.** Utilities need to give the usage data a context.
  - **Rate information** is another needed data stream that provides data context. However, rates apply to different customers in different ways, and some customers have their own specific rate.
  - **Customer equipment- or appliance-specific usage data** are another form of context. Residential appliance data are relatively easy to predict and model. However, commercial and industrial (C&I) data are much more complex because it varies across the type of business. Utilities typically are unable to discern the business type for a large percentage of their C&I customers.
  - **Weather data** provide context when combined with usage data, especially for buildings, where weather drives HVAC use.

To model customer and customer equipment usage, the above data are needed to establish a baseline, upon which changes in behavior and usage can then be examined. These data are generally available for residential customers, but not all of it is available for C&I customers. C&I customers make up about 5-10% of the total number of utility customers, but their usage and revenue are about 50% of the total. Turnover of commercial customer types in buildings causes additional complexity.

Additional data complexity includes:

- **Data formats.** Metering data use various standard formats (e.g., CMEP, MV90, LODESTAR, Enhanced LODESTAR, NEM12, and others), which becomes an issue when examining data from multiple utilities.

- **Data quality.** A VEE (validation, estimation, and editing) process can verify the quality of the data exiting a meter data management (MDM) system (e.g., data gaps and errors).

- **Data latency.** The length of time between data gathering from the meter, through a VEE process, to an application that requires real-time or near-real-time data may be problematic. Most metering systems were designed as "cash registers," not as real-time data gathering machines; they have insufficient bandwidth to pull all needed data in small time intervals and forward the data to an MDM. For example, gathering and conducting a VEE process on these data daily is insufficient for real-time optimization with demand response, or peak load management.

  Data latency also affects VPP applications (e.g., Schneider Electric partner AutoGrid). When low latency is required (e.g., for operational applications, including considering real-time pricing), obtaining data directly from the metering devices may be preferable, since VEE may not be necessary for these use cases.

- **Data verification.** In addition to verifying an effect of energy efficiency or demand response or other actions, data verification is necessary as data change during processing (audit trail). Further, actual metered consumption needs to be compared with the amount the customer would have consumed without participation in the demand response activity. This requires a defendable regression model and/or historical use patterns that produce "counterfactual" (manufactured) data.

- **Meaningful information.** Analytics transform data into information. Meaningful information varies by customer type (e.g., a large industrial customer with very high energy use has different needs than a homeowner).

Schneider Electric Solutions Related to DSM

Following are Schneider Electric solutions for the four DSM-related use cases described above:

- **Utility customer engagement and data access.** Schneider Electric's Energy Profiler Online (EPO) is primarily a utility customer-focused tool for cloud-based engagement, energy management and demand response (DR). It includes a messaging function to utility customers to request a time-sensitive DR action. Partnered with companies like AutoGrid (see below), EPO can enable automated DR.

- **Improving energy efficiency.** EPO can also promote energy efficiency with analytics to help identify ways for C&I customers to save energy. The tool helps C&I customers understand how they are using energy (e.g., load duration curves), compare the benefits of energy efficiency and demand management, examine what-if scenarios, and conduct other analyses.

- **Demand response (DR).** Schneider Electric partner AutoGrid is a virtual power plant (VPP) software provider and Schneider Electric partner. Its software creates a network of independent DER systems, including DR – physically operated using a dispatch and automated (machine-to-machine) control system to act like a single energy source. Through its digital platform, a distribution utility and its connected DER can be linked together to flexibly manage the demand and supply of energy in real-time. Using low latency data, AutoGrid enables visibility into, and real-time ramping up and down of, the assets to follow load. About 20% of all power plants run less than 20 hours per year. A utility-focused tool, AutoGrid Flex (one of the software products that AutoGrid provides) is an important enabler of flexibility (e.g., increasing load due to solar generation availability, or decreasing load to reduce peak usage) to defer construction of new power plants.

- **Distributed electric energy storage.** AutoGrid Flex can control batteries within the additional constraints of original intended uses for distributed stationary and mobile (EV) batteries. EPO can model solar PV and EV fleets through what-if scenarios to calculate changes in loads as well as revenue/cost impacts. EV and battery manufacturers also need to allow this sort of control, which may impact product life.

Value of Data Management in DSM

Cost Efficiency. Data management in DSM can provide the following cost-efficiency benefits:

- Utilities can improve grid operational efficiency through optimal use of DSM to defer power delivery and power generation investments.

- Utility account executives can more efficiently provide customer service.

- Utility customers can reduce the demand charge of the building via peak load management.

Sustainability/Flexibility. Data management in DSM can support rising interest in grid-interactive buildings, address building energy management, enable increased renewable resource penetration, and use buildings as a flexibility resource, which in turn enhances sustainability by avoiding use of fossil fuel generation to meet peak demand.

Resilience. Data management in DSM helps ride-through system instability during extreme events, supports use of microgrids, and enables faster restoration after outages.

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Smart Metering

Overview: Smart Metering Basics

For decades, electricity, natural gas, and water utilities measured usage of their commodity with a manually-read meter.

Since the mid-2000s, many utilities have installed smart meters that automatically transmit digital usage information back to the utility, through a central data collector typically located on a nearby power pole. From the central data collector, the data flow into a computerized billing system.

In addition to measuring customer electricity usage in near-real-time, smart meters measure voltage levels and the binary (on/off) status of electric service. These meters can also remotely connect and disconnect customers, detect tampering, and measure bidirectional flow of electricity.

Distribution Utility
Legacy Information and Management Systems

The **meter data management system** (MDMS) processes and stores interval load data for billing systems, web portals, and other information systems.

The **customer information system** (CIS) processes data from the MDMS and connects with billing; and stores data on customer locations, demographics, contact information, and billing histories.

The **distribution management system** (DMS) processes data on outages and customer voltage levels; and implements procedures to optimize voltage and volt-ampere reactive (VAR) levels.

The **geographic information system** (GIS) is a map-based database visualizing the utility infrastructure.

The **outage management system** (OMS) processes on/off data from the smart meter to identify and isolate outage locations, and connects with the GIS to dispatch repair crews and manage service restoration.

With smart meters, electric customers can better monitor and manage their energy use, and the utility receives information directly from the meter, leading to faster detection and restoration of power outages. Both the utility and the customer receive more detailed data about energy usage. The smart meter typically records and transmits a customer's energy usage several times per day, in 5-, 15-, 30-, or 60-minute intervals.

Smart meters are deployed as part of an advanced metering infrastructure (AMI) system, which includes integration of smart meters, a communications system, and a meter data management system (MDMS). To support AMI, utilities use a variety of wired (e.g., fiber optic cable, power line communications [PLC]) and wireless (e.g., radio frequency [RF] mesh, RF cellular) technologies.

The communications system delivers the data to a head-end software system, which manages communication between smart meters and other information systems, including the MDMS, CIS, DMS, and OMS (see the sidebar). AMI enables electric service providers to communicate with customers and offer time-of-usage rates and other services. Smart meters are typically the distribution utility's first encounter with the impact of digital data.

Today's Challenges and Objectives

After more than 15 years of experience with smart meters, the electric utility industry and regulators nearly universally recognize their value:

- Shorter outages and lower outage costs
- Lower costs for metering and billing from remote reading, with fewer truck miles and reduced labor
- Increased customer control over utility bills
- Lower capital expenditures from peak demand reductions via customer incentives and direct load control programs

The "why" of going digital with smart meters is rarely questioned. However, the "how" remains a formidable task. A central challenge is integrating several information and management systems to improve grid efficiency, situational awareness, customer restoration, and DER management.

Depending on their progress with smart metering implementation, utilities typically face one of the following two major challenges:

- **Integration.** Distribution utilities beginning to install smart meters and AMI need to integrate metering data with existing utility legacy systems, which can greatly enhance the value proposition of smart metering.
- **Data mining.** Utilities that have nearly or fully completed the smart meter and AMI conversion need to mine the metering data for value-laden use cases.

