Business & Technology Surveillance

Advanced Metering Infrastructure

Continued Evolution for a More Intelligent Grid Edge

BY: Kyle Kopczyk, Power System Engineering

OCTOBER 2024

NRECA

America's Electric Cooperatives

Business & Technology Surveillance

Advanced Metering Infrastructure

Continued Evolution for a More Intelligent Grid Edge

BY: Kyle Kopczyk, Power System Engineering

OCTOBER 2024

SUBJECT MATTER EXPERT ON THIS TOPIC:

David Pinney
Principal Analytical Tools & Software Products
Business and Technology Strategies
David.Pinney@nreca.coop

This article is a product of the Analytics, Resiliency and Reliability Workgroup.

ARTICLE SNAPSHOT

WHAT HAS CHANGED?

Over the past 50 years, metering technology has transitioned from manual, analog meters to digital smart meters with automated, two-way communication capabilities. The underlying meter device and communications networks continue to evolve, and new metering solutions enter the market every year.

WHAT IS THE IMPACT ON ELECTRIC COOPERATIVES?

The evolution in Advanced Metering Infrastructure (AMI) technology has enabled electric cooperatives to access real-time data, improving grid management and operational efficiency. Advanced metering systems allow for automated billing and quicker detection of outages, enhancing customer service and reducing operational costs. However, implementing AMI requires significant investment, which needs to be carefully considered. The upfront capital investment is still pertinent, making the AMI technology decision an extremely important one.

WHAT DO CO-OPS NEED TO KNOW OR DO ABOUT IT?

Staying informed about the latest AMI technologies will help co-ops understand how they can enhance operational efficiency and member service. Evaluating your current systems and developing a strategic plan for integrating new AMI solutions, including scoping necessary funding, is beneficial to operational and investment planning.

NRECA
America's Electric Cooperatives

Table of Contents

Introduction

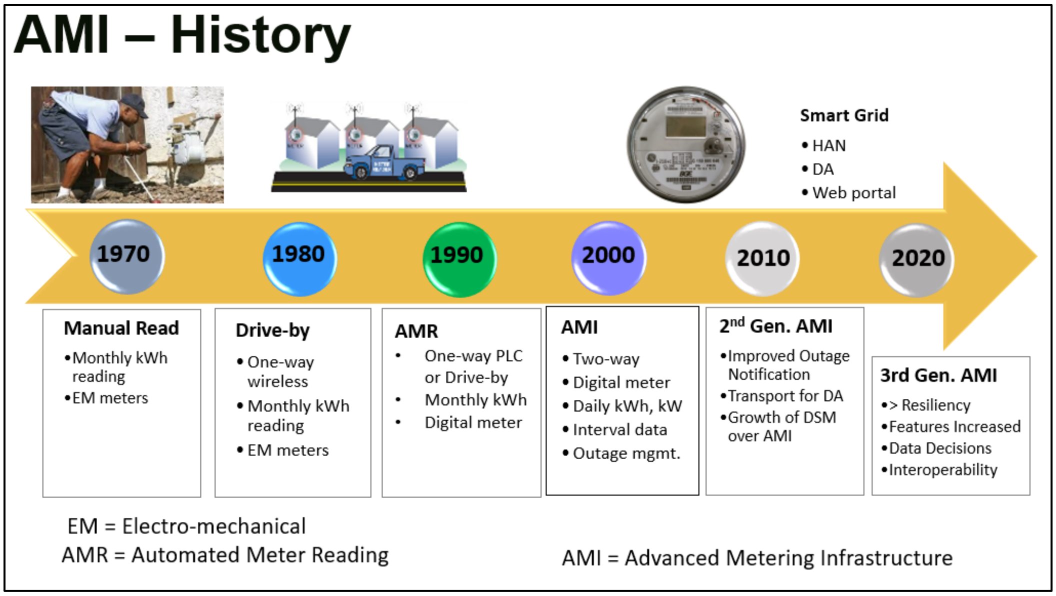
New fiber networks are being installed all over the country. 5G networks have taken over metro areas, and are even starting to be seen in small towns of just a couple thousand people. As Low Earth Orbiting (LEO) satellite networks fill in the holes, there are very few locations left where a connection to email, a streaming video, or a customer portal is not accessible. And yet, in the age where nearly everything is shipped globally in a day (minus lead-times, such as transformer orders) or instantaneously available digitally, there are still Advanced Metering Infrastructure (AMI) networks running which bring in a kWh reading only once per day at best.

