Meter Data Collection, Management, and Analysis

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1 The Smart Meter: A Foundational Element

It has been frequently stated in the utility industry and smart grid technology sector that smart meters are not synonymous with "smart grid," which represents a broader set of distributed generation, grid devices, communication networks, and data-management technologies interacting to solve key challenges. Smart meters are one element of the smart grid. However, by providing measurement, grid sensing, communication, and control capabilities at the customer premise and "edge" of the network, smart meters are foundational to the smart grid and it is important to understand their role in connecting the pieces and processes of that larger whole to meet key energy and environmental challenges in the years ahead. As the marketing director for one of the world's leading smart meter technology providers, the author has worked with utilities implementing these systems over the past 15 years, was a member of several industry associations and boards, and a frequent writer and speaker with the utility and smart grid industry. It is from this foundation of experience that he has assembled this overview of smart metering technology, market trends, and the value potential it, and related technologies can play in building a more efficient, reliable, and sustainable power grid. Throughout this chapter, the terms *smart metering*, *AMI*, and *advanced metering infrastructure* are very similar and are used interchangeably to refer to metering technology capable of two-way communications, detailed energy consumption measurement, and various sensing capabilities.

In general terms, a smart meter is an advanced electric meter that measures consumption in more detail and communicates that consumption information to the utility and customer. Smart meters are designed to facilitate energy efficiency, conservation, and related smart meter-enabled programs. The existence of smart meters also assists with improving operational efficiency and reliability, as well as empowering consumers to manage and make more informed decisions about their energy use. Smart meter technology typically includes hardware (meters), software, communications, customer-associated systems, and meter data-management (MDM) systems.

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A smart meter is a safe and secure digital device that measures energy consumption more accurately and frequently than traditional mechanical meters. Instead of relying on meter readers to go to peoples' homes every month, smart meters are equipped with two-way communications, enabling the utility to collect the usage data automatically and share that data in near real time with customers over the Internet, via an in-home display unit or through mobile apps. This also creates a platform for utilities to offer customers special rates and programs that enable people to save money on their utility bills, conserve energy, and reduce their environmental footprint. Smart meters also alert the utility immediately if your power goes out (and when it is restored), reducing the duration of power outages.

Unlike their mechanical forbearers with spinning cogs and disks, smart meters utilize solid-state technology and are capable of measuring energy consumption more frequently and more accurately than traditional meters. Smart meters consist of three main elements: the metrology, which measures consumption; the register board, which processes and stores the data; and communication board, which transmits consumption and event data to the network. Smart meters also feature an integral clock, which enables the meter to "time stamp" consumption and event data, to support time-based pricing tariffs, and to record when events such as outages take place.

1.1 Grid Sensors

In addition to measuring consumption, smart meters also act as sensors that represent the equivalent of "nerve endings" for the grid. They can be used to identify potential reliability problems before they become an outage. They can quickly detect and understand the scope of the outage, freeing the utility from reliance on customer calls to figure out exactly what is going on. Their data can help optimize the dispatch and management of field resources to speed restoration times, and they can help the utility provide customers with information that the utility knows about the outage and that they are working on it and deliver an accurate estimation of when power will be restored.

The ability of a smart meter to immediately signal an outage at the customer premise, as well as its ability to automatically verify when power is restored, adds an entirely new data stream and source of insight for outage management and restoration efforts. These capabilities, combined with voltage monitoring and the ability of field crews to "ping" meters over the network and from the field, provide utilities with new tools that have enabled a growing number of utilities to transform outage response business processes. This in turn has helped them achieve improvements in outage detection and restoration times, reliability metrics, and create a better customer experience in an inherently adverse situation for the utility.

Although it is still in early days, utilities that have integrated AMI data into their outage management and response efforts are seeing accelerated outage detection times (before customers call); improved prediction of the extent of the outage (i.e., localization); better and more efficient management of field service crews; and a reduction of costly "OK on arrivals," which are costly truck rolls to determine if there really is an outage at a given location. Although less tangible, the greatest value they are seeing may be in improving the customer communication and experience during an outage by making it clear that the utility is aware of the outage and they are working on it.

Once power is restored to the meter, the smart meter sends an immediate positive restoration notification (PRN) signal to the utility to verify that power has been restored to that customer. In many outage scenarios, utilities consider the restoration signals to be of greater value than the outage notifications because they help restoration crews verify that power has been restored to specific areas of the distribution system and individual customers without having to visually inspect each property or premise.

In addition to outage detection and restoration notification, smart meters are capable of measuring and monitoring voltage levels from large numbers of meters and reporting that information to the operator

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in near real time. Smart meters measure voltage very precisely (±0.5%) and this capability provides an additional and valuable data stream to support not only outage management and restoration efforts, but other programs such as volt/VAR (volt-ampere reactive) optimization, conservation voltage reduction (CVR), and revenue protection. In addition, voltage data can be used to identify potential problem areas in the distribution system, which can be addressed and fixed before they become outages or power-quality problems.

1.2 Tamper Detection and Notification

In North America, theft of energy through diversion and meter tampering is estimated to range from 1% to 3% of annual revenues. In some countries around the world, particularly in Latin America and Africa, energy theft reaches as high as 20–30% of energy delivered, which has a significant material impact on the utility's cost structure and finances. Therefore, smart meters provide functionality that helps utilities detect and deter theft of energy. Smart meters can send an immediate signal when the meter is removed from the socket, when it is inverted, or when other forms of tamper take place. This data can then be analyzed in conjunction with consumption and billing data to identify likely cases of energy theft and target field investigation resources accordingly.

1.3 Remote Connect/Disconnect

Smart meters are also typically equipped with an integrated service disconnect/reconnect switch, enabling the utility to disconnect and connect electric service remotely. Disconnect/reconnect commands are initiated through web services from the MDM system, customer information system (CIS), or other utility application. This enables the meter to be switched on or off remotely through the communications network. This functionality has been a huge benefit to utilities in terms of improving operational efficiency, reducing costs, reducing carbon emissions associated with utility vehicle fleets, and improving customer service. This is achieved by eliminating the utility's need to send a vehicle and field service person out to perform beginning- and end-of-service reads and disconnection-associated move-ins and move-outs, and credit/collections activities. Controls are available to require secondary authorization for disconnect and to limit the number of disconnect commands that can be performed in a specified period to ensure security of the system. As an additional safety measure, an optional push button on the front of the meter can be used to require a customer's participation in the event of reconnection. After the utility arms the switch, the customer presses the button to reconnect power.

1.4 Home Area Network Communications

Nearly all smart meters are also equipped with a home area network (HAN) communications card that enables the smart meter to communicate with similarly equipped devices in the home, such as smart thermostats, in-home energy use displays, smart appliances, or load-control devices installed on energy-intensive appliances. This technology can be used to provide real-time energy usage data to the customer, or with prior approval from the customer, provide a means to reduce peak load by cycling off certain appliances or devices during times of high energy demand. At this time, most smart metering systems utilize the ZigBee® communications protocol for in-home communications although other standards such as Wi-Fi can certainly be supported.

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2 Smart Meter Communication

Smart meters, equipped with integrated, low-power radios, are installed on new and existing homes and businesses. The vast majority of smart metering systems in the United States and Canada utilize radio frequency (RF) wireless communications. Smart meters securely transmit encrypted data back and forth to a collection device (collector). These collectors typically reside on existing utility power poles or other available infrastructure and communicate with approximately 1000–2000 meters. The collectors route meter data and messages between the smart meters and the utility.

Working together, the smart meters and collectors form a "mesh" network that is low cost and inherently reliable. If there is an interruption in the communications anywhere along the path, the network intelligently redirects the information to a nearby meter or collector, ensuring that data will be received at the destination. The data is then passed from the collectors to the utility's back office for analysis and billing via a highly secure cellular phone network, utility fiber network, or newer technologies such as WiMAX (worldwide interoperability for microwave access).

With their low-power radios, smart meters are able to communicate metering data using very short and infrequent transmissions throughout a 24-h period. On average, a meter only "speaks" to a collector to transmit its data for <2 min per day, and a collector device typically transmits or receives data for <15 min per day.

