White Paper

Multi-Sensing Platforms Unlock Full Grid Visibility

Filling in the Gaps of Grid Management and Operations

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Introduction

Transmission and distribution (T&D) networks are at the core of utilities' businesses. Many are in dire need of an injection of both technology and capital to maintain the high levels of grid performance demanded by customers today. This is exacerbated by the proliferation of distributed energy resources (DER), renewable energy systems (RESs), microgrids, and new forms of power aggregation.

With these transformational changes occurring on the grid, operators are increasingly in search of tools that can provide end-to-end visibility. To facilitate higher levels of situational awareness, utilities demand more accurate, precise, and real-time data streams. The use of advanced sensing devices, combined with data analytics, can provide greater visibility and produce actionable insights without overwhelming grid operators. The ingestion and analysis of enhanced data sets is being used to deliver more accurate fault location (AFL) in support of grid and outage management, as well as facilitating higher levels of DER integration. These technological evolutions create room for advanced solutions and network architectures to assist with a growing list of operational challenges.

This Guidehouse Insights white paper explores how innovative applications of T&D sensing and measurement (TDSM) and analytics technologies can improve fault detection efforts, facilitate higher levels of DER integration, enable asset performance management (APM), and support a number of larger grid modernization goals. It discusses the role that multi-sensing platforms can play in delivering more timely, relevant, and actionable insights for grid operators. In recent years, more sophisticated TDSM solutions have been adopted to help utilities gain full and near-real-time situational awareness through end-to-end T&D network visibility.

Solving for Today and Planning for Tomorrow

Grid operators are facing immense pressure to meet the needs and demands of stakeholders and customers while lowering costs, improving reliability and safety, and driving efficiency gains. As Figure 1 shows, these metrics are key building blocks in enabling future grid networks.

Figure 1 Key Building Blocks to Enable Future Grids

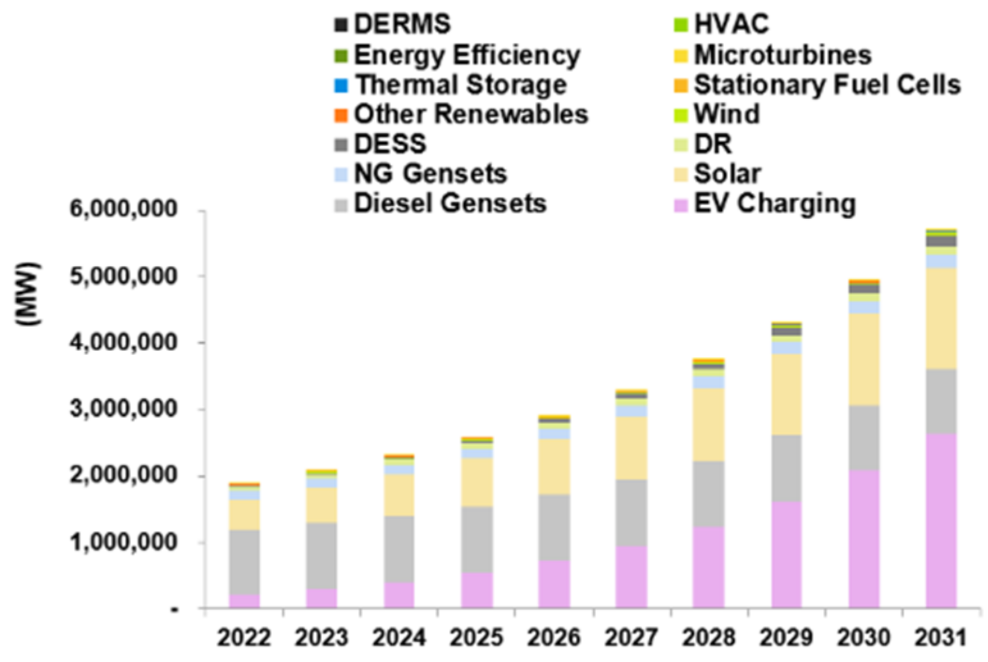
(Source: EGM)

The pressures created by evolving grid networks are incentivizing the use of more advanced analytics technologies. To maximize the value and efficacy of sophisticated analytics solutions, insights should be based on genuine data from the field. While existing methods of analysis tend to rely on estimations, re-valuations and historical data, emerging TDSM platforms can support genuine data streams within their analytics engines to deliver enhanced insights for utilities and grid operators.