In the past 10 years, there has been a transition from Power Line Carrier (PLC) and first-generation radio frequency (RF) systems into the 3rd and 4th iteration of AMI technology. The industry is now on the cusp of unlocking the next generation of AMI technology to feed growing data appetites: fiber networks which support streams of data flow; cellular connected devices which are always on; and finally, to explore a slightly alternative path to leveraging backhaul – using intelligence at the end device. While all the changes in the field are happening, either with backhaul or the edge device, there are also new techniques on how to process the information collected. Analytics, data reporting, and now Meter Data Management Systems (MDMS) are still providing data storage to utilities, as more options for the industry are starting to emerge.

Everchanging Evolution of AMI Communications

Through the changes and evolution, the AMI industry and the related systems are not as they were even 5 years ago.

Figure 1: Evolution of AMI Technology



Expansion of Cellular Systems

Cellular AMI technology has been around for quite some time – over 30 years. In the early deployments, the use of cellular was sporadic and expensive. Cellular was used to fill in gaps and holes left by power line carrier (PLC) systems where communications just did not work or there was no other practical means of communication to the meter, such as Digital Subscriber Line (DSL) and other wired telephone-based technologies. Cellular costs were high, and data plans were not as affordable as today. In a time in the early 2000s when cellular phones were just starting to send text messages, using cellular technology in a meter was an expensive feat on a case-by-case basis, let alone deploying it across an entire electric service territory.

The industry had RF coming up behind PLC, and this mostly took over the AMI industry. Utilities started building their own privately-owned data reading networks and this trend continues to this day. In parallel, the cellular industry was improving the coverage, affordability, and bandwidth in their networks. The first big data leap was moving from 3G to IP-based 4G systems. This was accompanied by continued expansion of the coverage of the systems. As the consolidation of the cellular companies happened and the build out to rural parts of the country started, cellular became more practical – but still only from a personal communication standpoint. This was the turning point at which cellular meters became less of a fringe, AMI technology used only in gap filling applications and more of one that now supported the possibilities of wide-spread meter deployment.

Changes in Longevity and Costs

As the first hurdle of lack in coverage and reliable service was being overcome, the second and third hurdles started to emerge – longevity and cost.

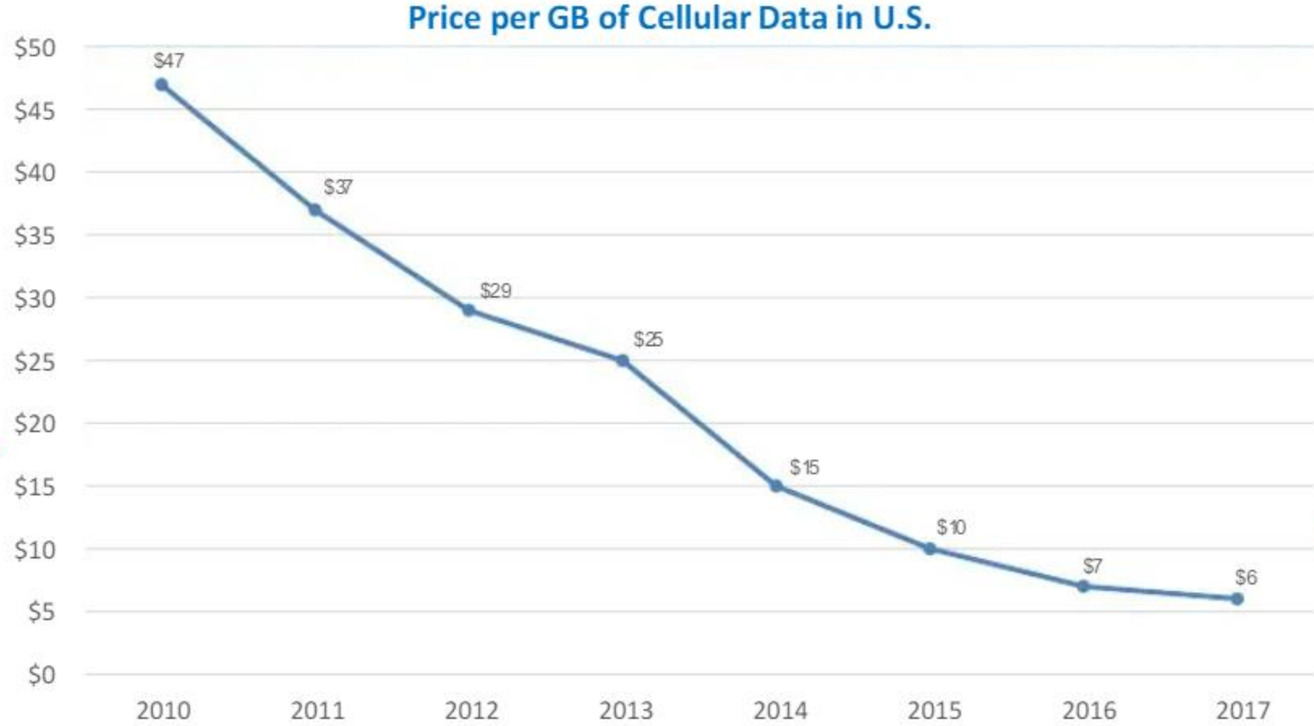
Longevity is a difficult balance between the old and the new. It is also tied to a decision between the amount of cost of the initial investment and the perceived long-term value which one gets from that initial purchase. More succinctly, AMI systems are expensive and proprietary, meter changeouts are a challenge, and the system put in place today has an expectation to last a long time. Historically, this is assumed to be 30 plus years by traditional business accounting functions.