Integration

Meters initiate the first step in a financial transaction, which is the billing function. The volume of smart meter data significantly exceeds the amount that field workers previously gathered. Applying that data to additional functions beyond billing follows a series of steps:

- The smart meter data management system (MDMS) collects data from smart meters and transmits the data to billing and other software systems.
- A primary function of an MDMS is to detect and correct errors or omissions in meter data. This process is known as validation, estimation, and editing (VEE).
- Once the data are processed, exchanging the data with other systems brings new technical challenges. As shown in Figure 23, utility data management systems are typically siloed from each other and the smart meter.

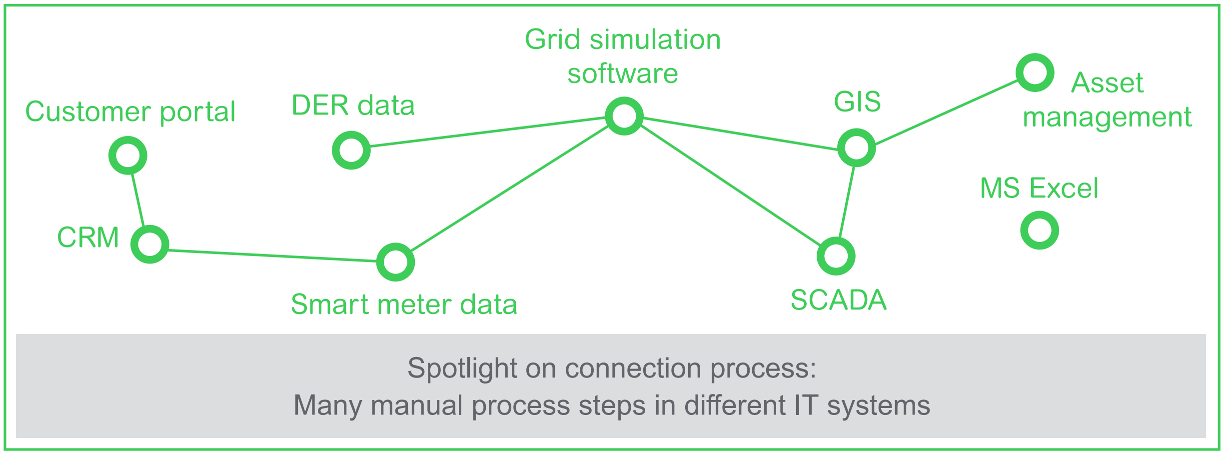

Figure 23. Integrating smart meter data with other siloed information systems is challenging

Integration among AMI, MDMS, CIS, and the billing function improves the accuracy of billing and therefore enhances customer satisfaction. CIS integration provides customer service representatives access to billing data to resolve billing questions. However, problems often arise when AMI, billing, and CIS systems originate from different vendors.

Integrating AMI with an OMS and DMS can improve reliability (e.g., fewer and shorter outages). This integration provides the OMS with on/off signals from smart meters, enhancing the ability of control room operators and field crews to pinpoint the source of outages. Integrating smart meters and AMI with internet-of-things (IoTs) devices and rapidly evolving customer energy management technologies can present interoperability issues.

Another area of utility interest is integration of smart metering data with DER to recognize the status of distributed resources and improve distribution automation. Utilities expect grid connection of many EVs over the next decade. Realizing maximum value from this area of integration – knowing when EVs are charging or sending power to the grid – requires careful management and coordination.

Data Mining for Value

Utilities are recognizing that smart meter data are a useful source of information, but extracting value from the data requires integration of smart meter data with a variety of legacy information and data management systems. This task may also require mining large stores of unstructured data to uncover patterns within an increasingly decentralized distribution network. Analysis of these data could improve forecasts of energy usage and provide evidence of electric system anomalies. This can help improve operational efficiency and customer satisfaction.

Some utilities send their smart meter data to a so-called “data lake,” where AI/machine learning technologies can access it. Today, some vendors offer cloud services with built-in algorithms to detect unusual energy usage or provide data on meter outages. Some analysts speculate that data analytics could help utilities size distribution assets, develop new rate plans, or balance energy resources in an increasingly complex DER environment.

Today's Recommended Practices

Low-voltage communications technology includes smart meters and various sensors and IoT devices.

The influx of data from these devices creates a challenging situation: the utility needs to direct the correct data to the correct software system to inform the correct business processes. But today, in many utility systems, smart meter and other data are manually sorted and sent to the various IT and OT platforms.
The following recommended actions can facilitate data management in utility's complex legacy systems:

- **Digitize utility data interfaces.** Utilities manage several legacy platforms that import and export different kinds of data for different processes and may also reside in "siloes" in different departments. Any remaining manual and paper-based processes should be digitalized.

- **Automate complex IT and OT infrastructures.** Today, in many utilities, smart meter data are transmitted to a meter data administrator, who validates the data and distributes relevant portions to regulators, suppliers, and other parties to perform various tasks. This complex IT and OT infrastructure slows the transfer and use of these data. Automating this process would provide substantial benefits to a distribution utility.

- **Automate grid impact analysis.** With data originating from smart meters, GIS, CRM, and other sources, an automated process to digest, analyze, and visualize these data is the best way to improve the operation of the low-voltage network.

- **Specify interoperability.** Specify interoperable, meter-agnostic head-end, MDM, or low-voltage analytics systems to ensure future-proofing and ease of integration with ADMS, GIS, and billing systems.

Value-Producing Business Outcomes

- **Improved cost efficiency.** Smart meters have demonstrated their ability to reduce labor costs for meter reading. Effective automation and integration of this and other low-voltage data can also reduce the labor intensity of delivering data to various utility operating and information systems.

- **Enhanced resilience/reliability.** Utilities can improve resilience and reliability via enhanced visibility and improved analysis and control of the low-voltage network.

- **Improved sustainability.** Smart meters have already significantly enhanced sustainability by reducing truck rolls to read meters. More effective data management of the low-voltage network enables utilities to integrate more DER and optimize their use, again with potential large impacts on sustainability.

- **Greater flexibility.** Integrating smart metering data with utility information systems enhances the granularity of data from the low-voltage network, enabling improved grid analytics (e.g., power flow, state estimation), optimizing system performance, and providing operators more flexibility.

Schneider Electric Solutions

Schneider Electric offers three products in the smart metering area that improve traditional advanced metering infrastructure (AMI) and meter data management (MDM) functionality with data analytics and operational data storage and management capabilities.

EcoStruxure™ Grid Metering Operations is a head-end system or meter operations center. Schneider Electric's head-end system can connect with multiple meter technologies and protocols, and therefore has a high degree of interoperability. The system also provides device management. It receives data from, and sends, operational signals to smart meters, and stores load data from smart meters for customer billing.

EcoStruxure™ Grid Metering Advisor is an MDMS that covers the data management lifecycle. In addition to streamlining billing and improving revenue processes, the Schneider Electric solution supports integration of multiple, disparate data sources, including most AMI head-end systems, remote terminal units (RTUs) and intelligent electronic devices (IEDs). Schneider Electric's solution functions as a single, security-focused platform, through which meter data can be enriched and analytics can be applied. It offers:

- Data aggregation
- Incorporation of multiple disparate data sources
- Visualization tools
- Visibility of smart meters, AMI network, and distribution network
- CIM integration model

EcoStruxure™ Grid Metering Expert offers low-voltage grid analytics. Offered as a cloud-based software-as-a-service, it provides DER analysis, losses calculation, load balancing, and electric topology, among others.

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Cybersecurity

Overview

Cybersecurity challenges and practices transcend all aspects of data management covered in this guide.

- **Data** are the lifeblood of the new digitalized utility, the building block of data management, and the ultimate enabler of value.
- **Data management** is an important way for utilities to achieve goals, including sustainability, resilience, cost efficiency, flexibility, and more.
- Effective **cybersecurity** is the essential, enabling element that must pervade all aspects of data management.

Today's Challenges and Objectives

Cyber Attacks

Cybersecurity challenges are becoming increasingly sophisticated. Most involve the compromise of sensitive data, and they are motivating government responses across the world to tighten cybersecurity.