In the future, the most effective distribution technologies are expected to be those with the ability to provide utilities with real-time, actionable grid data, allowing network operators to predict and better manage power outages. This will provide broader network efficiency while seamlessly integrating a growing base of RESs and DER. The integration of distributed intelligence into grid devices such as line sensors leads to further grid performance improvements.

Highlighted in Chart 1, the ongoing proliferation of DER across the globe presents a series of challenges for distribution networks in terms of voltage stability and power quality. Integrating increased levels of DER onto electricity grids reliably and cost-effectively requires solutions that improve grid flexibility, including enhanced monitoring and control, smart meters, and Volt/VAR optimization (VVO).

Chart 1 Cumulative Installed DER Capacity by Technology, World Markets: 2022-2031



(Source: Guidehouse Insights)

The influx of advanced technologies is growing constantly and brings significant upside to grid reliability. Distribution automation (DA), the use of technologies to enhance control and visibility of the distribution grid, is fully deployed on only about 15% of distribution networks in North America, and even less globally. That means that on ~85% of US distribution networks, utilities are often left in the dark and have no way to sense and repair an outage without the significant time and cost of sending a crew out to find and repair the fault. Through DA, the integration of advanced sensors and a strong communications network can greatly benefit utilities and their reliability metrices by monitoring grid operations and detecting faults in near real-time.

While traditional approaches to outage management (e.g., fault current indicators [FCI]) have shortened the average time in locating a fault, emerging TDSM solutions can enable more advanced AFL functionality to pinpoint exact fault locations. This has the potential to reduce the System Average Interruption Duration Index for specific feeders by more than 50% over traditional FCIs. And while other mechanisms are available to achieve similar results, such as the widespread deployment of reclosers, the use of digital systems will likely prove more cost-effective given the lack of additional hardware expenditures.

As the industry and its stakeholders transition from a static grid into a digital, adaptive, dynamic, and flexible grid, a new iteration of sensing, measurement, and analytics tools is required. The effective integration of DER, the increase in customer demand for grid reliability and stability, and recent advances in grid technology are driving utilities and grid operators to equip their distribution network with more sophisticated TDSM solutions.

Can Today's Solutions Meet Tomorrow's Demands?

Grid management solutions in use today often lack the precision, forecasting accuracy, and real-time data requirements needed to manage and optimize future grid networks. The aforementioned operational pressures of reliability, resiliency, decentralization, and more, are demanding more comprehensive, high resolution, and real-time data from the field to address a growing list of grid-based use cases. In order to create the reliable, flexible, efficient, and renewable grid that tomorrow's demands elicit, utilities and grid operators require a full picture of what's happening and anticipation of future grid issues.

- **Operational Technology (OT) Systems Provide Limited Downstream Visibility:** Advanced distribution management systems (ADMS) provide distribution-level visibility for grid operators and are typically used to assist with utility planning and operations. However, ADMSs have their limits, as these systems typically rely on SCADA measurements as the primary source of data ingestion. The number of phenomena monitored is often low, and real-time data availability is confined to the substation. Furthermore, there is typically minimal monitoring at the actual feeder-level, particularly across longer power lines. This gap highlights the need for visibility between the substation and end customer, particularly in areas where feeder lengths exceed 10 or more kilometers, for example. ADMS also have scalability issues given their upstream, substation-level orientation.
- **Smart Meters Provide Limited Upstream Visibility:** The low-frequency data capture and limited processing power of first-generation smart meters cannot support real-time measurements or true edge-based analytics, and only a handful of utilities have deployed second-generation devices to date. Less than half of global electricity customers even had a smart meter as of 2021. Furthermore, on-meter analytics architectures rely on location awareness and peer-to-peer communications (with other metering devices) to provide visibility primarily on the customer side of the transformer. At the feeder level, there remains a lack of true situational awareness. Sensors are needed between the substation and meter, at a minimum, to deliver real-time measurements throughout the entire T&D network.