Smart meters and the mesh network are at the heart of the smart grid and form the measurement, communication and control foundation for future applications, including electric vehicle (EV) charging, solar resources, energy storage, and community-based generation. Most importantly, customers choosing to take advantage of in-home energy-management tools, such as smart thermostats and in-home displays, can choose to monitor electricity usage and shift how and when they use appliances and heating and cooling systems – often through mobile applications on their smart phone – to conserve energy and save money on their utility bills while also protecting our precious environment.

2.1 *Evolution of Smart Meter Network Architecture and Topology*

There is an ongoing evolution of the utility and smart meter communication networks as the industry addresses the opportunities and challenges associated with the transition to the smart grid. Utility network communication systems must provide the capabilities to collect interval energy usage data, outage and restoration alerts, and tamper alerts and communicate that data to a central system for billing, troubleshooting, outage management, theft detection, and other applications.

In addition, the smart grid use cases of revenue assurance, outage management, integration of distributed generation resources, and consumer engagement require two-way communication flows with increased speed, data throughput, and network reliability. Existing low-bandwidth communications networks with higher latency are quickly evolving into higher bandwidth networks offering lower latency in order to support these emerging and more integrated smart grid use cases.

As we have discussed, the smart meter plays a critical role in smart grid applications as the meter not only delivers detailed energy consumption and energy quality data but also logs events indicating malfunctions, outages, alarms, misconfigurations, and potential physical tampering. These monitoring capabilities, which effectively transform the smart meter into a "grid sensor," coupled with large-scale smart grid data aggregation have the ability to transform utility-business processes, mitigating the problems of energy theft, successfully integrating distributed generation, leveraging analytics, and expanding the network to include distribution automation (DA) for improved energy availability. The result is that global energy generation and delivery systems are transitioning to "smart grid" networks. Information technology is converging with

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operational technology. Key to this transition is full, real-time, two-way communication between many types of grid devices and the utilities' software systems.

There are two main communications network topologies available for these purposes: data concentrator-based networks and data router-based networks. It is important to understand the attributes of these two topologies, with particular focus on the advantages and benefits a data router-based network topology offers compared to the concentrator-based approach.

2.2 Data Concentrator-Based Networks

There are two implementations of the data concentrator topology to consider; the distributed data concentrator model and the centralized data concentrator model. Data concentrators are devices at multiple locations and/or levels in the network infrastructure that aggregate data from groups of meters and send the data to the utility servers. Concentrators typically are responsible for managing meter configuration, programming meters, monitoring meters, and collecting meter data (consumption and event data), and any security information is stored at the concentrator level. There are limited numbers of meters per concentrator based on the physical links between the transformer/concentrator and the meters connected to that transformer. A common example of this network topology is a powerline carrier-based (PLC) network – in which data is transmitted over the utility's power lines – with data concentrators located at each distribution transformer using the G3 or Prime standards as the communications link. Physical polling occurs between the concentrator and the fixed number of meters. The storage and forward data concentrator architecture was designed specifically for one-way communication to the head end, based on the head end initiating a connection request to the data concentrator.

2.3 Distributed Data Concentrator Networks

Distributed data concentrators are commonly deployed for low-bandwidth PLC networks and are also sometimes used for low-power RF mesh networks. The data concentrator collects usage information from the downstream meters and stores that information while waiting for the headend system to collect the data. The distributed data concentrator is an effective model for distributing data collection to endpoints that do not have much bandwidth. However, this approach causes other problems due to the large number of data concentrators that must be deployed and the architectural necessity to separate the meter configuration management function, which takes place at the remote concentrator, from the system head end.

2.4 Data Router-Based Networks

Router-based networks are designed for two-way, high-speed communication between the endpoint and the head end. By removing the storage requirements and forward bottleneck found in concentrator networks, the smart grid router-based network is optimized for

- on-demand meter reading,
- real-time alert reporting,
- remote connect/disconnect,
- communications between distribution automation devices, and
- network connectivity monitoring,
- scalability without an increase in complexity.

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In router-based smart grid networks, the flexibility of today's current enterprise IT data network topology is leveraged to allow smart grid endpoints to establish and utilize multiple paths to the head end. With dynamic routing capabilities, end points form mesh networks that provide multiple links and alternative paths to the head end elements through redundant routers within the mesh network. Router-based communication networks provide near real-time two-way communications that are required by many of the emerging smart gird use cases.

Field area networks (FANs), which is the combination of neighborhood area networks (NANs) and local devices attached to a field area router (FAR) offering the backhaul (wide area network) WAN interface(s), have emerged as a central component and preferred topology of the smart grid network infrastructure. In fact, they can serve as backhaul networks for a variety of grid control devices and sensors, multitenant services (gas and water meters), and data exchanges to HAN devices, all connected through a variety of wireless or wired-line technologies.

This multidevice, multiapplication approach to network architecture has created the need for deploying the Internet protocol (IP), suite of protocols, enabling the use of open standards that provide the reliability, scalability, high security, internetworking, and quality of service (QoS) required to support the fast-growing number of critical applications for the grid brought on by more distributed generation, higher expectations from consumers for reliability, and disruptive technologies such as EVs.

IP also facilitates integration of NANs into end-to-end network architecture. A routed FAN is flexible to support all types of endpoint devices (electric, gas, water, and DA) and facilitates a mix of technologies under a single unified network. A FAN leverages IP technology making this network easy to understand and maintain, and, ultimately, part of the "Internet of things (IoTs)." This type of network is the way of the future due to the real-time nature, end-to-end, or meter to datacenter management and network visibility, while also providing the ability to utilize additional applications and devices across a common network infrastructure.

3 Communication Types

Within each of the typical network topologies, there are two primary NAN technologies utilized to establish the communication links between devices: RF and PLC.

3.1 Powerline Carrier (PLC) Communication

A PLC depends on the utility distribution infrastructure for the communications links between smart meters and other grid devices. The concentrator is typically deployed using the distributed data concentrator network topology. Many utilities have been taking advantage of this technology for years for not only metering but home automation or electrical grids applications, in mostly low data rate implementations. Basic metering applications are usually based on low data rate technologies (few hundreds of kilobits/second max). The communication from the concentrator to the utility head end servers is typically Ethernet, cellular data, or WiMAX (private) networks. PLC is widely used in European and Asian markets and has been used extensively in rural areas in North America.

In a distributed data concentrator network, PLC communications can deliver a bidirectional communication link between the meter and a concentrator, usually located in a transformer. The "PLC-G3" Alliance led by ERDF (French DSO; G3-PLC Alliance, 2015) and "Prime" Alliance led by Iberdrola (Spanish utility; Prime Alliance, 2015) are among the main promoters of this technology.

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The latest standards for PLC networks (IEEE 1901.2) also provide for support of PLC links in IPv6-routed networks. This opens new options for utilizing the power distribution connections for data communications links in data-routed networks. Because of the long range that PLC can travel over power distribution lines (several kilometers), its ability to reach endpoints that are hard to access via RF links (high buildings in large cities or basements), or in low-density environments where RF mesh is not practical or cost effective, PLC is an attractive solution for some utilities.

However, there are inherent limitations of PLC communication links when it comes to traversing the distribution transformers within the power distribution network. The attenuation of PLC signals when attempting to go "through" a transformer currently limits the PLC links to devices that are connected to that specific transformer. Without a means to "bridge" these transformers, PLC links have been mostly limited to distributed data concentrator networks. PLC communications for smart metering are favored by many utilities in Europe.

3.2 Radio Frequency (RF) Communications

RF communication employs radios (utilizing both licensed and unlicensed spectrum) to establish communication links between smart meters and other grid devices over the airwaves. Unlike PLC, the RF links can be utilized in both data concentrator and data-routed network topologies. RF communications play a critical role in the communications systems that we depend on every day, such as police and fire radio systems and pagers, radio and television broadcasts, and cellular telephones.

Many of the conveniences we have grown accustom to in our homes, such as cordless phones and wireless Internet (Wi-Fi), utilize RF. So it makes sense that it has been applied to smart metering and smart grid communications. Smart grid networks are typically operated in frequency bands that are either licensed or more typically, unlicensed. RF communication represents the dominant communications technology for utilities in North America.