In December 2015, hackers used malware to cause a 6-hour power outage affecting hundreds of thousands of homes in the Ivano-Frankivsk region of the Ukraine. Researchers say this is the first instance of malware disabling SCADA devices and the first power outage caused by malware.[36]

In early 2020 in the U.S., hackers penetrated SolarWind's system that manages the information technology (IT) resources of more than 30,000 companies and organizations. When this system distributed a system update to its customers, the update contained hacked code that allowed hackers to monitor up to 18,000 of these organizations, including Microsoft, Cisco, Intel, the U.S. Department of Homeland Security, and the U.S. Treasury Department, undetected for months, exposing sensitive data.[37]

On April 29, 2021, in the U.S., hackers accessed the IT network of Colonial Pipeline, and on May 7, demanded a $4.4 million ransom. In response, the company shut down its pipeline – the largest fuel pipeline in the U.S. – which led to gasoline shortages across the U.S. east coast. The company paid the ransom, verified that its pipeline was undamaged, and restarted the 2.5 million barrel per day pipeline on May 12.[38]

Government Action

These and other cybersecurity attacks motivated U.S. President Biden to issue an Executive Order on cybersecurity.[39] The scope of protection and security in this order spans systems that process data (IT systems), vital machinery that ensures our safety (operational technology [OT] systems), and security and integrity of critical software.

[36] Trend Micro, "First Malware-Driven Power Outage Reported in Ukraine," January 6, 2016.
[37] Business Insider, I. Jibilian and K. Canales, "The US is reading sanctions against Russia over the SolarWinds cyber attack. Here's a simple explanation of how the massive hack happened and why it's such a big deal," April 15, 2021.
[38] Bloomberg, W. Turton and K. Mehrotra, "Hackers Breached Colonial Pipeline Using Compromised Password," June 4, 2021.
[39] The White House, "Fact Sheet: President Signs Executive Order Charting New Course to Improve the Nation's Cybersecurity and Protect Federal Government Networks," May 12, 2021.

In December 2020, the European Commission published its EU Cybersecurity strategy. The strategy "aims to build resilience to cyber threats and ensure citizens and businesses benefit from trustworthy digital technologies."[40] The proposal strengthens security requirements for companies by imposing a risk management approach that includes a list of minimum basic security elements that must be applied. Furthermore, the European Commission proposes to require individual companies to address cybersecurity risks in supply chains and supplier relationships. In the energy sector, in July 2021, the EU Agency for the Cooperation of Energy Regulators (ACER) published a non-binding "Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows."[41] The Framework Guideline "provides high-level principles for the development of a binding Cybersecurity Network Code that will further contribute to maintaining the security and resilience of the electricity system across Europe."[42]

Today's Recommended Practices

Government Regulations Regarding Sensitive Data

Across the world, government regulations require that sensitive data remain "private." The data cannot leave the country and cannot be exposed on the Internet. For example, in North America, the North American Electric Reliability Corporation's (NERC) Critical Infrastructure Protection (CIP) regulation does not permit access of these data to the Internet.[43]

In Europe, "A European Strategy for Data" identified an energy data space as one of the nine data spaces needed to "promote a stronger availability and cross-sector sharing of data, in a customer-centric, secure and trustworthy manner."[44] This strategy outlines generic data governance mechanisms. Furthermore, the Regulation of the Free Flow of Non personal Data - (EU) 2018/1807[45] and the General Data Protection Regulation - (EU) 2016/679[46] have created a transparent and well-functioning data protection framework. The proposal for a Regulation on European Data Governance[47] sets the principles for data exchange and data spaces.

Models for Security

The following practices and approaches (in the next five subheadings) can then be used to create models for security that, in turn, can be used when building secure systems.

The Scope of Sensitive Data

Sensitive data includes:

- Macro-level (e.g., substation level) utilization data, such as capacity, consumption, cost, fuel mixes, sources of primary energy, etc.
- What grid resources are in-service, what are out-of-service

[40] European Commission and the High Representative of the Union for Foreign Affairs and Security Policy, "EU Cybersecurity Strategy," December 16, 2020.
[41] European Union Agency for the Cooperation of Energy Regulators, "Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows," July 27, 2021.
[42] European Union Agency for the Cooperation of Energy Regulators, "Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows," July 27, 2021.
[43] NERC CIP, "CIP Standards," accessed August 2021.
[44] European Commission, "A European Strategy for data," webpage accessed September 2021.
[45] *Official Journal of the European Union*, "Regulation (EU) 2018/1807 of the European Parliament and of the Council of 14 November 2018 on a framework for the free flow of non-personal data in the European Union," November 28, 2018.
[46] Publications Office of the European Union, "Regulation (EU) 1016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data..." webpage accessed September 2021.
[47] EUR-Lex, "Proposal for a Regulation of the European Parliament and of the Council on European data governance (Data Governance Act)," COM/2020/767, November 25, 2020.

- The network model
- The data model
- Protocols used to communicate with devices in the field
- Certificate information so that no authentication can be subverted

Data Protection and Security During System Development

Hence, during solution and system development, an infrastructure is required that:

- Ensures that these data (and sessions themselves) are encrypted
- Ensures that the data originate from machines that use virtual private networks (VPNs) that are dedicated to prevent split-tunneling and that prevent accessing the Internet
- Ensures this data protection is in place whether working within a utility network or working within a regional solution center (RSC)
- Includes secure controls on which machines are used, who has access to these machines (access control), who can see the data and manipulate the data, what storage mechanisms are used, what replication mechanisms are used, etc.

Data Protection and Security in Utility Applications

Then, when the utility accesses these data using real-world solutions and systems that require communication between central systems and between operations and the field (e.g., ADMS, SCADA, OMS, and field systems), security must protect access to these data, while enabling legitimate data uses. This requires:

- Data encryption
- Multi-factor authentication
- Properly-configured firewalls that open proper ports, enable appropriate communication, and perform deep packet inspection to filter out malware and unwanted traffic
- Mechanisms that ensure the direction of data access always proceeds from a relatively higher security zone to lower security zone; the lower security zone cannot access data from the higher security zone

In the smart grid domain, various standards (e.g., IEC 62443, see below; and IEC 62351 from Working Group 15 on “Data and Communications Security,” see the Standards section in this guide) can help system integrators and solution providers establish defense-in-depth approaches and protect OT applications.

Data Security in Smart Field Devices

Today, smart devices (aka the industrial internet-of-things [IIoT]) understand the internet and cloud-based systems. For example, today’s sensors use architectures with operating systems that provide “built-in” capabilities (e.g., cryptographic identity, secure boot, secure update, and end-to-end secure communication) – all with no human intervention. This enables these smart devices to be efficiently integrated into cloud-based systems. The most relevant and globally-accepted cybersecurity references in the industrial domain are those that are part of the IEC 62443-4-2 standard.

Data Security in the Cloud

Cloud computing is becoming much more prevalent (e.g., large GIS data systems in the cloud), and cloud security models are becoming more mature, using various capabilities:

- The data in the cloud must be protected while at rest (e.g., in storage) using proper encryption keys that are stored properly.
- The data needs to be securely communicated back and forth to developer and utility on-premises systems.

Security Development Lifecycle (SDL)

To properly "build in" security to its systems that gather and process data, Schneider Electric recommends use and enforcement of the SDL based on the applicable standard (e.g., IEC 62443-4-1 is the standard for the SDL for industrial automation hardware, firmware, software, and systems). Schneider Electric, for example is certified as compliant to the IEC 62443-4-1 standard at the "practiced" maturity level by the internationally-recognized TÜV Rheinland[48] process and safety auditor. Figure 24 shows a process for development of security for any product that implements the following steps in a closed loop:

- Starting with security requirements (including a threat model that enumerates threat vectors)
- Designing appropriate capabilities to mitigate these threats (e.g., authentication, authorization, and encryption)
- Reviewing designs for security
- Reviewing implementations for security
- Conducting penetration testing, vulnerability scanning, and security update management as part of the standard software and hardware development process
- Developing end-user security guidelines for configuration, maintenance, and operation

Figure 24. The Secure Development Lifecycle

[48] TÜV Rheinland website, accessed August 2021.