The pure size of the distribution network makes it difficult to monitor the entire system effectively via existing solutions, such as OT systems (e.g., SCADA, ADMS) or smart meters. While grid operators have dramatically improved the level of visibility within their networks over the past two decades, there remains a significant blind-spot, from the substation to the home, that requires a new iteration of grid management technology.

New Solutions Provide Full Grid Visibility

The visibility limitations of OT systems and smart metering illustrate the technological gap in delivering the full range of real-time, actionable insights to grid operators that are increasingly needed. This gap in situational awareness, as well as in existing solutions, can be filled by additional TDSM and data analytics technologies.

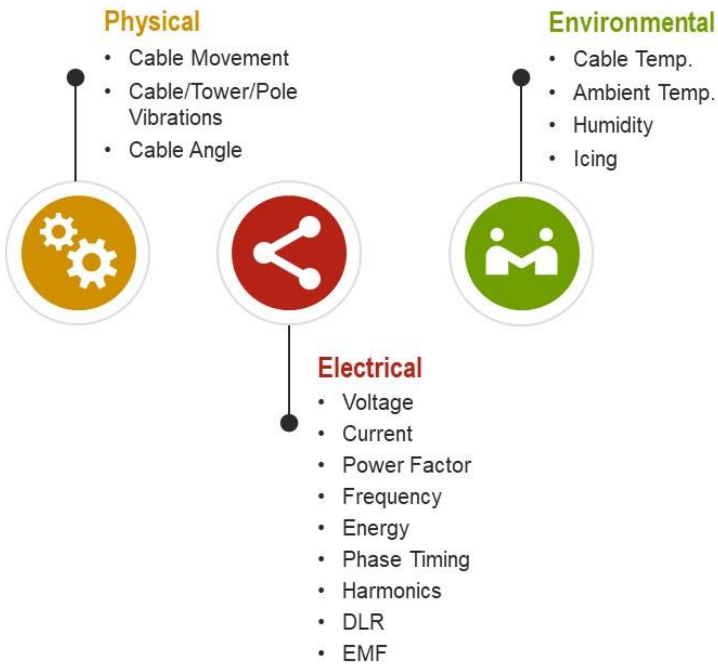
This section discusses the foundational components of advanced TDSM solutions that aim to fill these gaps. This encompasses hardware, communications, and software elements that are increasingly being delivered under platform-based approaches. From sophisticated sensors and reliable data transfer to advanced algorithms and actionable insights, emerging solutions aim to elevate traditional approaches to grid management in delivering full network visibility and greater situational awareness.

Sophisticated Sensing and Measurement

The evolution of TDSM devices has resulted in more powerful sensors capable of capturing multiple parameters per unit, at sub-second intervals, and can deliver actionable insights locally, in the cloud, or on premises. While traditional sensors may only measure a few parameters, advanced sensors can perform measurements across tens of adjustable parameters (e.g., electrical, current, discrepancy, frequency). For example, companies such as EGM offer multi-sensing unit (MSUs) that are capable of continuously and accurately capturing between 60 and 70 different measurements including accurate voltage measurement without reference. The combination of physical, electrical, and environmental parameters listed in Figure 3 highlight the depth of data collection available within a single MSU. The incorporation of these additional phenomena, beyond what is typically measured at the substation- or meter-level, widens the range of enabled grid-based applications.

This approach also significantly reduces the number of sensors required to support a given use case, helping to improve program economics and deployment complexity. Advanced MSUs can be deployed on transmission lines, transformers, and distribution feeders, opening up a world of opportunity in terms of stacked use cases and grid-wide value creation.

Figure 2 EGM Measurement Parameters



(Source: Guidehouse Insights, EGM)

TDSM manufacturers have also dramatically improved the onboard computing power, memory, and programmability within their sensing devices in recent years. This enables new applications to be developed inside-the-sensor that were previously unavailable or illogical, including pattern recognition and anomaly detection. Given the bandwidth and latency constraints of field area networks, localized analytics can be more appropriate for real-time (i.e., time sensitive) use cases that require proactive responses.

This combination of enhanced capabilities (i.e., multi-sensing, ultra-high-speed sampling, onboard analytics) provides the foundation for the advanced platform-based approaches to TDSM discussed within this section.