Legacy RF smart meter networks typically depended on proprietary network architectures and implementations from the specific meter and network vendors. However, these RF networks have been rapidly evolving to standards-based solutions supporting the IEEE 802.15.4.g/e standard. Along with the move to standards-based physical interfaces, these networks are also moving toward an underlying standards-based IPv6 architecture to open and expand the ecosystem of devices and applications that can run on the network.

The ecosystem of utility capabilities now goes well beyond the initial smart metering and billing functions. Theft detection, outage and restoration notification, and advances to enhance the customers control over their consumption allow utility management and reduction of peak power demands, volt/VAR optimization, and increased proactive maintenance to avoid outages are just some of the applications these data-routed networks support. They also provide a technology platform to support new emerging markets such as Smart Cities and the Internet of things. In other words, standards-based network architecture enables utilities to do many more things than smart metering with the network infrastructure while minimizing the risk of stranded assets and technological obsolescence of the network.

In terms of performance, the RF links between devices can be established at distances that can vary from several feet/meters to several miles. These links can range from individual meters creating a mesh of RF links to tower-based solutions with links to several thousand meters and grid devices.

With this wide range and flexibility in link distance, RF communications lend itself to both centralized data concentrator (tower based) networks and data-routed networks (mesh based). In the mesh-based RF networks, data routers are deployed as "take out" points within the mesh or in a cluster of meshed meters or end points. Like the data concentrators, these data routers typically implement backhaul communications to the utility head end servers over Ethernet, cellular data, or WiMAX (private) networks.

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3.3 Future of Data-Routed Networks

As highlighted earlier, data-routed networks, along with the latest standards for IPv6 RF (IEEE 802.15.4g/e) and PLC (IEEE 1901.2), open the possibility of combining the best of each of the physical link technologies with the flexibility of data-routed networks to deliver the "Best of Both Worlds" and eliminate any compromises inherent in the choice of single-communications network technologies.

The needs of the utility industry are converging to necessitate a reliable, interoperable, flexible, and high-performance field communications network to support both the smart metering use cases developed over the past 10 years and the emerging smart grid applications. Utilities are realizing that the implementation of one network to support basic metering applications and yet another network (or more) to support evolving smart grid use cases (such as DA) is not an economically viable approach for the utility, regulators, and consumers.

This need is driving development of a new generation of communications capabilities that support multipurpose network technology. The technology can now be implemented to first enable smart metering applications, while retaining sufficient performance and architectural attributes to support a wide range of smart grid solutions, both now and in the future. The flexibility provided by the data-routed FAN network is much better suited to supporting these new requirements. Limitations of the data concentrator-based networks, such as the lack of concentrator failover, lack of support for IPv6, and secure multiapplication traffic routing, limit the utility to a network that is lower on initial cost but short on long-term benefits, high on technology risk, and burdened with additional future expenditures (integration of additional devices and applications) for a higher total cost of ownership.

Low-cost networks focused on basic metering, such as the current generation of data concentrator-based networks, will require additional overlay networks to deliver on the longer term capabilities of the utility. This results in a short-term savings but higher overall ownership costs in the long term. When both the near-term and long-term challenges that utilities face are fully considered, the flexibility of the data-routed network can deliver on these needs while providing acceptable investment protection and risk mitigation.

Data-routed FAN networks now set the standard for network performance, flexibility, security, and cost-effective solution delivery. This results in lower overall costs with a single network to deliver on all of the utility's needs today and into the future.

4 Security Challenges and Solutions

The smart grid, including smart metering technology, is a complex system of systems that requires multiple layers of security controls to protect its mission of reliable energy distribution. These security controls are very diverse, ranging from physical fences and security cameras to encryption algorithms and digital certificates. Adding to this complexity is the fact that the smart grid will be comprised of both new and legacy technologies, so determining the specific security controls required – and where to place those controls – is a challenging task. Further complicating the security landscape is the changing nature of information flow throughout a smart grid network and new uses/users for that information.

Utilities that use security monitoring and management can identify, manage, and counter information security threats and maintain compliance through ongoing monitoring of cyber events. Today's leading smart metering systems are designed with tightly integrated and multilayered robust security to ensure the integrity and safety of the system. These security features meet or exceed current requirements for critical cyber assets, protecting all areas of the system, and scale to support millions of metering end devices. Among many other security features, the robust security of the systems also allows utilities to ensure the privacy of their customer's information.

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4.1 Multilayered Security Approach

Effective security is security deployed in layers. For smart metering networks, enhanced security offers command authorization and traffic encryption at the application layer. Commands are digitally signed and encrypted before being sent to the meter endpoints. Application security at the meter will only act on an authorized command sent from the head end. In addition to application layer security, state-of-the-art systems provide additional layers of security at the network level. Here, device authentication is provided to join the network, allowing full encryption across the RF mesh network (which includes everything operating at the radio packet interface), access control lists on the router controlling access to the device, and full WAN encryption including hiding the routers' IP address.

Combining application layer with network layer security provides the strongest smart metering security position to utilities and end users. Designed to meet the requirements of next-generation multiservice energy networks, security solutions take advantage of an extensive portfolio of cybersecurity and physical security products, technologies, services, and partners to help utility companies reduce operating costs while delivering improved cybersecurity and physical security for critical energy infrastructures.

In the smart meter collection engine, standard web services security is used to protect the interface to the MDM system and other head end applications. The collection engine does not store customer meter data; that information is passed to the MDM, which is always located in the secure data center. By combining network layer security with application security, only devices authorized on the network can even begin the process of registering with the smart meter collection engine head end. The secure network can provide network access control for authorized devices and payload protection for older supervisory control and data acquisition (SCADA) protocols. Protocols with application layer security controls incorporated in the smart grid network add another level of control by hiding the network addresses, authenticating the devices and interfaces allowed to use the network, monitoring traffic flow, and providing class-of-service metrics for priority traffic. Keeping unauthorized devices and users off the smart grid network is a security control that is critical to the safe and reliable distribution of electricity.

4.2 A Strong Security Foundation

The smart meter collection engine enables strong authentication and enhanced security for use in AMI deployments. System software for smart meters should be fully compliant with security and encryption to meet industry and ANSI C12.22 standards. Using elliptic curve cryptography (ECC), leading manufacturers are utilizing meter communication digital signatures and key management appliances in their systems to secure end-to-end messages from the collection engine all the way down to the smart meter in a true end-to-end security solution.

Because network encryption ends at the edge of the network, leading smart meter providers are also using advanced encryption standard (AES) symmetric key encryption at the application security layer to provide confidentiality from the control server to the end device processor. With the combination of digital signatures and symmetric key encryption, the application layer provides authorized and authenticated command protection from the originating server to the endpoint receiving the command, which is the essence of end-to-end application security.

Distributing safe, efficient, and reliable electricity is the primary mission of the smart grid and security must support that mission by preventing service disruptions. Smart meter security controls support that mission by providing defense in-depth, network layer security, application layer security, and physical security. The security architecture inherent to these new-generation systems and the network layer security inherent to the IP router-based network architecture are designed to meet the two-way command and control needs for

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AMI and other smart grid use cases. Together they provide the strongest integrity of control, nonrepudiation, availability, and confidentiality of any solution offered today.

The security controls to read usage data from a meter could be completely different from the security controls required for operating DA equipment such as a recloser, essentially a circuit breaker equipped with a mechanism that can automatically close the breaker after it has been opened due to a fault or a voltage controller. The security controls for a multiservice, utility-wide shared infrastructure will be different from the security controls required for siloed network infrastructures. Having the flexibility to implement security layer by layer, from the network connection all the way to the application protocol, allows the security planner maximum control and flexibility to assure the safe and reliable distribution of energy.

5 Managing all that Data

As utilities consider the various benefits of smart meters or AMI, it is critical that they also consider the transformational impact of this new technology on current business processes and IT infrastructure. The drivers for a utility to adopt smart metering technology, with its ability to collect interval data for all customers and two-way communications to a metering device in the home, are many. In many areas, such as California, Texas, and Ontario, capacity constraints and peak demand are driving time-of-use (TOU) pricing and load control at the residential level.