When thinking about cellular phones these days, it is likely very few of us have a phone which is more than 3 years old. Innovation and cheap compute power has given rise to minicomputers bouncing around in our pockets. As the hardware advanced to demand more from the networks, the infrastructure supporting them also evolved, rapidly. This put the early years of placing a cellular communication board in a meter in peril. A meter with a historical expectation of 30 years is being deployed today with a much shorter anticipated life span (10 to 15 years). If you built your own RF network, it would be a bit easier to keep that system going; difficult, but not impossible. When you have no control over when a 3G, 4G, or a 5G network is decommissioned, your only option is to replace it. That long-term asset is now reduced to much less than was intended, and accounting does not like early write-off of undepreciated assets – nor does the meter technician or the consumer who just had their meter replaced.

Over the years, progress continued, coverage increased, and now you can traverse most of the U.S. and have some reasonable confidence you will remain on your conference call and keep your turn-by-turn navigation. Now it appears, with some caution, we are turning a corner in terms of longevity guarantees. There are AMI vendors providing long-term commitments for their cellular based systems, with data plans for 10 and 15 years – but more importantly, contractual terms to match. This step forward is an important component in securing cellular as a viable meter reading system.

Cost likewise has been another barrier of entry to a complete cellular meter reading system. What utility-built RF networks were able to do, that cellular was historically not, was keep the costs of deployment and maintenance of the AMI system low. In some cases, there is a factor of 2X greater (and more) monthly operating costs for a cellular deployment, compared to a more “traditional” RF mesh or point-to-multi-point AMI systems. The business model and financial payback to deploying an all-cellular AMI system just was not there and still it remains to be seen when cellular AMI systems will become cost competitive. With the lack in commitment of a long-term guarantee, the devices and the network needed to be replaced in less than 5 years, and therefore, were not a practical endeavor to pursue. However, the cost of cellular network data has been dropping by roughly 10% per year over the past decade (Figure 2 below), so we expect that cellular AMI systems will eventually become much more cost-competitive.

Figure 2



Source: Scribd Qualcomm[1]

In 2017, Verizon announced they would be launching a 4G LTE Category M1 (Cat M1) network where data plans started at $2 per month per device.[2] This offering was the first example of a cellular network product that addressed cost and support longevity concerns.

The shift comes with the Internet of Things (IoT) and the carve out made within the cellular industry to support the low bandwidth use cases. To the prospective of the average cooperative or utility, the amount of data present, in say ten thousand electric meters, is huge. In reality, the meter data as compared to streaming services, applications, and everything else we use our cell service for today is tiny. This is a perfect application for AMI metering located on the Cat M1 network.

[1] https://www.scribd.com/document/407463620/Qualcomm-opening-statement#fullscreen&from_embed
[2] https://www.verizon.com/about/news/verizon-launches-industrys-first-lte-category-m1-cat-m1-nationwide-network-iot

4G LTE Category M1 (Cat M1) Network

The LTE-M / LTE-MTC (Long-Term Evolution Machine Type Communication) is a radio technology developed by the 3rd Generation Partnership Project (3GPP) for machine to machine and Internet of Things (IoT) applications.

The 3rd Generation Partnership Project is an overarching term for a standards organization working for the development of protocols for mobile telecommunications. This includes work in GSM and 2G, UMTS and the 3G standards, and LTE and the related 4G standards.