Real-Time Communications

In order to maximize the value of enhanced data streams, real-time, secure, and reliable communications networks are required. Sensors can leverage either existing communications networks, such as advanced metering infrastructure (AMI), DA, or DER communications, or proprietary networks for local and backhaul data transfer. While the use of existing networks has been particularly common to date, bandwidth and latency constraints can arise with this approach, particularly as the number of devices continues to grow.

Meanwhile, certain TDSM solution providers have developed their own grid communications networks to complement their device offerings. For example, EGM developed its own proprietary mesh-based neighborhood area network (NAN) to feed local gateway units, which then piggyback off existing backhaul networks to deliver information to the utility control or IT room. This approach not only avoids existing network constraints, but can add a new layer of cybersecurity, as it creates an isolated monitoring system that can act as an additional pair of eyes to detect malfunctions created by cyberattacks.

Figure 3 EGM Communications Features

EGM Communications Architecture
Unique Features
Independently gathering field data from all grid installed sensors and other devices
Internal sensor-to-sensor communication (i.e., peer-to-peer)
Transferring operational commands from the server to sensors (automatic and manual commands)
Remote adjustment to built-in sensor's parameters (min / max value of each parameter in each sensor can be changed at any time)
Remote software upgrades to all sensors

(Source: Guidehouse Insights, EGM)

Highlighted in Figure 3, there are several unique communications features offered by TDSM providers today that can unlock additional value from sensor deployments. For example, the ability to remotely upgrade software to sensors in the field, rather than performing lengthy firmware modifications, improves the flexibility and time-to-value of functionality upgrades and patch management procedures. The development of peer-to-peer (P2P) communications between sensors has also unlocked additional value streams, as P2P networking can enable precise location awareness and pinpoint accuracy in detection.

Actionable Analytics Insights

With the advent of P2P device communications and availability of enhanced data streams, data analytics can now support a wider range of grid-based use cases, at the device-level, in the cloud, or on premises. For example, P2P communications can operate in conjunction with high resolution data streams to optimize outage detection and reporting—pinpointing the accurate fault location (AFL), theft detection (immediate detection and remediation), asset management (targeted APM and proactive maintenance), renewables integration (real-time grid balancing), and more.

In addition, the use of multi-sensing devices can help improve the diagnostic capabilities and accuracy of analytics insights, as several symptoms are typically considered in the determination of specific problems. Table 1 illustrates the wide range of use cases that can be improved with sophisticated, multi-sensing TDSM platforms.