In other areas, the Energy Policy Act of 2005, environmental concerns, and conservation are driving the consideration of AMI projects. In New York, the “Reforming the Energy Vision” (New York State, 2015) initiative is reshaping the electricity market and how it functions. Still other areas, such as Texas, are looking to AMI for improving their infrastructure management and distribution system reliability. Diverse business drivers and potential benefits aside, utilities face common challenges when considering the rollout of a smart metering system:

- New AMI systems must interface with existing utility systems, including legacy CIS and other back office applications.
- New AMI systems must peacefully coexist with multiple meter data collection technologies with diverse reading requirements.
- AMI systems produce high volumes of data for both billing and analytic purposes.
- AMI systems require interfaces so that existing systems may participate in two-way communications with smart meters; with many utilities already struggling with CIS systems that run from one software patch to the next, utilities must look closely at how AMI will impact this critical utility system.

5.1 Meter Data Management

MDM bridges the critical gap between new cutting-edge smart metering systems and existing utility CIS and other legacy systems, thus delivering the full value of AMI during and after implementation. Introducing new systems into the patchwork of hardware and software that comprises a utility’s IT infrastructure is replete with technological and business process challenges. In particular, two types of large system rollouts present utilities with critical challenges.

5.2 Smart Metering Rollout with Legacy CIS

This is by far the most common situation that will present itself to utilities moving forward with smart metering in the next 5–10 years. Most utilities that decide to implement smart metering will do so within their

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current business process environment. In most cases, this means that AMI technology must be integrated with an existing CIS system that has a relatively simple relationship to the utility's various meter data collection systems. Whether gathering data by handheld computer or mobile data collection, AMR (automatic meter reading) or non-AMR, the majority of CIS systems are only processing monthly consumption reads from residential customer accounts.

The primary focus of the CIS is customer billing, not the collection and long-term storage of raw usage, tamper, leak, or outage information. Even in a phased deployment, AMI introduces a huge amount of data into the billing process. A modest population of 1000 smart meters reading at hourly intervals to support TOU billing will produce 26,000 readings each day, or almost 10 million readings each year. Many existing CIS systems cannot handle the scale of the incoming data, let alone the interface to some of AMI's key functionality, such as remote connect/disconnect and off-cycle reads. Implementing an MDM solution allows the CIS to keeps its focus on billing and at the same time, utilities can maintain a scalable and flexible IT environment through the AMI rollout.

While it may be ideal, it is unrealistic to assume that utilities can undertake a CIS upgrade at the same time they are deploying an AMI metering system, which will realistically take 2–4 years. An MDM system provides accurate and reliable data warehousing of all utility meter data, regardless of source or account type, and deliver that data in the "bill-ready" format needed to the CIS. Utilities can use an MDM system to off-load processes and functions in parallel with the billing system to achieve needed performance and accelerate time to value. When deployed along with AMI, utilities can insulate their CIS from change, reducing risks to existing CIS processes while getting the full value from each AMI meter as it is deployed.

5.3 New CIS with Existing AMR/AMI

A new CIS implementation is a high-profile utility project that is inherently complex and expensive. Many utilities have no option but to unplug the cash register to perform the switchover, which can result in deferred or backlogged revenue. An MDM system can be used to streamline communications among data collection technologies and operational systems that use the data, reducing the number of interfaces that must be re-built in a new CIS implementation project. In addition to saving time and resources during a CIS implementation, an MDM system allows the utility to perform a phased rollout of a new CIS system, versus the risky "big-bang" approach. Under this scenario, the MDM solution manages the data collection process and the meter data is securely stored and then delivered, exactly as needed, to the appropriate CIS until all meters are transitioned to the new CIS.

Regardless of the CIS challenge facing today's utility, MDM is key to connecting critical utility systems effectively and securely, and to harvesting value from all that new data. MDM is an enterprise-wide solution designed to store meter data and provide isolation of business processes and business systems from the details of metering and meter data collection in a multivendor, multitechnology environment. The MDM's comprehensive capabilities allow for the application of consistent processes and the maintenance of consistent interfaces independent of how, when, or where various meter reading technologies, including AMI, are deployed. This simplifies and significantly reduces the likelihood of errors in utility-business processes that utilize meter data. It also allows the most cost-effective AMR and AMI technologies to be deployed, without affecting upstream billing processes.

MDM also provides long-term storage of register, interval, tamper, and outage and meter event data in a fully versioned database. Typically, a utility can choose between a Microsoft SQL Server and Oracle relational database architecture to provide a central repository for integration, access by all business and analytical systems, and users of meter data throughout the utility. Additional functionality includes extensive validation, estimation, and editing (VEE) capabilities; advanced TOU, aggregation and calculation services;

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request brokering among multiple meter data collection systems (legacy and AMR systems); sophisticated export management capabilities; and auditable change tracking.

5.4 Synchronizing Master Data

To effectively manage the diverse metering information in an AMI system, the utility must assume a "system of record" for each type of data and a "requestor" for each data transaction or command request. Controlling who owns and who is accountable for what kind of data is critical for managing the large amounts of incoming data, new commands and requests. Each system of record (AMI, MDM, or CIS) owns master configuration data relevant to its functional role in the system. To eliminate unnecessary data redundancy and processing, MDM uses a simple integration point to tie the data together. Representing a unique point of service delivery at a specific location, the "service point" is the main link between the MDM and the CIS.

Depending on utility needs, the master data can be synchronized based on specific events or batched daily. Because legacy CIS systems have limited objects and integration methods, utilities often use enterprise application integration (EAI) tools to synchronize among systems. At a minimum, the following transactions should be synchronized between the CIS and MDM to provide for accurate billing determinant calculations and operational reporting:

- Meter or endpoint exchange
- Rate/billing determinant change (reprogram)
- Meter status change (disconnect/connect)

5.5 Delivering Bill-Ready Meter Data

With the above architecture, MDM manages interaction among data collection technologies and provides information to billing systems upon request. The CIS initiates requests for revenue-relevant data based on specific on-cycle or off-cycle business processes. The MDM is responsible for interpreting the CIS request, forwarding it to the appropriate collection system if necessary, and formatting the response back to the CIS. To deliver bill-ready data to the CIS, MDM normalizes the raw endpoint/meter data from the smart metering system into billing determinants and delivers service point-level billable values to the CIS. Balancing routes and billing cycles has been the traditional CIS mechanism for timely billing.

By owning the meter reading routes as well as the billing cycles, the CIS manages the cash flow of the utility, determining when and how meter readings were converted into billing information. In a smart metering technology environment, routes are less relevant to data collection as the meters do not need to be organized based on the location of the meter itself and billing cycles trigger processing. MDM provides the collection point for metering data from across multiple time horizons and collection technologies, allowing the CIS to continue owning cycles, regardless of routes, and trigger both on-cycle and off-cycle activities. With this approach, the CIS treats the MDM as a service – requesting and receiving data from the repository as needed to complete on-cycle, off-cycle, and customer service inquiries.

5.6 Issuing Commands to the AMI System

In the same way that it brokers meter reading requests, MDM may also broker two-way commands for power verification, remote disconnect/connect, and meter reprogramming. In this scenario, the CIS issues control commands and MDM leverages its service-oriented architecture (SOA) to format ad hoc requests

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for data or control. As the industry adopts standards to manage these complex systems, MDM technology helps streamline utility adoption of new technologies for home gateway and two-way control functions.

Although many standards organizations are working diligently to define a standard integration across the AMI-to-CIS boundary, the reality is that many utilities require integration of multiple collection technologies from multiple vendors with existing legacy systems. Not all technologies behave the same; MDM can manage the varying capabilities of the collection technologies as well as the multiple choices that arise during an AMI rollout. While each utility will have varying business drivers for rolling out an AMI system, they will all share the need to maximize the return on their investment as quickly as possible. MDM is a critical component that enables utilities with legacy CIS and multiple meter data collection technologies to bridge the technology gap between old and new technologies to deliver better customer service and optimize revenues with each new smart meter deployed.