The standards placed by the 3GPP and enacted by the industry are allowing for the addition of communications devices that were seemingly just out of reach. Some of those examples include:

- Improvement in Automatic Vehicle Location (AVL)
- Personal trackers
- Irrigation
- Car rentals
- Thermostats
- Smart watches
- Utility Meters (Electric, Water, and Gas)

CAT M1 operates within the same LTE band as other applications; there is no additional hardware or infrastructure needed. It is a secure and private network bundled within the existing cellular network. The network can support up to 1 Mbps with a low latency of data transmission. There is no streaming of security video, but it is certainly robust enough to handle a lot of AMI traffic consistently and continuously – so long as there are not times of congestion.

Unfortunately, there are some drawbacks. Most of it centers around the devices being in the background. If a tower gets overloaded with unusual traffic, then you may see meters start to drop off and stop communicating until later. Now, with the size of memory storage available, getting past information is not a problem, unless you are trying to perform on-demand tasks such as verifying voltages, getting a move-out reading for final billing, or getting the reconnect message out after payment was processed.

Table 1: LTE Cat M1 Specifications[3]

3GPP Release	Release 13
Device Receive Bandwidth	1.4 MHz
Downlink Peak Rate	1 Mbit/s
Uplink Peak Rate	1 Mbit/s
Latency	10-15 ms
Power Requirement	Very low
Duplex Mode	Full/Half duplex
Device Transmit Power	20/23 dBm

Source: EverythingRF website

The cellular AMI is not only centered around the meter. Cellular communications and AMI are extending to all aspects of the utility, but it will depend on the vendor. Not all metering vendors currently offering a cellular metering solution will also be able to include solving gaps for load management, distribution automation, water meter reading, or gas meter reading. This leaves the need to reach out to other providers to fill in the holes, whereas traditional AMI has all these solutions now. The market needs some time to grow into additional equipment offerings, but they will come in short order. Soon, there will be electric meters, load management, and distribution automation hardware offered by one or more AMI vendors in a 100 percent cellular solution.

[3] https://www.everythingrf.com/community/what-is-lte-cat-m1

Fiber to the Premises

Fiber to the Premises (FTTP), a telecommunications technology, delivers high-speed internet, television, and voice services directly to homes or businesses using optical fiber cables. Unlike traditional copper cables, fiber cables use light to transmit data, offering significantly faster speeds and greater bandwidth. This technology is becoming increasingly popular due to its ability to support modern digital applications, including streaming, gaming, and smart home devices.

The use of fiber for AMI can and should be done, but it should be strongly encouraged to seek outside and internal opinions before deploying fiber for the sole purpose of AMI. With cost estimates ranging from $20,000 to over $60,000 per mile, fiber can be a significant investment. The longevity of it is certainly one factor to consider, but AMI should not be the sole use of FTTP, as it will not justify the cost.

For utilities that either have fiber as part of their offering to their consumers or fiber is available throughout their service territory via a shared agreement, FTTP can offer options in the way of AMI.

There have been several different uses for fiber communications when it comes to AMI, the first and most obvious being backhaul for AMI collectors. With most fiber loops starting out small and private, they are run from the office to the substations, maybe to a few important regulators, and back to the office. Certainly, this setup worked well for powerline carrier and staying within the substations. As RF needed to be expanded into the distribution network, the backhaul needed to follow. As mentioned previously, this sometimes took the form of cellular. At other times, it took on the form of partnerships and longer-term construction plans. Building out fiber was and is intentional, to plan out routes, splice locations, cabinets, having enough fiber strands, etc.

Now with more and more communities having access to fiber internet, phone, and services, the AMI vendors are starting to provide options to take advantage of these high bandwidth networks. However, no AMI vendor can provide a mass-market meter with an Optical Network Terminal (ONT) connection. There are no options today to deploy a true FTTP AMI system.

Most are taking advantage of the backhaul speed and low latency to pull large amounts of information and data from their collectors, but that advantage is lost when the AMI network to the meter is still the same RF or powerline carrier system it has always been. The bottleneck is between the meter and collector.

So far, only one AMI vendor (Tantalus) supports an FTTP metering solution. Instead of mounting the collector or repeater at the pole and transformer, the communication and functionality is contained at the meter socket. An ONT compatible collector is put strategically at some 2S meter sockets, and an AMI meter is then placed in front of it. The meter’s job is to mesh with its neighbor meters to bring in all the data. The data is then provided to the socket-based collector and sent via the fiber backhaul connected at the premises back to the utility. The collector also monitors the socket it is connected to, sending voltage, load, demand, and numerous other data points as if there was a power quality meter installed at that location.