Table 1 TDSM Applications and Benefits

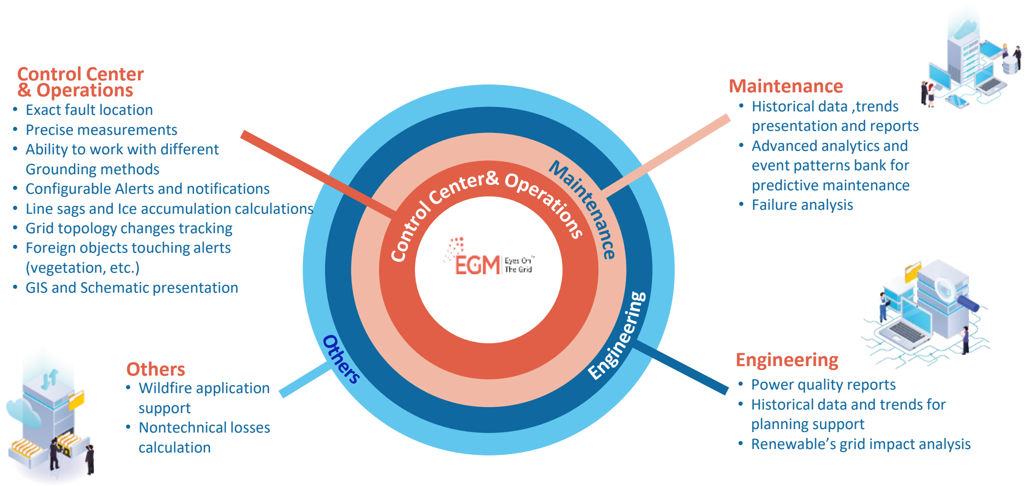
Application	TDSM Description
Accurate Fault Location (AFL), Isolation, and Restoration (FLISR)	Self-healing grid; has intelligent switches, relays, reclosers, and other devices with strategically placed sensors to increase utility's fault recognition speed and dispatch of crew for repairs.
Dynamic Line Rating (DLR)	Actively monitors lines, identifies potential capacity, and increases power flow to maximize system utilization.
Conservation Voltage Reduction (CVR)	Voltage sensors at the distribution level in transformers, lines, or meters provide accurate real-time voltage information, enabling precise adjustments for reduction.
Non-Technical Loss (NTL) Prevention	A significant problem in many developing regions. Sensors in the distribution network can accurately identify where theft or NTL is occurring. Feeder and meter sensors also allow utilities to detect irregularities caused by electricity theft.
Intermittent Renewable Energy	Sensors enable real-time monitoring of renewable generation for power balance issues resulting from fluctuations in generation. Line sensors monitor voltage swells or sags due to changes in weather.
DG Integration	Integration of distributed generation (DG) requires the control of the flow of energy into the grid. Substation, feeder, and line sensors with real-time sensing and communications will be critical to grid visibility and system reliability. Smart meters and inverters will help maximize DG efficiency and control.
Condition Monitoring	T&D substation, feeder, and line sensors monitor asset health information and can detect failures before they occur. Assets are maintained based on the detected condition, cutting maintenance costs and improving system reliability.
Fleet and Crew Management	With an enhanced network of sensors, utilities can remotely address grid issues and more effectively dispatch crews for issues requiring onsite maintenance.
Volt/VAR Management	Voltage sensing function integrated into meters and other distribution assets provide more granular and actionable data, increasing efficiency of integrated VVO.
Phasor Measurement Units (PMUs)	Time-synchronized sensing devices for measuring system power flow across many geographical points, detecting faults, disturbances, and other critical network information.

(Source: Guidehouse Insights)

There are a number of existing solutions that address one or more of these use cases, such as meter data management systems (MDMS) for theft detection, APM for condition monitoring, or mobile workforce management systems (MWMS) for fleet and crew management. However, the embedded analytics algorithms within these IT systems may only pull from one or few sensing parameters and won't support this longlist of applications.

The concept of multi-sensing TDSM platforms mirrors the single-pane-of-glass approach increasingly adopted throughout the utility software landscape. Supporting multiple modules and applications under a 'single-pane-of-glass' approach provides a number of value-added benefits, including simplified operations, enhanced user accessibility, and native interoperability. Figure 4 provides an example of the types of customized displays that can be created for different users of advanced TDSM platforms.

Figure 4 Customized User Interface Displays for Different Users



(Source: EGM)

The following section describes the enablement of grid optimization applications by these advanced TDSM platforms. This list of use cases is likely to evolve, but for the purposes of this white paper, leading applications are highlighted. Some applications are in widespread adoption, such as theft detection, while others are in early stages at a few leading utilities.

Tomorrow's Solutions Enable Value Stacking

The TDSM solution framework highlighted above can deliver more accurate, actionable, and real-time insights to utilities and grid operators. This helps to uplift the value and efficacy of a wide range of grid management and optimization applications. From reducing outages and improving service quality to maximizing infrastructure utilization and streamlining renewables integration, sophisticated, end-to-end TDSM solutions can deliver greater value across the energy value chain.

Outage Detection and Restoration

Utilities rarely have information on grid health until a component fails or causes an outage. Traditionally, outage management may have been handled by a call center and process workflow to track reported faults and ensure that maintenance teams were dispatched to the presumed location of the problem. These outage cause power losses, resulting in significant financial losses to utilities and local economies. This also has the unnecessary impact of inflating maintenance costs due to long and tedious fault, location, isolation, and restoration (FLISR) processes. In the world of outage management, the ability to know where your power if failing is ever-more critical.