End-to-End Security

Schneider Electric recommends an end-to-end security solution that extends across the entire data path and product development lifecycle. The first step is to identify and categorize the information that requires protection – an evolving area as new supply chain requirements are promulgated. When the data are categorized, the goal is to apply the appropriate security controls:

- At the point of system design
- When the data are in transit
- When the data are at rest, and whether the data needs to be anonymized
- How the data are used in different systems
- How the data are interchanged with cloud-based systems that use analytics and AI
- How the data are used at the utility

Privacy Goes Hand-in-Hand with Security

Data privacy is a broad, complex area that involves compliance with an evolving set of regulations:

- In the U.S., the California Consumer Privacy Act (CCPA, in force 2020)
- In the European Union, the General Data Protection Regulation (GDPR, in force 2018)
- New Chinese cybersecurity and data privacy requirements
- Privacy requirements in individual countries

Questions to Ask Vendors

The relevant questions to ask a vendor are:

- Do you follow an SDL that is certified to be compliant to IEC 62443-4-1?
- Do you have a vulnerability response process that is compliant to ISO 30111?
- Are your devices compatible with cybersecurity requirements in IEC 62351 standards?
- Are the systems you deploy in the field certified to be compliant with the IEC 62443-3-3 standard?
- Are your field devices IEC 62443-4-2 certified?

Value-Producing Business Outcomes

Implementation of a broad array of cybersecurity practices can enable the following business value:

- **Resilience/Reliability**. Reducing the incidence and severity of cybersecurity attacks can improve a utility's power system reliability and resilience.
- **Corporate and Financial Sustainability**. Enhancing cybersecurity practices, minimizing the occurrence and severity of breaches, as well as transparency when a breach does occur, and compliance with security and related standards and regulations can maintain or enhance (rather than damage) corporate brand image and customer satisfaction with the utility.
- **Cost Efficiency**. Enhancing cybersecurity practices and reducing attack incidence/severity can reduce the costs of responding and mitigating these attacks.

Schneider Electric Solutions

Schneider Electric has implemented the best practices described above in its own business practices and in client engagements.

Describing Schneider Electric's extensive security practices and initiatives is beyond the scope of this document. However, following are highlights of Schneider Electric's culture of cybersecurity that are particularly relevant to data management.

TÜV Rheinland has certified Schneider Electric's SDL process as compliant with the IEC 62443-4-1 cybersecurity standard, which ensures that cybersecurity is considered in every phase of Schneider Electric's product development process, as well as support and maintenance phases. Schneider Electric also reinforces cybersecurity via:

- ISO/IEC 27001 certification (information security management)
- High-security R&D centers
- Continuous training
- An incident/vulnerability management process for customers
- A penetration testing process and certification for all products before feature release and at least annually

Schneider Electric aligns its solutions with major regulations and initiatives around the world. For example, Schneider Electric is aligning its strategic initiatives with the U.S. Executive Order on cybersecurity (May 12, 2021),[49] including the SDL for a secure supply chain, secure business environments, and applicable certifications. This also includes maintaining a framework for classifying sensitive data, as well as a dedicated process for data management and controls to help secure sensitive data.

In the area of government relations, Schneider Electric participates in U.S. Department of Energy initiatives such as:

- The Idaho National Laboratory's Cyber Testing for Resilient Industrial Control Systems (CyTRICS),[50] which tests cyber resilience of OT in the energy sector
- The Cybersecurity Manufacturing Innovation Institute (CyManII),[51] which combines cybersecurity, smart and energy efficient manufacturing, supply chains, and more

Schneider Electric's Digital Grid (its digital grid and grid modernization initiative) has launched a new cybersecurity initiative that brings together strategy and planning, conformance and compliance, product development, and delivery and operations under a single organization to flow security value to its customers.

Schneider Electric team members and Schneider Electric sites hold extensive certifications and have cooperated with numerous third-party security and standards audits and assessments. The Schneider Electric team fuses experience in the IT and OT realms, and addresses cybersecurity challenges on multiple levels:

- Cybersecurity solutions for the operational lifecycle
- Technology partnerships for situational awareness, compliance, change management, and big data security
- Product and system deployment that follows IEC 62443-2-4 and includes more secure delivery of products and services
- End-to-end cybersecurity by design
- Cybersecurity assessment services for installed base systems

Schneider Electric partners with its customers to provide the following:

- Supports initial setup, configuration, and testing
- Provides improved access security to specific assets for pre-defined, authorized users and user groups via a web interface
- Establishes multiple security protocols for use once users are connected and authenticated
- Enables users to request file transfers or other activities on authorized remote systems
- Authenticates these requests to more securely send and retrieve files
- Documents the session in a log file and live video recording
- Provides full capabilities for post-incident forensics and auditing

[49] The White House, "Fact Sheet: President Signs Executive Order Charting New Course to Improve the Nation's Cybersecurity and Protect Federal Government Networks," May 12, 2021.
[50] Idaho National Laboratory website, "CyTRICS; Cyber Testing for Resilient Industrial Control Systems," accessed August 2021.
[51] The Cybersecurity Manufacturing Innovation Institute (CyMannII) website, "Cyber Innovation to Secure U.S. Manufacturing," accessed August 2021.

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Future Vision: Digital Twins, Analytics, and More

Introduction

Digital twins merit special attention because they:

- **Cut across** all nine of the use cases described above
- **Help organize thinking** on near-term enhancements to grid data management
- **Serve as a bridge** to powerful families of analytics that promise significant business benefits

A digital twin is a general term for any software or model that emulates the as-built or as-operated state of a real-world system. However, this definition does not do it justice. This section explains why, and it is perhaps the most important section in this guide.

Purpose and Scope of Digital Twins

The purpose of a digital twin is to aid improved decision making (i.e., better informed, faster decisions), using powerful simulators and/or analytics in a virtualized/software-defined environment, in order to optimize the utility's business.

While expertise and reasoning will increasingly be part of the software, in the near term, the digital twin will continue to support human decision makers, who provide the broader context.

Today, digital twins can meet multiple types of decision support needs that typically reside in silos across the following dimensions (see Figure 25). For example, the twins can follow a solution hierarchy, including a physical asset or device (e.g., circuit breaker or protection relay), system (e.g., substation, feeder), the entire grid, or the grid and the grid edge. The content of the digital twin of a device will evolve over time, from simple to sophisticated, but will contain at least a static model of the asset.

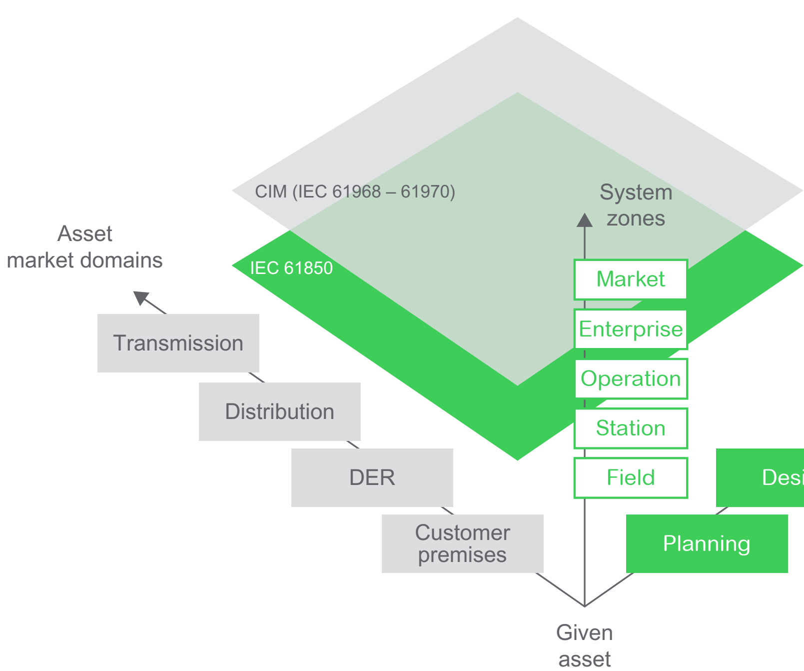

Figure 25. A digital twin for the electric grid can improve business process efficiency across multiple dimensions

The system level and higher-level twins can be created from scratch (today's situation) or will be inherited from lower-level digital twins (future). The latter correspond to the above digital twins for individual physical assets or associated with a "system modeler," which EPRI is investigating in its Grid Model Data Management (GMDM) Initiative.[52] When considering grid edge resources, the model will need to be dynamically adjusted according to the DER policy with regard to grid participation.