6 Key Meter Data-Management System Features

As discussed in the previous section, the industry move toward smart metering has firmly established MDM as a critical component to realizing the full value of AMI, especially when implemented before a large-scale residential AMI rollout. Many large investor-owned utilities advocate that with the proper architecture in place, AMI will have an immediate impact on their company's business processes.

The MDM system eases IT integration of AMI and facilitates the distribution of the meter data across the utility enterprise by framing the volumes of interval data retrieved from the field into manageable and familiar information. In addition, by consolidating reading data from multiple collection systems into one MDM, utilities can set consistent validation routines to truly evaluate the performance of their AMI systems. The definition of a MDM solution can vary widely. At a minimum, MDM provides a database repository and utility-specific business logic to

- automate and streamline the complex process of collecting meter data from multiple meter data collection technologies and customer segments;
- evaluate the quality of that data and generate estimates where errors and gaps exist; and
- deliver that data in the appropriate format to utility billing systems and other data subscribers.

The critical role of an MDM system is to preprocess high-resolution interval meter data at large volumes very quickly. In the past, only commercial and industrial (C&I) meters collected interval data, while no specialized systems were required to collect, store, and compute bills. However, with the onset of smart metering, the entire meter population is now bringing back this data in much greater volume. Not only is there more data, but the data is more complex. The CIS will still be responsible for the commercial processing of this data, but an MDM system must aggregate and preprocess this interval data as specialized C&I data-management systems have done in the past, albeit for a small number of customers.

The sheer volume of meter data from large-scale smart meter systems requires consistent, corporate-wide "best practice" rules for managing the increased potential for data error and confusion. As smart meters are deployed, the MDM must also handle the storage and distribution of nonbilling data and messaging such as two-way commands, outage alarms, tamper alarms, and demand-response (DR) events. As the utility industry evolves, an MDM solution must also have the ability to facilitate change within the IT department by isolating changing collection and back office solutions and practices.

Most MDM systems today claim to integrate multiple collection systems, calculate billing determinates, and do some level of VEE of meter data. However, when utility business and IT departments embark on the purchase and implementation of an MDM solution, it is critical to understand the key features and true

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system capabilities that distinguish each and to understand whether those features can perform at AMI scales.

6.1 Collection System Integration

Utilities are investing in solutions that often include multiple meter reading systems that supply meter data through a complex set of interfaces to one or more utility billing systems. Different read rates and multiple smart meter network choices and legacy meter reading systems are just a few of the challenges of daily utility life that can humble even the best utility CIS. An MDM solution that can effectively broker read requests and responses between the billing system and each meter reading system not only ensures timely reads to the CIS but also can

- simplify future integration of new AMI technologies,
- enable ad hoc, off-cycle read requests by the CIS,
- manage collection of meter readings and facilitate two-way requests from multiple technologies for the same meter,
- simplify integration of new meter reading and billing system technologies acquired through merger and acquisition,
- validate, edit, and store C&I readings along with mass market residential readings,
- allow utilities to migrate from AMR to AMI over time,
- enable the piloting and deployment of multiple AMI technologies.

Request and response brokering allow a billing system to request and receive aggregated billing determinants and meter reads in its existing mode of operation, as if a single meter reading system were deployed even though multiple technologies may be in use. The MDM maintains the necessary information about the collection system used to obtain readings from each meter in order to interact with each one appropriately. When a reading window opens, the MDM can bundle readings from multiple reading systems into a single, integrated response to the billing system. Effective collection system integration allows merged utilities to adopt new technologies and unify billing processes without having to completely re-engineer existing meter reading processes or extensively modify the chosen billing system or billing processes. All meter reading processes can follow the same automated, consistent path to billing. This also simplifies the selective deployment of new meter reading technologies, once again without modifying the existing billing processes or systems.

Because meter reading systems can vary widely in read frequency and overlap in geographic area, request and response brokering functionality should also include user-definable logic for processing "questionable" reads, where data appears to be inaccurate. The MDM should enable users to define "best read" logic for using multiple and overlapping readings within the same request window. If valid readings cannot be obtained within the reading window, the MDM can derive an acceptable reading or initiate a new read request using a variety of business rules. With these capabilities, MDM can be configured to calculate an estimated read, include an invalid reading flagged with an invalid indicator, or invoke an automated gap fill process to re-request readings from the appropriate collection engine.

6.2 Interval Data Management

With smart metering technology, utilities have a new challenge – and opportunity – to manage interval data across the entire meter population. In contrast to monthly consumption meter reads, *interval data* refers

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to consumption data measured and recorded by smart meters at more frequent intervals, such as once per hour or every 15 min. AMI brings the need to provide what was once considered complex billing for C&I customers to the residential mass market. Utilities are well accustomed to the fact that some percentage of C&I interval data will be missing, redundant, or incorrect. Interval data collected from residential meters provides no exception to this rule. Data VEE is a process that identifies problematic data that comes from meter data collection systems before it reaches other utility systems and provides tools for addressing quality issues according to a utility's specific best practice rules and meter-specific parameters.

Each utility is unique. Having the flexibility to handle data anomalies such as gaps, overlaps, and redundancies, as well as tolerance issues between consumption reads and interval data with a reliable, auditable process is a critical MDM feature. MDM should provide utilities with the ability to specify validation logic via an integrated calculation engine. When validation fails, the MDM system can be configured to execute contingencies, such as automatically estimating the read or passing a "no-read" to produce a failed validation report.

VEE capabilities are critical to ensuring a utility's business and regulatory process needs are met with a successful MDM deployment. Effective VEE should provide utilities with the ability to create a host of standard parameter-based and user-defined algorithms, with full transparency and reporting on the development of those algorithms. MDM vendors can vary widely on their VEE capabilities.

With regard to billing, utilities have traditionally relied on external spreadsheets for the complex calculations required to convert interval data into large C&I energy charges. TOU and critical peak pricing (CPP) programs, for example, require unit conversions, complex load calculations, and aggregations. While the pool of customers that have traditionally been billed in this manner have been comparatively small, many utilities are now looking at interval data, time-, and price-sensitive rate structures for residential and small C&I customers to better influence consumption patterns and manage changing energy markets.

MDM solutions that provide an integrated calculation engine enable utilities to do away with hard-to-maintain spreadsheets and manual, error-prone methods for producing billing determinants. A calculation engine should support all of the common mathematical operators and functions and conditional and logical functions, ideally in a simple, intuitive spreadsheet interface. Examples include the following:

- Common operators: +, −, ×, /, square root, square, sine, cosine, and so on.
- Condition/logical functions: if, and, or, not, >, =, and so on.
- Time and date functions: max, min, avg, total, and so on.
- Unit conversions: kWh/kVARh to kVAh, power factor/V2H to V, and so on.

This broad functionality enables users to calculate nearly any complex load, loss, or aggregation for billing applications, as well as calculations for other utility processes, such as the estimation in VEE. Within the context of an MDM solution, billing determinants can be calculated and delivered automatically upon the request of the billing system with no manual interventions. A calculation engine simplifies updating and maintaining calculations. Versioning tracks the changes. Standard MDM interfaces make new and edited calculations immediately available for all utility applications. This puts an end to three problems utilities have had for years:

- Replaces manual data import and export processes with automated processes that are secure and auditable.
- Provides a single calculation for use by all utility systems. No longer does the same load data generate slightly different values depending on which utility spreadsheet was used.
- Provides scenario planning to run "what if" scenarios for different rate types across different customer classes or other strata.

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6.3 Versioned Data Storage

Understanding what load data was "the best available" at a point in time is a critical MDM capability. MDM load data versioning maintains snapshots of each meter read associated with a time reference, making it much easier to resolve billing and settlement questions and disputes. Versioned data are also critical to maintaining data integrity as that data is shared across multiple utility systems (DR, load research, forecasting, distribution-asset analysis, etc.). As this single source of data becomes a central resource to multiple utility systems, the ability to reproduce a data set as it would have appeared at a particular date and time becomes vital. In some jurisdictions, it is a requirement to be able to reproduce versions of data that were sent at various stages for market settlement. New accounting standards and regulations, such as the Sarbanes-Oxley Act, make auditors much less forgiving of undocumented data changes.