Emerging TDSM solutions, such as EGM's AFL concept, can help improve existing approaches to outage management and FLISR by pinpointing the exact location of a fault, even if the sensors are miles apart in some cases. Information can then be used to prepare and optimize dispatch and work schedules for crews. This has been shown to have a dramatic impact on outage downtime, with NREL simulations estimating a reduction in downtime of approximately 5.8 hours to 1.8 hours. The results were presented at the Institute of Electrical and Electronics Engineers Power & Energy Society Innovative Smart Grid Technologies conference. Power restoration processes uses similar techniques, leveraging P2P communications and high resolution data to provide accurate estimates while avoiding transformer overload in the safe restoration of power.

Grid Optimization

In addition to improved outage detection and restoration, advanced TDSM platforms can elevate several other grid optimization applications, including damage assessment, system modeling, power quality optimization, voltage optimization, real-time network operations and grid balancing, DER integration, state estimation, AMI network visualization, meter connectivity, outage notification, root cause analysis, and more. Examples include:

- Load Balancing: Load balance between parallel electrical lines can result in significant loss reduction. Advanced TDSM platforms can analyze accurate load measurements from each feeder segment, provide load balancing recommendations, and predict/simulate new load conditions.
- Technical Losses: MSUs can detect leaking grid components and provide leak levels and trendlines. Analytics can then be applied to identify the exact location and type of problem with proactive action recommendations.

With grid visibility increasing due to technological advancements and installation of OT systems, utilities, regulators, and customers are now privy to grid efficiency information, including line losses, heat loss, and low-capacity utilization figures; thus far, they are not satisfied with what they see. TDSM platforms, like what is offered by EGM, can help utilities collect utilization and efficiency data, make decisions on grid projects, and in some cases, defer capital investment as part of non-wires alternatives projects.

DER Integration

The global utility business faces unprecedented challenges—and opportunities—as DER proliferate. As the penetration of DER continues, utilities are requiring greater visibility and transparency in their networks.

Distributed and intermittent generation can result in unstable voltage conditions across the distribution network which necessitates greater real-time monitoring at the circuit-level. Utilities are meeting this demand by monitoring for voltage sags and swells, voltage harmonics, capacity issues, and pole reversal. While ADMSs and DER management systems (DERMSs) can support some of these functionalities, OT platforms will not be able to address everything that advanced TDSM solutions can claim to offer.

Furthermore, disturbances and irregularities are commonly found in the grid, causing malfunctions at users' equipment and loss of money. The disturbances and irregularities may be caused by RE generators, unbalanced (and bad phase angle) loads, or other factors. Advanced TDSM platforms can detect high order frequencies, phase drifts, as well as harmonics on circuits, and measure them with FLISR applications. And MSUs can act as quasi-PMUs in measuring precise phase angles, allowing utilities correct the loss of energy (VARS) in real-time.

Vegetation Management

Outages, a result of equipment failure, is not only due to aging equipment but can also be caused external factors such as wildlife or vegetation incursion, severe weather, wildfires, theft, vandalism, or automobile accidents. While there are many factors that can cause an outage, Guidehouse Insights estimates that 80%-90% of outages impacting the distribution grid are caused by object-on-wire faults. These types of outages are caused by events that typically follow patterns and are difficult to detect and avoid. In response, advanced TDSM solutions are emerging in the market to help detect, diagnose, and plan assistance in the restoration of power during an outage.

Inspection programs rely on varied, complex, and unstructured data, much of which is collected infrequently. In the US, utilities conduct scheduled detailed inspections on approximately 10% of their assets each year. This means that the average transmission line is inspected once every 10 years and may be done manually.

Using AI-based applications, a utility can detect accurately indications of an impending failure and dispatch a work crew to replace the asset before any impact to customers. This scenario replaces the run-until-failure approach, which assumes that backup systems or alternative routing will continue to provide service. It is also superior to scheduled maintenance where assets are retired based on set schedules, which tends to underestimate the useful economic life of many assets.

Theft Detection

One of the primary drivers for smart metering is to mitigate NTLs (theft of service is also known as NTLs). While this is often a stronger motivation in some territories, it exists to certain degree in most countries, which makes NTL reduction as a primary driver behind its use of machine learning and smart metering.