In addition, the twin can follow a lifecycle approach, including asset design, operation, maintenance, planning, and others, as well as interdependencies between these (see Figure 25). Simulations using digital twins can be grouped in the following way:

- **Technical simulations**
  - Three-dimensional spatial and geometrical constraints
  - Electrotechnical (e.g., voltage levels, system stability, component ratings)
  - Dependability (i.e., a combination of availability, reliability, maintainability, and resilience), which involves technology choice, maintenance program type, system architecture, and ultimately, the utility service level agreements with its ecosystem
  - Lifecycle of each product, including addressing product obsolescence
- **Sustainability simulations,** including energy efficiency, CO_2 footprint, thermal aspects, and total energy (electric power and energy processes)
- **Financial simulations,** including asset investment planning, return on investment (ROI), total cost of ownership (TCO), and delivery models such as software-as-a-service (SaaS)
- **People-related simulations** for the purposes of training, operation and maintenance support, health and safety, work order management, etc.

Multiple Types of Digital Twins

Digital twins are likely to evolve in the following way, and this section will illustrate this evolution in the asset management and building subsections below:

- A **"static twin"** facilitates data model exchange between, for example, a control center and a substation.
- A **"functional twin"** incorporates some dynamic behavior, facilitating dynamic data model update and validation between, for example, an ADMS and GIS.
- An **"adaptive digital twin"** incorporates dynamically changing capabilities, which are relevant to the grid edge, including DER.
- An **"intelligent digital twin"** incorporates autonomy, learning, and reasoning, facilitating complex planning scenarios, including optimizing the grid and grid edge.

[52] EPRI, "Grid Model Data Management (GMDM) Vendor Forum: An EPRI-Sponsored Vendor-Funded Collaborative Initiative," 3002017776, February 19, 2021.

Enablers and Drivers of Expanded Use of Digital Twins

Well-established enablers or drivers of digital twins include the increased presence of software (which in turn requires models) and continuous improvement of various simulators, co-simulation, and multi-phasic simulation.

Looking forward, Schneider Electric has identified various business and technical enablers or drivers of digital twins.

New Business Enablers

At a high level, digital twin growth reflects the realization that further optimization requires a wider system view (e.g., interaction between assets such as grid and grid edge resources). Another driver is the willingness to place a value on data, as more stakeholders view data as an asset. At the same time, relatively new aspects of various applications – such as sustainability, risk management, and cybersecurity – are driving the need for digital twins. Emerging regulation is generating interest and establishing a framework for the data business (e.g., an ongoing European Commission survey documented in an Inception Impact Assessment, the “Data Act”).[53]

In the future, a marketplace for digital twins is likely to emerge. In this arrangement, multiple parties will create value using data, which may be simply a relation between various types of data, or a simulation layer that uses this relationship to aid decision making. So, if a utility needs a digital twin, it will be able to obtain it from a digital twin market.

New Technical Drivers

Technical drivers of digital twins include the maturity of software defined everything (SDx), including software-defined automation (which is a possible future of utility substation automation), networking, storage, data center, etc. Another driver is the platform business (i.e., the capability to exchange information with various stakeholders) to selectively share data within an ecosystem. A related driver is emergence of hybrid cloud technologies, where public information can be stored in a public cloud, whereas sensitive information can be stored on a private cloud. Similarly, evolution toward asset libraries that “containerize” data to accelerate business processes drives digital twins. In the field, device and equipment QR codes can be used to access a native product digital twin, for input in turn, to various simulators.

In addition, emergence of various ontologies (i.e., representations of knowledge) plays a role, initially in specific domains:

- Building information modeling (BIM), Common Information Model (CIM), IEC 61850, and others
- A Microsoft new energy grid ontology, digital twin platform, and associated open modeling language (the digital twins definition language)[54]
- UK efforts on top-level ontologies and industry data models, which include a Foundation Data Model, Information Management Framework, and National Digital Twin[55]
- A CIRED 2021 conference paper on a data management perspective for overcoming difficulties met in deploying digital twins in the electric power industry[56]

[53] European Parliament website, “Legislative Train Schedule, A European Fit for the Digital Age, Data Act,” accessed August 2021.
[54] Microsoft, OP Ravi, “Energy Grid Ontology for Digital Twins is Now Available,” May 6, 2021.
[55] University of Cambridge, Centre for Digital Build Britain, Angela Waters, “Top-Level Ontologies and Industry Data Models,” November 17, 2020.
[56] L. Guise et al., “How to overcome difficulties met in deploying digital twins of electrical assets over their whole life cycle? A data management perspective,” paper 0547, CIRED 2021 Conference paper, 20-23 September 2021.

Future Applications of Digital Twins

This subsection covers the following topics:

- ADMS and digital twins
- Building data management and digital twins

ADMS and Digital Twins

The volume of data that utilities gather and process is significantly increasing, as a result of the scope evolution described above. The main reasons for this data growth are grid extensions, penetration of new industrial internet of things (IIoT) devices, integration of new systems into the utility information technology/operational technology (IT/OT) landscape, and others. All of these data are delivered to the ADMS. This presents challenges in the everyday activities of ADMS model managers – impacting their focus and efficiency. Challenges include how the data are imported, validated, and integrated into a common network model for all ADMS applications, so that even greater benefits can be achieved.

Schneider Electric's vision of model management in the ADMS is a highly-automated, end-to-end, seamless model management experience with only the minimal user intervention needed for grid management. This means:

- Requiring the model manager's attention only for critical and important activities
- Enabling the model manager's control of the entire process, including determining what and when to trigger data export from other systems, when to validate the data, when to integrate all models, etc.
- Providing a high-quality product that is easy-to-use so that achieved model quality can be sustained

The goal is to provide an accurate, up-to-date, accessible network model that enables utilities to address climate change and other challenges.

Building Data Management and Digital Twins

Building Energy Modeling

With regard to grid data management and digital twins, the scope of this guide includes the grid edge, which consists of buildings. Hence, an examination of building data management is relevant and useful.

In developed countries, the building sector is one of the largest, if not the largest, consumer of final energy, consuming up to 40% of total energy. Existing buildings, especially commercial ones, represent an enormous opportunity to improve end-use energy efficiency, demand response, local grid support, renewable penetration, and resilience.

When evolving from a building energy *monitoring* solution (in which measured data are simply displayed on a dashboard) to building energy *management*, the dynamic behavior of the building needs to be compared with an optimal model of that behavior. The model is the predicted desired behavior of the building, and energy management strives to operate the building as close as possible to that model.

In this context, the "model" is a digital twin of the building. The digital twin should consist of the following:

- **A static structural model** – using building information modeling (BIM) – indicates how the building is organized and structured. It includes the building architecture and use, building zones, and room use, as well as the technical architecture, such as the electrical network, HVAC network, etc. Architects and others in the building industry are increasingly adopting BIM worldwide to improve and accelerate productivity in the design and construction of buildings, while reducing errors and costs.

- **A functional, dynamic energy model** – using building energy modeling (BEM) – indicates how the building is expected to behave, including predicted energy use. BEM capability remains in its infancy, and further work is needed to enhance BEM.

- **Evolution towards an adaptive model** incorporates real-time data from meters and sensors, which indicate what actually happens in the building, including actual energy use. This technology is advancing rapidly today, with the increasing implementation of IoT devices.

A building digital twin would not only facilitate a more accurate, predictable design and construction delivery process, it would provide facility operations and maintenance (O&M) teams a complete, unified view of all building architectural and energy characteristics. In turn, this would enhance O&M of the building after construction and commissioning. This is possible because the BIM model can include (or reference) all information on the building's structure and contents, the BEM model can optimize energy operation, while receiving real-time data from sensors and other IoT-enabled devices. Building O&M personnel could use this digital twin to analyze the building's behavior and ultimately define new control scenarios, adjusting the building's performance to targets.

Furthermore, buildings will have a central role to play in the EV smart charging landscape. Smart charging at the building level avoids large infrastructure investments, increases the resilience of local and global grids, and generates significant operational savings.