MDM solutions with versioned data storage should provide log records indicating which user or VEE process made changes to the data. For example, if a reading changes five times, the MDM creates five versions of that reading, each of which also has a reference time period, indicating when it was the current version.

6.4 Two-Way Communications between AMI and CIS

With two-way communication to the smart meter, utilities can perform on-request reads to help settle customer bill disputes. With a customer on the phone, customer service representatives can request the most recent meter read for accurate and timely information relative to the disputed bill. Two-way communications allow interval meter data to be requested to fill gaps in information that may not have made it to the collection engine database.

Two-way communication also opens the door for ping commands, load-side voltage checks to determine customer-side breaker issues, and remote connect and disconnect. In addition, MDM can help initiate these events and broker the request back to CIS or other systems. Further, there are advanced capabilities yet to be considered. This value-added potential offers promise given the capabilities of AMI systems and future demands for more near-real time availability of data.

7 Platform to Enable Other AMI Applications

Consideration should also be made for other applications that can easily leverage the same software platform without a lot of custom design. Other applications that leverage the MDM database platform should be available either by add-on modules or integrated as part of an enterprise MDM approach. Some common AMI applications include the following.

7.1 Revenue Protection and Theft Analysis

In terms of suspected theft, the importance of meter usage data cannot be overlooked. Utilizing consumption data, along with smart meter-tamper data, helps to better create suspect lists for energy theft. An MDM solution offers the infrastructure and analysis capabilities to analyze this information, native within the MDM or as part of an add-on application or module. Combining this added functionality with today's smart metering systems reduces a utility's workforce in the field, as well as transportation and gasoline costs, and carbon emissions. In turn, the MDM and its more robust data analysis can be used to offset the loss of a monthly presence in the field.

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7.2 End Customer Usage Analysis and Data Presentment

MDM systems enable utility customers to have more information about their energy use and, therefore, more control over it. The MDM solution is a key enabler for allowing the presentment of information back to end consumers. When considering an MDM system, keep in mind that it should provide additional applications or open application program interface (API) standards to integrate into customer service systems so the utility has the flexibility to ensure its consumers and customer service representatives have the tools they need.

7.3 Load Curtailment and Demand Response

An MDM system stores information and makes it available to dramatically improve the extent of load curtailment and DR by

- offering load studies across broader customer sets,
- providing the tools necessary to determine the most appropriate rate-based DR programs,
- producing applications to administer C&I load curtailment programs,
- presenting applications to manage rate-based residential DR programs via dynamic rates.

High-resolution data from smart meters is emerging as one of the utility's greatest business assets. As utilities adopt both smart metering and MDM technologies to manage their ever-increasing meter data, the industry is witnessing the revolutionary impact MDM and AMI can have on operational efficiencies, customer service, energy forecasting, distribution system reliability, regulatory compliance, and more. In addition to the smart metering network itself, an MDM solution is not only important to achieve a reasonable return on these investments, but critical for achieving the transformational changes that can position utilities for success in an ever-changing business landscape.

8 Putting Smart Meters and the Data to Work

8.1 Managing Peak Demand

In the past few years, DR programs have garnered renewed interest and attention. They are hailed as a significant benefit, even a "killer app" for smart meters and a method for end-use consumers to engage in managing their energy usage, environmental impact, and costs. The emergence of new cost-effective technologies appears to make the process of responding to high-priced or emergency periods easy and therefore palatable to most consumers. However, while the opportunities are great, challenges still remain to fully realize the potential benefits. Those challenges exist across the full landscape of this promising field and those who have spent years developing programs and analyzing the benefits of those programs are now faced with a new paradigm – DR for all.

The Federal Energy Regulatory Commission (FERC) reports that the United States' full-participation DR potential is 20% of grid peak demand or around 188 GW by the year 2019, Federal Energy Regulatory Commission, 2009. In addition, while the full-participation model is the best-case scenario, the achievable-participation model also shows significant reduction potential, roughly 10% above the business-as-usual model where DR adoption continues on its current path, achieving 138 GW reduction. In other words, when compared to the costs and environmental impacts of new-generation and/or transmission resources, the demand reduction potential is significant and worth investment in technologies to enable its broad application.

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Both dynamic pricing and DR programs promise significant benefits for consumers and utilities. Some utilities state that these programs are nearly 40% of the business case supporting the cost of smart metering along with labor savings, call center cost reductions, reduced theft, and increased customer satisfaction. In addition, small demand reductions during peak hours have repeatedly resulted in significant price reductions, suggesting that participation in DR programs by even a portion of an enrolled population can benefit all ratepayers. In addition to those benefits, DR programs promise to assist in overall grid management. The department of energy (DOE) reports that "10% of all generation assets and 25% of distribution infrastructure are required <400 h per year, roughly 5% of the time." Implementation of large-scale demand-response programs can assist in the management of that peak condition and limit the need for additional construction of peaking power plants.

8.2 Demand Response and Dynamic Pricing

The terms *DR* and *dynamic pricing* are sometimes used interchangeably, but the concepts are related yet different. DR is a distinct reduction in energy usage for a defined and typically short period of time and can be achieved in a wide variety of ways, but typically involves a conscious choice by the consumer. *Dynamic pricing* refers to the rules under which an end-use customer is charged for their energy usage. In some jurisdictions, introducing dynamic pricing tariffs, such as CPP rates, to mass market customers is considered a key benefit of smart metering. However, this idea is not without controversy, as some stakeholders claim that time and event-based rates place some ratepayers, such as low-income customers or retirees, at a disadvantage. When a program is defined, the two concepts of DR and dynamic pricing merge. The common mass market dynamic pricing, DR programs currently being implemented are CPP and peak-time rebate (PTR) or critical peak rebate (CPR). These programs combine a more targeted approach to peak load reduction with financial incentives and/or increased charges and their successful implementation is critical to the realization of the promised benefits.

8.3 Demand Response Components

On the surface, DR is a simple concept; during a period of high usage, causing system constraints and/or high energy prices, end users reduce their usage and are rewarded for that reduction with an incentive payment/rebate or some other form of financial compensation. The reality of DR is more complex, involving program design, generation of baseline usage profiles, billing and compensation rules and management or regulatory decisions, application of complex billing determinants, technology implementations from smart meters to analytic solutions, and customer engagement efforts from basic energy education to community awareness campaigns and competitions. Each component within the DR universe presents its own challenges, but addressed together, there is promise for successful programs benefiting utilities and end-use customers alike.

8.4 Design

The design of a DR program or a dynamic pricing rate is critical to its adoption and success at achieving demand reduction. Because success is entirely dependent on the response of end-users, resulting in a change of normal behavior, customer perception and understanding must be a primary goal in any design.

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While simplicity is key to success with customers and technical implementation, end-user perception does not always lead to the most straightforward program. For example, pay-for-performance programs such as PTR are designed to offer an incentive to those who reduce their usage during event periods and refrain from imposing higher prices that may be perceived as a penalty. Logically, this makes sense and feels friendly, but it introduces the concept of predicting the energy that each end-user would have used during the event period had the event not occurred. This is called a *baseline* and is required to calculate the customer incentive payment. That predictive model can be the source of many long hours of discussion, implementation, and customer education. Most current billing systems are not capable of calculating such baselines. Therefore, this task is performed by an MDM solution. At high volumes, baseline calculation requires significant processing resources that cannot compete with loading of meter reading data and calculation of billing components. Getting the baseline right can be a challenge and poses risks to utility call center operations.

8.5 Forecasting

Effective management of a DR program requires accurate forecasting. Unless the load reduction is predictable and repeatable, it cannot be used as an energy procurement or grid management tool. Historic event performance, customer behavior, event deployment strategies, direct load-control technology, weather, and much more factor into an effective forecasting model. Fortunately, existing load forecasting methods are well-established and have been proven to be highly accurate. Existing models with modifications for broad spectrum DR programs can be just as effective.