Theft detection is a common functionality of enterprise MDMS; and can be offered as an embedded capability or value-added module. However, there is also a market for standalone analytics solutions to address more advanced theft detection applications such as diversion theft detection and revenue protection applications. Emerging use cases expand well beyond tamper and theft and aim to achieve visibility into issue quality, phase issues (e.g., C&I customers), etc.

While MDMSs enable basic NTL detection capabilities, the use of advanced TDSM solutions with dedicated line sensors can elevate the efficacy and value of these detection efforts. With more accurate and timely consumption data, utilities can use analytics to detect increasingly sophisticated attempts to defraud electricity suppliers. Machine learning is being used to reduce false positives and identify previously undetected methods to defraud suppliers. AI can identify this behavior and shut off the equipment or send crews to remove unauthorized connections that are costly and dangerous.

Transmission Applications

Like much of the global electricity grid, many of the high voltage transmission systems in service rely on the same technologies that existed at their conception over 100 years ago. However, since the early 2000s, transmission technologies have benefited from significant innovation, leading to enhancements in transmission efficiency over long distances, reduced system costs, and increased grid stability and reliability.

The addition of enhanced sensors and monitoring capabilities to transmission lines can significantly enhance grid reliability and visibility. Transmission SCADA systems are widely deployed, and the quality and granularity of transmission network data is growing, propelling the integration of enhanced grid analytics to provide deeper insights. Transmission line monitoring and dynamic line rating (DLR) applications can have a profound impact on system utilization and efficiency. DLR gives utilities a real-time view of the power flow on a transmission line and identifies its true capacity. Among other things, this allows utility personnel to maximize the power on the line, increasing system utilization. These applications are increasingly supported by devices beyond PMUs, such as the MSUs profiled in the previous section.

Conclusion

Since grid transparency is no longer stalled by expensive equipment or underdeveloped technology, there are fewer justifiable excuses for utilities to lack a granular snapshot of their T&D grids at any point in time. Traditional methods of measurement and analysis that rely on manual data capture, estimations, re-valuations, and historical-based facts are quickly becoming outdated as energy and digital transformations continue to permeate global power grids. This is further exacerbated by mounting regulatory and consumer pressures to improve grid reliability, resiliency, and availability. The situational gaps created with existing solutions can be addressed by investing in new and advanced TDSM technologies. Enhancements to sensing and measurement are now high up on the priority list for grid improvements universally, helping to accelerate the global market.

Utilities with mature grid deployments should start exploring sophisticated TDSM technologies as a tool to optimize grid utilization and increase resilience while reducing operational costs. This is prudent given the alternative of costly grid upgrades that might seem necessary to support the electrification of new segments of the economy, like heat and transport. In emerging markets, utilities can also benefit from exploring advanced solutions, whether it be to shore up age-old issues like energy theft, or to help usher in future grids while avoiding the challenges seen across evolving, developed markets.

Acronym and Abbreviation List

ADMS .... Advanced Distribution Management System

AFL .... Accurate Fault Location

APM .... Asset Performance Management

BTM .... Behind-the-Meter

C&I .... Commercial and Industrial

CVR .... Conservation Voltage Reduction

DA .... Distribution Automation

DER .... Distributed Energy Resources

FLISR .... Fault Location, Isolation, and Restoration

IT .... Information Technology

MDMS .... Meter Data Management System

MSU .... Multi-Sensing Unit

MWMS .... Mobile Workforce Management System

NAN .... Neighborhood Area Network

NTL .... Non-Technical Loss

OT .... Operational Technology

PMU .... Phasor Measurement Unit

RES .... Renewable Energy System

T&D .... Transmission and Distribution

TDSM .... Transmission and Distribution Sensing and Measurement

VVO .... Volt/VAR Optimization

Table of Contents

Scope of Study

This Guidehouse Insights white paper explores how the rapid pace of digitization across the energy sector has fundamentally led to a shift toward digitized, dynamic, and flexible grid networks. It also discusses how sophisticated T&D sensing & measurement technologies can be used to improve upon existing approaches to grid management by delivering more accurate, real-time, and actionable insights to utilities and grid operators.

Sources and Methodology

Guidehouse Insights' industry analysts use a variety of research sources in preparing research reports and white papers. The key component of Guidehouse Insights' analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Guidehouse Insights' analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Guidehouse Insights' reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

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