A Standardized Data Model for a Building Electrical System

To realize an effective digital twin, a standardized data model is needed that describes a building electrical network topology, switchgear, switchboard, control network, and specific devices and equipment. The digital twin needs to model the building data continuum, and hence, a data model is needed that consistently models each of the parts of the continuum:

- Electrical products, which are characterized by product data (using product classification standards such as ECLASS,[57] ETIM International,[58] and IDEA[59]) and are assembled into equipment such as switchboards and cabinets while also being parts of the electrical network and wiring diagram
- A switchboard, which is designed using electrical computer-aided design (CAD) tools
- Integration of the electrical products into the electrical network, which produces an electrical CAD schematic
- Representation of the switchboards and parts of the electrical network in a building model (which uses BIM CAD in the form of IFC,[60] buildingSMART International,[61] and others)
- The CIM and electrical system model using IEC 61850
- The various building energy management systems (EMS), which use real-time data to optimally operate the building systems

Technical Challenges with Digital Twins

Distribution utilities need more than one digital twin.

This is not a matter of software generation (i.e., a "convergence" between different software). Instead, this recognizes that:

- Simulation is a trade-off between reality and some sort of model (whether a simple relation between data or complex formula).
- The amount of data is growing rapidly (from various sources, including IoT).
- New simulation needs are emerging.

Independent digital twins are not ideal because various twins have common data needs. Failure to address this commonality leads to redundant costs and lack of consistency over the lifetime of the installation, which can be detrimental to the goals of safety, resilience, and TotEx (the sum of capital and operational expenditures). In addition, interactions between the different domains and simulations are likely, which calls for ways to avoid digital twin model divergence.

Hence, one key technical challenge is the need for multiple digital twins to work in concert via a collaboration or federation (i.e., exchanging data in a system architecture, to achieve expected goals defined in use cases).

[57] ECLASS website, "The ECLASS Standard," accessed August 2021.
[58] ETIM International website, "ETIM, the international classification for technical products," accessed August 2021.
[59] IDEA website, "IDEA Standards," accessed August 2021.
[60] buildingSMART International website, "Industry Foundation Classes (IFC)," accessed August 2021.
[61] buildingSMART International website, accessed August 2021.

Digital twin development and proliferation face the following additional technical challenges:

- In **greenfield (new asset) projects,** each device should have a digital identity that references a common model to feed various simulators. Device data should include a 3D representation, electrical representation, maintenance and dependability information, physical connectivity, and logical connectivity between different twins for purposes of automation, maintenance, markets, etc.

- **For existing brownfield work,** collecting data includes initial manual data collection for existing legacy work (possibly with image recognition; reuse of software needed for installation, commissioning, and upgrade services), and use of APIs to other software. Automation is needed as the amount of data multiplies. Understanding and/or improving data quality is done at this level or during digital twin creation. Updating is needed following installation changes or audits.

- **Integrating data** from various domains via dynamic discovery of digital twins (and their capabilities) and multi-domain ontologies is challenging. This area not only includes adding data from different domains, but also assembling the digital twin according to simulation needs and accessing a subset of the databases. OSIsoft is contributing to the solution in this area.

- **Federating data** that various parties own, each with their own time-sensitive agenda (i.e., free to do what they want, and not necessarily willing to be part of a larger system) also presents challenges. This considers data to be an asset with a value (that may be intellectual property), which ongoing regulation (e.g., via the European Commission) and technical initiatives (e.g., International Data Spaces [IDS][62] as part of Industry 4.0) will support. Additional complexity stems from the dynamic evolution of data resources (as they are added and removed), such as data related to grid edge resources (e.g., virtual power plants). Distribution utilities may become an orchestrator of this federation of data. This calls for a “publishing” capability.

- **Digital twin management** includes data collection, verification and validation (V&V), improvement (e.g., quality issue clearance, simulator requirements, meta data computation based on completed scenarios, V&V regression), and governance (e.g., stakeholder access right management, versioning, splitting and reintegration, connection with other twins, sub-model standardization for installation extension).

Business Challenges with Digital Twins

Digital twins require software and services.

Software is fundamentally about the different types of simulators, running off-line or fed by real-time data, and model management platforms. Services (conducted by various parties) may grow to cope with the data and consist of the following:

- **Data governance** involves maximizing data value, including its availability, quality, use case interest, and cybersecurity.

- **Model management** is not the most visible part, but is foundational for all activities, despite its significant cost.

- **Simulation execution** selects the most promising analysis, defines the type of scenario, and may leverage historical data.

[62] International Data Spaces Association website, “International Data Spaces; The future of the data economy is here,” accessed August 2021.

- **Recommendation formulation** extends beyond the software outcome through application experts (e.g., contextualizing the results and proposing an actionable plan).

- **Implementation follow-up** usually improves digital twin accuracy and the need for additional simulations.

Additional business challenges include the following:

- **Establishing the business case** is challenging, but usually involves the value of avoiding recreating digital twins for each application, generating more value from data, and risk mitigation (e.g., improved safety, avoiding false results due to an accurate model).

- **High initial set-up costs** can be somewhat mitigated by starting with a pure simulation, and then feeding the model with real data and keeping the model up-to-date; progressively refining the model over time through new use cases; and ensuring that new devices have QR codes (embedded digital data).

Schneider Electric Digital Twin Vision

Schneider Electric provides model-driven grid management solutions for distribution utilities through interoperable grid digital twins.

These solutions are applied at the enterprise level, at the substation and feeder level, and at the connected asset level using its Digital Logbook. Schneider Electric's aims in this area include:

- Breaking down data silos across the three axes shown in Figure 25

- Providing relevant standardized and templated digital twins of grid assets

- Continuing to develop deeper integration between the different software applications:

  - Between ADMS and GIS

  - Between ADMS and substation automation engineering

  - Between DERMS and flexibility platform

  - Between asset performance management and ADMS

  - And others

The Digital Logbook

A digital logbook is an online repository that keeps all equipment information, maintenance records, and project documentation received from all stakeholders in a more secure, easily accessible location. The logbook can be accessed using a variety of digital tools. For example, the digital logbook can be initiated by a panel builder using EcoStruxure™ Power Commission during switchboard construction. Then during the project handover, this digital twin can be shared with the contractor or directly with the utility. The digital twin enables personnel to keep record of important construction documentations, user guides, and maintenance schedules. This improves collaboration and insights, while lowering costs.

Evolution of Analytics

Digital twins are a prerequisite to analytics and merging of silos of information.

Application of analytics will evolve beyond a focus on improving cost/benefits for grid users, to include a broad range of additional important value measures, including the following domains:

- Sustainability, including climate change
- Flexibility, including the increasing importance of the grid edge
- The aging utility workforce and need to capture institutional knowledge and enhance training

This evolution in analytics is possible due to:

- The availability of more data, and higher-fidelity data, from network automation, substation automation, smart meters, DER, energy markets, and other sources
- The capability to consolidate disparate, siloed data into integrated databases
- The availability of new types of data platforms that incorporate analytics – combining pure data science with deep application knowledge

The latter is possible via platforms such as the PI system from OSIsoft, which provides a data infrastructure that helps utilities and others develop analytics (see Figure 26). Here, a data archive that consists of data from a broad range of sources feeds into a defined framework of assets (e.g., substations). Calculations and analytics can be defined for each of these asset types. Events and event frames can be defined for these asset types, and when these pre-defined events occur, emails and service requests (notifications) can be initiated.

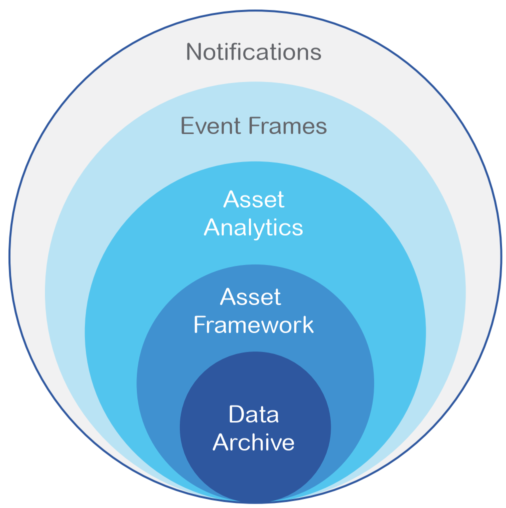

Figure 26. The OSIsoft PI platform establishes a toolkit for development of asset frameworks, asset analytics, and more

Platforms like this will offer distribution grid analytics, delivering an end-to-end view of the grid from both operational and economic perspectives. These platforms give rise to a broader array of relationships between data, such as energy models. For example, end user energy consumption or production can be represented in an energy model. A broad array of data sources can be tapped to develop this energy model, including not just electricity consumption from meter data, but also socioeconomic data, behavior patterns such as EV charging/discharging/driving tendencies, and much more. A digital twin of this end user can be developed, and the higher fidelity of this twin can inform improved analytics. These analytics can, in turn, inform a variety of applications, including power system operation, planning, etc.