8.6 Execution

Execution of DR events is a multistep process dependent on successful communication, operational and responsive control systems and hardware, willing participation, and accurate measurement and verification. Both manual and automated responses require notification. Manual customer response can be effective but is less predictable. Success depends on received communication and action taken by an end-user who may be otherwise occupied, unaware of possible load reduction strategies, or simply uninterested. Technology-enabled automated response, using direct load-control technologies, such as programmable communicating thermostats, are more expensive, require installation and maintenance and functioning communication channels, but achieve greater and more predictable load reductions. All reductions must be accurately measured along with mid-event changes such as system overrides or opt-outs.

8.7 Settlement

Settlement of DR programs can take many forms, from those used by ISO/transmission-level capacity markets to individual charges and credits on an end-use customer's utility bill. All settlement types require accurate metering data and the implementation of standard program rules. As smart meters are installed at millions of end-use customers' homes, enabling dynamic pricing, DR and usage visibility, utility MDM, and billing systems must be prepared to support the new options while continuing to meet existing operational requirements. Above all, settlement calculations must be understood by the end-use customer as part of a timely feedback loop, enabling reliable participation in events and minimizing the use of customer service resources.

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8.8 Evaluation

Evaluation of program performance brings the process to a full circle as it is an opportunity to modify program design, forecasting methods, communication, and execution strategies and identify required technology improvements. It marries disparate data to illustrate what may not otherwise be visible.

8.9 Empowerment

Empowering end-use customers to understand and manage their energy use is key to the success of DR and the only way to realize the many of the energy efficiency and peak load management benefits envisioned in the business case. Therefore, all components of DR programs must have customer empowerment as the primary guideline. In addition, empowerment is achieved through communication. Successful programs will offer multichannel communications, as different customer segments prefer different notification, education, and engagement methods. Websites are effective for presenting energy usage and detailed cost analytics. Text messages can be used for brief notifications and alerts. Emails can do the same along with deliver more detailed reports and educational materials. In-home displays can be an effective medium for real-time usage information and can serve as a visual reminder for consumption awareness. Traditional paper bills and even online bill presentment offer opportunities to educate and inform. In addition, the increasing penetration of smart phone use offers a powerful touch point with almost all customer segments via mobile apps.

The challenges of a successful DR program are varied, numerous, and continue to change as the DR landscape shifts and develops. The rate at which the DR landscape is changing is likely the greatest challenge to utilities struggling to gain a foothold or even to those leading the way. However, a change in landscape is paramount to actualization, for there are still many barriers to success. A few of the challenges are listed in the following sections.

9 Dealing with the Data Explosion

With the growth of the smart grid and the proliferation of smart meters come increased challenges presented by networks, especially in the rise of large amounts of new data streams to distribution network operators (DNOs). Ensuring these data management and communication challenges are overcome requires innovation and a new brand of resourcefulness throughout North America and across the globe that spans technology, people, resources, business models, and organizational culture. However, from there, the commonalities among regions and utilities begin to dissipate, and strategies for deploying smart metering and smart grid technologies to address a broad array of strategic and operational objectives vary significantly from region to region, even within North America.

Utilities and DNOs in various regions face their own mix of broad, common challenges, such as the need to increase energy efficiency and manage peak load through DR and other customer engagement programs. However, they also face specific business problems, such as reducing losses due to theft, ensuring reliability with aging infrastructure, and providing good customer service.

Smart metering technology provides more than just the metering assets to measure energy consumption. The utility's role has evolved into a solution provider, and consultant for communications, data collection and management, and service provision among others. Generating copious amounts of data on energy consumption and network performance is of no use unless this data can be transmitted securely to those who can make sense of it and generate new business value. Integrated and interoperable systems are key in making sure this happens and smart technology providers play a leading role in the design and execution of data transmission.

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The ultimate goal of the smart grid is to improve the management and delivery of energy in a more effective and efficient way. Operational and predictive analytics are key to achieving that goal, and utilizing analytic software applications to create business value from the data smart meters provide is a key focus for both utilities and technology providers in the market.

Analytics supports the complete data intelligence lifecycle and helps utilities reach a state where predictive analytics enable more proactive management strategies and optimization. Through a combination of both software and services such as energy diversion detection, forecasting, power quality, transformer load management, energy efficiency and DR, financial analytics, and end-user analysis, utilities are given the tools to gain valuable insight into their operations. In addition, the combination of smart meters, the data they generate, and the insight and business intelligence produced by analytics will be critical to successfully managing the new use cases brought on by new smart grid technology.

9.1 Distributed Generation

Distributed energy resources, especially customer-owned photovoltaic (PV) solar, are taking off. According to GTM Research, it took the industry four decades to reach 100 GW of cumulative capacity globally. In 2020, the world will see more than that installed in a single year.

Solar energy clearly brings benefits to consumers and the environment, but it also presents technical and economic challenges for the utilities industry. Distributed solar assets create new business process challenges around billing as well as power-quality and potential safety issues that the utility must manage. In addition, as more people generate more of their own electricity, their share of funding the distribution system declines under the current business model and regulatory structure.

The advanced monitoring, communication, and control capabilities of smart meters and other sensing devices will be critical for the successful integration and management of these resources, no matter how the utility-business model shifts. The ability to measure power flow in both directions, control inverters intelligently, monitor voltage levels in real time, and quickly summon additional resources, including DR, load control, and energy storage, will be key to maintaining grid stability and integrating these distributed resources. Smart meters and their associated communication networks will play a key role in managing this challenge.

9.2 Renewable Energy

Setting aside the significant economic questions around cost and grid parity for the moment, renewable resources, both wind and solar at the wholesale level and rooftop solar at the residential level, are making significant inroads. Utilities in southern California and the Southwest United States are successfully managing hundreds of thousands of customer-owned solar installations and connections, and the rate of adoption is accelerating.

They are doing so by leveraging smart meters as well as grid sensing and DA with no appreciable disruption or degradation of utility service to this point. However, there is no doubt that as that trend continues – and as distributed and intermittent resources make up a greater share of the resource load – smart grid technology will be key to ensuring the reliability, efficiency, and flexibility of the grid. In addition, monitoring and management of solar assets is a growing business opportunity for smart grid technology companies, whether for third-party- or utility-owned solar installations.

With increasing consumer adoption of renewable energy and EVs, smart meter deployments also require the deployment of multiapplication networks that support additional applications and devices beyond just

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smart metering, including DA, DR, and integration of EV and renewables. Utilities must closely integrate smart metering technology with other grid technologies to manage peak load, mitigate the intermittency of renewables to stabilize the grid, and manage the potential disruptive effects of EVs on the local distribution system.

Moreover, the untapped potential of consumer engagement will play an increasingly important role in addressing the challenges of increased generation from intermittent power sources by providing reliable and dispatchable DR resources and load-control capability. Smart systems are critical for utilities to manage a diversifying portfolio of energy resources when consumer expectations for reliability and value are higher than ever.

9.3 Distribution Automation

As utilities look for cost-effective solutions to improve grid operations, DA is a key to improving operational efficiency and reliability. It used to be that the business case for widespread DA was economically challenging and utilities would focus on deploying the technology where there were clear needs and problems to address.

However, that is changing. Instead of deploying separate communication networks and systems (which increases costs), leveraging an open-standards, multiservice network is key to success. Specifically, IP-based networks, the same standard that accelerated the growth of the Internet, can accommodate data from multiple devices from multiple vendors with various protocols and software applications. This provides a network infrastructure that delivers true interoperability of applications and devices.

In addition to DA, smart meters and other new sensing devices are increasing grid awareness. The visibility and data provided by these devices is used by distribution system operators to improve system reliability and outage restoration; increase grid efficiency through voltage optimization; and support innovative, cost-saving practices such as condition-based asset management. Specific DA capabilities include voltage monitoring and load balancing; fault isolation, sectionalizing, and intelligent switching; and volt/VAR optimization. So we are seeing a true convergence of smart metering and smart distribution technologies, made possible by the performance and cost advantages of multiapplication networks.

9.4 Big Data

Today's industry has done a good job of innovating and developing the technology to gather data and apply it to transform billing and revenue cycle services. The challenge now is to manage it effectively and put it to work to drive better operating and business decisions.