In Figure 26, the asset framework can include not just traditional assets, such as substations, but can also accommodate end users. Utilities and third parties can develop various analytics about these end users, define events and corresponding event frames, and trigger notifications when these events occur. This enables users to identify specific events among the vast volume of data available to utilities – find the proverbial needle in a haystack.

These capabilities will enable application of “advanced analytics” in various ways. For existing domains, advanced analytics will enable greater depth of analysis, as well as faster and more reliable analyses. For emerging domains, advanced analytics will bridge traditionally separate analyses into integrated analyses (i.e., support “sector coupling”), with improved results:

- **Sustainability.** Advanced analytics can integrate traditional analyses of energy efficiency, asset management, power system planning, and others to more effectively address the complex domain of sustainability. For example, advanced analytics can provide a utility more confidence in relying on non-wires alternatives (rather than traditional investment in new assets) to serve customers reliably.

- **Flexibility.** Advanced analytics can integrate traditional analyses of DER (including demand response and EVs), power system operations, short-term planning, energy markets, and others to effectively address the challenging domain of flexibility.

In conclusion, analytics will remain in traditional applications, while software architecture, such as the PI System from OSIsoft, enables end users to develop even more versatile sets of analytics to create new value.

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How to Deploy Grid Data Management Practices

Overview

This section covers how to get started, where to begin, and which value-based practices distribution utilities can consider implementing in a data management process.

It addresses these questions through considerations of common integration topics, including data governance, change management, and others.

The Starting Point Matters

The way forward depends on the utility's current starting point, such as its bundled/unbundled status, and more fundamentally, the status of various exogenous (external) and endogenous (internal) factors:

- **Exogenous factors** include:
  - Regulation, especially energy and flexibility market regulations
  - Software considerations, including the way software is valued, considerations of CapEx, OpEx, and TotEx, etc.
  - The current state of the grid edge (e.g., in terms of EV and smart thermostat penetration)
- **Endogenous factors** include the utility's management culture (e.g., in terms of innovation willingness, risk tolerance, growth expectations) and existing utility assets (e.g., software, substation automation, smart metering, etc.)

A Data-Backed Strategy of Data Governance

For any organization, such as a distribution utility, execution of its business strategy should be data-backed (i.e., data support the execution of business strategy).

As a result, business capabilities will be backed by trusted, available, and sustainable data that are validated across data production chains.

While data assume a central role in business decision making, there are no "data projects" per se. Instead, business projects are use cases that require data scalability, data reliability, data quality, and data with other characteristics. This is consistent with a vision for *data-backed execution of strategy,* rather than a vision of enhanced data. Achieving data-backed strategy requires utilities to transform their *data maturity.*

Utilities need to establish data foundations prior to scaling analytics, dashboarding, and embarking on AI initiatives. The goal is to empower utilities to implement data-backed strategy in a self-managed, self-governed framework. This ultimately enables analytics scaling, etc.

As shown in Figure 27, data-backed execution includes three pillars:

- **Policies and rules.** Ensure data compliance, data protection, and data quality, while supporting the deployment of a data excellence delivery model with clear rules of the game.
- **Common data repository and glossary.** Implement an end-to-end data enterprise structure that leverages a common glossary and data repository. Implement best-in-class data foundations that clarify data vision and knowledge around a common definition.
- **Roles and responsibilities.** Ensure smooth and efficient data operations across the organization. This can be implemented in a hub-and-spoke model:
  - The hub at the center (core structure) sets the rules and provides enablers (e.g., various data tools, reusable data objects, data and analytics platforms that are ready to operate, control mechanisms, key performance indicators, and more).
  - The spokes correspond to the various operations within the organization, which use the data based on central enablement of the hub, and therefore gain the most in terms of analytics.

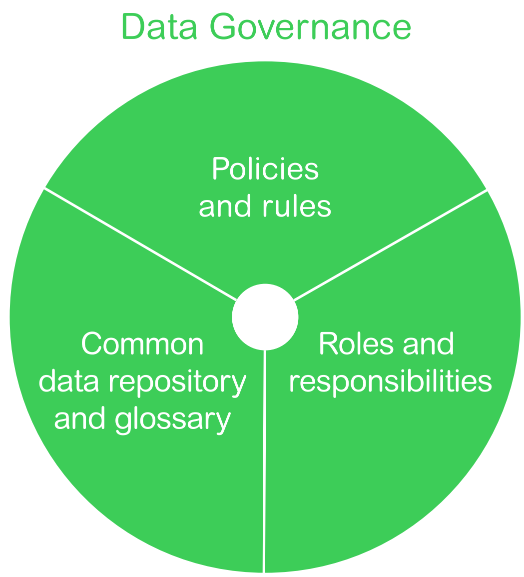

Figure 27. The pillars of data-backed execution

The Structure of a Data Initiative

Figure 28 shows the overall structure of a data initiative. From the bottom-up in the diagram, the rapidly growing volume of raw data from multiple sources requires data transformation for reusability, resulting in homogenized data.

Today, this complex process typically consumes 80% of data initiative efforts, including a broad array of common practices, modeling, cybersecurity practices, and more. At the top of the diagram, this effort results in reusable data models that can provide business insights from the data, using business intelligence, AI and machine learning, and analytics.

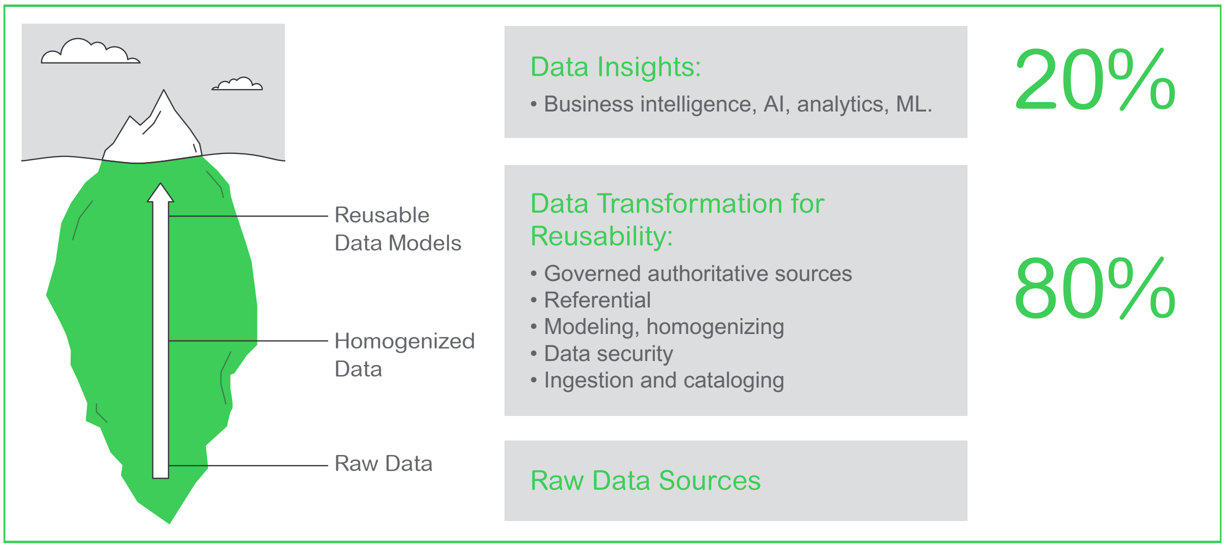

Figure 28. The structure of a grid data management initiative

Using the Industry Standard DCAM Framework

The Data Management Capacity Assessment Model (DCAM® from the EDM Council) is a market standard of best practices that can be leveraged, possibly complemented by specific critical activities for a given electrical distribution utility organization.