Increasingly, the industry is moving toward modernizing utility infrastructure by supporting multiple applications and interconnected smart devices beyond meters. With more smart devices, including meters, sensors, DA devices, and smart thermostats for consumers, utilities will collect information about the distribution system and energy consumption like never before. In doing so, utilities will have to contend with much larger amounts of data than they are used to. Systems are in place to manage the data, but the bigger challenge lies in applying analytics specifically suited to their key business challenges and making those analytics available in a timely manner to inform grid operations and decision making.

A few of the places where utilities are having the most success applying big data are in DR targeting, revenue protection, distribution-asset monitoring (transformer loading), and demand forecasting. Some big data analysis is fairly straightforward: for example, interval data gives utilities great insight into demand forecasting and where to shed load. In other cases, the data needs to be combined with deeper analysis.

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For instance, a meter-tamper alert by itself may not be that useful, but when combined with load data, transformer metering, account-billing history, and utility-field-service dispatch information, it can enable utilities to identify potential cases of energy theft with much more precision and target investigative and collection resources accordingly.

In addition, utilities are struggling with the best approach to big data and analytics. A "big-bang" enterprise approach can be costly and time-consuming, and applications may not have the utility-business-process knowledge and domain expertise baked in yet. In terms of time to value, more focused analytics solutions, preintegrated with meter data-management systems and addressing specific utility-business problems, are like the more efficient route to value and results.

9.5 Microgrids

It is important to note that microgrids are a compelling approach to providing electricity to underserved or poorer countries around the world. These less-developed areas could serve as proving grounds before microgrids are widely adopted in more developed countries. Access to electricity is a key component in business and economic growth as well as to public health. Microgrids give these developing and, often, poor communities access to locally generated electricity without the immense capital investment of a larger, connected electrical grid and central station generation.

Microgrids will play an increasingly important role in creating energy efficiency, resiliency, and independence. Microgrids enhance the integration of distributed and renewable energy sources, meet consumer-reliability needs, and support the macrogrid. As a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries, microgrids enable energy efficiency and reduce losses by locating generation near demand.

These self-contained entities have the potential to reduce large capital investments by meeting increased consumption with locally generated power. Most importantly, they can be quickly "islanded" in the event of a disruption to power supply. In the wake of recent storms and power outages in the Northeast region of the United States, microgrids are seen as a potentially valuable tool to keep vital services or areas running during power outages.

For microgrids to be more widely deployed in economically developed countries with highly evolved energy delivery infrastructure, costs must come down and/or specific use cases must be better defined and proven. Legislation or policy changes regarding carbon emissions from traditional, central station coal generation plants could change the equation, as well.

9.6 Consumer Engagement and Energy Efficiency

In the age of big data, when utilities have access to more information than ever before, energy efficiency takes on a new dimension of opportunity. There are new dynamics enabling greater energy efficiency and how it is helping strengthen energy security, environmental quality, and economic vitality.

Utilities with smart metering deployments will continue to find new sources of value from this technology and the data it delivers, through analytics. For example, through the introduction of new behavioral sciences and "gamification" techniques, energy-management software will create new and easier ways for consumers to save energy and money on their power bills.

With utilities collecting more and more interval data through their AMI systems, the opportunities to utilize this information to increase the effectiveness of energy efficiency programs, especially in the C&I customer

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segment, is enormous. AMI technology, combined with analytics and behavioral science, is helping utilities help their customers save energy and money.

9.7 Analytics and Action at the Edge

More and more smart meters are utilizing common IT technologies also used in laptops, personal computing, and smart phones including the memory, processing, and multicommunication capabilities. Today's smart metering and smart grid networks increasingly utilize open-standards communications (TCP/IP, transmission control protocol/Internet protocol) allowing a multiservice network that supports prioritized network use and can be managed by standard network management system tools. In essence, a smart meter network represents a geographically dispersed networked computing and communications platform that overlays the utility's service territory. It becomes an extension of the enterprise IT network into the field.

This distributed intelligence and digital measurement metering technology can be leveraged in several ways to offer advantages and new exciting capabilities in the smart grid analytics arena. A meter that is aware of network connectivity would enable the analysis of grid issues near the root cause of the problem, minimizing the burden on the communications network and the need to send data to the back office. Peer to peer communication between meters provides a lower latency communication opportunity for complex event processing in real time. This type of scenario utilizes the millions of meters' CPUs for coordinated analytic processing at the edge. This processing at "the edge" will become a clear trend in the years ahead and will actually achieve the vision of the smart grid by enabling various grid devices and applications to interoperate with minimal human intervention.

10 From Smart Grid to Smart Cities to IOT

In Charlotte, North Carolina, a groundbreaking community-based project is underway to harness the power of energy efficiency, water resource management, and environmental sustainability. Its core purpose is to drive economic growth and provide a higher quality of life to Charlotte residents. The "Envision Charlotte" project, with its pro-business approach to sustainability in the downtown core, is delivering clear, measurable, and broadly shared benefits to the City of Charlotte, its businesses, and its citizens. The goal for the Envision Charlotte project is to use new technologies and awareness to reduce energy and water consumption in the downtown corridor by 20%.

A partnership of Itron, Cisco, Siemens, Verizon, Duke Energy, and others is providing the measurement, communication, and data-management technologies that form the foundation of Envision Charlotte's energy efficiency and water conservation efforts.

These systems provide Charlotte businesses with the information they need to better understand their energy and water usage, as well as the ability to make informed decisions to reduce consumption, save money, and conserve these vital resources. Improved energy and water resource management is just the beginning as Envision Charlotte looks to other potential applications to optimize nonutility infrastructure (street lights, parking meters, even "smart garbage") to make the city a better place to do business and drive economic growth.

The Envision Charlotte project is an example of growing trends in municipal governance and management commonly referred to as *Smart Cities* and the *IoTs*. These cities are taking a technology-savvy and data-driven approach to energy efficiency, water conservation, and environmental stewardship. The goal is to build cities that are more livable, more economically vibrant, and more sustainable by targeting specific initiatives and measuring specific outcomes.

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10.1 The Opportunity

Cities around the world share a common opportunity with the City of Charlotte. By selecting and deploying a multiapplication network architecture based on open IP standards, new devices and applications can be added to the network with relative ease and at low cost compared to a purpose-built, proprietary network created exclusively for meter reading and related utility applications.

This technology strategy would enable cities to utilize and extend the value of the network for a broadening array of applications into the future aimed at making them more livable, sustainable, and economically vibrant. This also has the potential to create new business and potential revenue opportunities for utilities by leveraging the network for applications beyond the utility.

By choosing a multiapplication network with distributed intelligence, cities will have the technology foundation and network infrastructure in place to pursue a wide range of Smart City benefits related to energy efficiency, grid reliability, water conservation, integration of renewable energy, and other operational and customer service improvements. By utilizing this technology, developing supporting programs, and enlisting community support, the cities would have the opportunity to be a pacesetter among "Smart Cities" by achieving meaningful improvements in energy efficiency and, perhaps most importantly, water resource management and conservation amid the moderate- to severe-drought conditions that forecasters say could persist for the next 20–30 years.

10.2 Looking to the Future

As we look to a broader future that goes beyond utility operational benefits, building a platform for economic growth starts with ensuring that businesses and residents have access to a reliable, efficient, and affordable source of energy and water. It also requires recognition of the fundamental connection between energy and water, that is, it takes lots of energy to deliver clean water to a city and it requires lots of water to generate electricity. Utilities will have the ability to drive improvement in both areas.

Most importantly, a growing body of research reveals the fundamental connections between a city's sustainability, livability, and its economic vitality. While the goal of sustainability encompasses a broad range of areas, increasing energy efficiency and water conservation while reducing the city's environmental footprint are among the "highest leverage" opportunities.

With an advanced energy and water information network in place, visionary cities have a powerful platform and source of data to evaluate and measure benefits, develop new programs and services for its citizens, and an opportunity to develop and execute to an ambitious vision of how energy and water resources, as well as other urban infrastructure will be most effectively managed in a "Smart City" and the IoTs in the twenty-first century.

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