DCAM references and documents practices that are organized into activities. DCAM "defines the scope of capabilities required to establish, enable, and sustain a mature data management discipline." Refer to the DCAM framework.[63]

[63] Data Management Capacity Assessment Model (DCAM® from the EDM Council), "Data Analysis Lifecycle," page 8, accessed August 2021.

“Bricks” Across Dimensions

A multi-layered approach should be considered to address the scope of data:

- A **utility internal layer,** which examines utility assets data down to the residential user, and examines how to create more value from these data. This layer involves examining at least the grid elements (i.e., corresponding to an unbundled distribution operator), since the other aspects are examined in the next dimension to some extent.
- The **utility + other main energy players layer,** including other utilities, large power producers, markets, etc.
- The **utility + the grid edge layer,** which examines other stakeholders, usually considered to be DERs, beyond the meter.

Key Success Factors

Key success factors include the following:

- Establish an agile setup that evolves along the maturity level, including consideration of a hub-and-spoke arrangement
- Develop with use cases that are tied to business outcomes
- Communicate and animate (e.g., community, events, ambassadors, etc.).

Approach to Grid Data Management Projects

- **Human resources.** Assign sufficient existing human resources with “digital” competencies, consider internal training to enhance team competencies, and consider recruiting new personnel with the needed competencies. Identify, train, lead, and support. Assign project leaders, ambassadors, and drivers.
- **Communication.** Deploy a strong communication plan that clearly articulates the rationale for data governance, begins the communication process early in the project, defines the roles of project participants, and conveys the business results.
- **Proof of concept.** Begin with a proof-of-concept phase, which can increase personnel acceptance and improve integration of data management solutions.
- **Specify project goals, the business case, and expected benefits.** Carefully define the project objectives (and map them to corporate goals), the business case, and expected business outcomes, and gain executive level and team agreement.

- **Design stage.** Starting the project with a design stage provides team training on the new solution and its possibilities, and can help them foresee the broad possibilities, compared to existing tools and approaches.
- **Phased approach.** Establish priorities and define an overall technology transformation path. One key is that project participants experience benefits of the new solutions as soon as possible, so that they can convey to others in the organization the value of the new approach. Consider implementation in the following two phases:
  - Begin deployment on a specific area of the network, and then extend it to the full network.
  - Begin by enabling some functionalities, and then incorporate others step-by-step.
- **Limit customization.** Once the vendor has been selected, limit customization of the solution. Excessive customization can lead to implementation of a solution similar to existing practices, with little innovation, limited business value, a slower learning curve, and long-term risks of obsolescence.
- **Focus.** Maintain a stable project scope and remain focused on the defined strategic intent.
- **Systems integration.** Integration of new solutions with existing ones is crucial and is primarily a business process challenge. The project needs to define how it will support people, and how it will "make their life easier." People as key business process players need to be front-and-center.

About Schneider Electric

Schneider's purpose is to **empower all to make the most of our energy and resources, bridging progress and sustainability** for all. We call this **Life Is On**.

Our mission is to be your **digital partner for Sustainability and Efficiency**.

We drive digital transformation by integrating world-leading process and energy technologies, end-point to cloud connecting products, controls, software and services, across the entire lifecycle, enabling integrated company management, for homes, buildings, data centers, infrastructure and industries.

We are the **most local of global companies**. We are advocates of open standards and partnership ecosystems that are passionate about our shared **Meaningful Purpose, Inclusive and Empowered** values.

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Acronyms

Acronyms

ADMS	Advanced Distribution Management System
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AI	artificial intelligence
AIP	asset investment planning
AKA	also known as
AMI	advanced metering infrastructure
API	application programming interface
APM	asset performance management
AR	augmented reality
ARES	alternative retail electricity supplier
AS	ancillary services
ARO	asset retirement obligation
AVL	automated vehicle location
BEM	building energy modeling
BIM	building information model
BRP	balance responsible party
BSDD	buildingSMART Data Dictionary
BTM	behind the meter
CAD	computer-aided design
CapEx	capital expenditure
C&I	commercial and industrial
CCA	community choice aggregator
CCPA	California Consumer Privacy Act
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CfD	contract for difference
CIGRE	International Council on Large Electric Systems
CIM	Common Information Model
CIP	critical infrastructure protection
CIRED	International Conference on Electricity Distribution
CIS	customer information system
CMEP	California Metering Exchange Protocol
CMMS	computerized maintenance management system
CPUC	California Public Utilities Commission
CRM	customer relationship management
DCAM	Data Management Capacity Assessment Model
DER	distributed energy resources
DERMS	distributed energy resources management system
DG	distributed generation
DLC	direct load control
DMS	distribution management system
DNO	distribution network operator
DNMS	distribution network management system
DNP3	distributed network protocol 3
DNSP	distribution network service provider
DR	demand response
DRMS	demand response management system
DSM	demand-side management
DSO	distribution system operator
EaaS	energy-as-a-service
EAM	enterprise asset management
EAOA3D	EcoStruxure™ Augmented Operator Advisor 3D
ECSO	European Cyber Security Organization
EMA	Ecostruxure™ Microgrid Advisor
EMO	EcoStruxure™ Microgrid Operator
EMS	energy management system
ENTSO-E	European Network of Transmission System Operators for Electricity
EPAS	EcoStruxure™ Power Automation System
EPO	Energy Profiler Online
EPRI	Electric Power Research Institute
ERP	enterprise resource planning
ESO	electricity system operator
ETSI	European Telecommunications Standards Institute
ETL	extract, transform, load
EU	European Union
EV	electric vehicle
FAT	factory acceptance testing
FERC	Federal Energy Regulatory Commission (U.S.)
FiP	feed-in-premium
FLISR	fault location, isolation, and service restoration
GMDM	Grid Model Data Management
GDPR	General Data Protection Regulation
GEB	grid-interactive efficient buildings
GENCO	generation company
GIS	geographic Information system
GMS	grid management system
HES	head-end system
HMI	human-machine interface
HV	high voltage
ICCP	Inter-Control Center Communications Protocol
IDS	International Data Spaces

Acronyms

IEC International Electrotechnical Committee
IED intelligent electronic device
IEEE Institute of Electrical and Electronics Engineers
IEM internal energy market
IFC Industry Foundation Classes
IIoT industrial internet of things
IoT internet of things
IPP independent power producer
IRENA International Renewable Energy Agency
ISO independent system operator
IOS International Organization for Standardization
IT information technology
ITU International Telecommunication Union
IVR interactive voice response
KPI key performance indicator
kW kilowatt
kWh kilowatt-hour
LSE load serving entity
LV low voltage
MDMS meter data management system
ML machine learning
MOC meter operations center
MV medium voltage
MWFM mobile workforce management system
NEM normalized electrical model, National Electricity Market (Australia)
NERC North American Electric Reliability Corporation
NIST National Institute of Standards and Testing
NRA national regulatory authority
NWA non-wire alternatives
O&M operations and maintenance
OMS outage management system
OpEx operating expenditure
OSI Open Systems Interconnection
OSMOSE Optimal System Mix of Flexibility Solutions for European Electricity
OT operations technology
PLC programmable logic controller
PLM product lifecycle management
PUC public utility commission
PV photovoltaics
PX power exchange
QR-code quick response code
R&D research and development
RFQ request for quotation
RIO remote input-output
ROI return on investment
RSC regional solution center
RTO regional transmission operator
RTU remote terminal unit
SaaS software-as-a-service
SAMU stand-alone merging unit
SAPM South Australia Produce Market
SAT site acceptance testing
SCADA supervisory control and data acquisition
SCL substation configuration language
SDL security development lifecycle
SDO Standards Development Organization
SDx software defined everything
SEEM Southeast Energy Exchange Market
SEPA Smart Electric Power Alliance
SGAM Smart Grid Architecture Model
TC technical committee
TCO total cost of ownership
TNSP transmission network service provider
TotEx total expenditure (capital plus operating)
TOU time-of-use
TSO transmission system operator
UI/UX user interface/user experience
V&V verification and validation
VAR volt-ampere reactive
VEE validation, estimation, and editing
VPN virtual private network
VPP virtual power plant
VR virtual reality
VVO volt/var optimization
WFM workforce management
WG working group
WMS workforce management system
XML extensible markup language

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