This can be a powerful tool to deploy if the conditions are right. The headwinds can be the entry costs. Fiber, as mentioned earlier, is expensive. In most cases, there is just not a strong or practical financial business case to be made to deploy it. Sometimes there is. When it does make sense, the deployment can take a significant amount of time. To deploy a collector at each home is not practical, certainly not from a cost perspective. This approach enables the utilization of the existing fiber investment, while also reducing the collector cost. Note, however, that polyphase applications are not supported yet in this type of system.

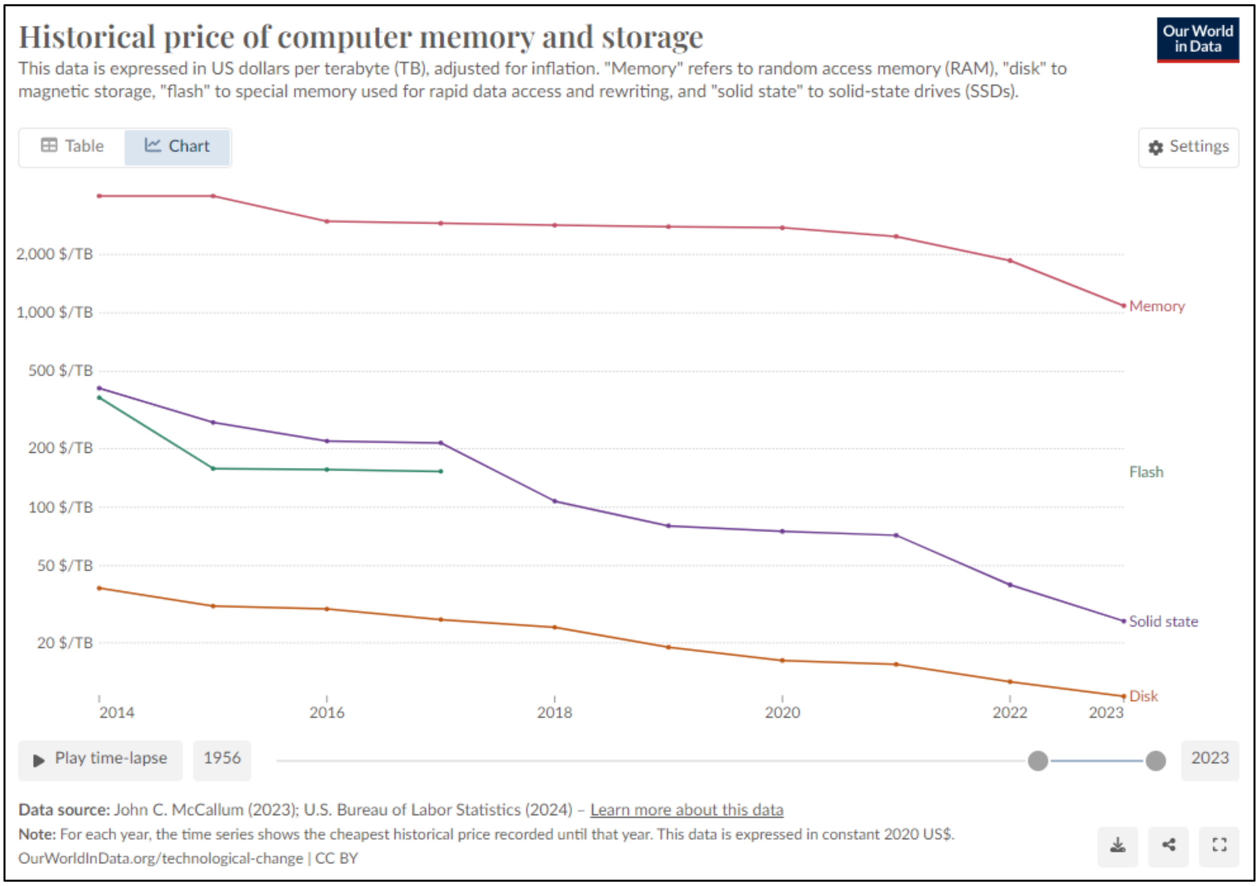
This is a good place to investigate a few other options in AMI which are also taking a hybrid approach or a dual band radio and cellular solution. There is another vendor, Nighthawk owned by Tesco, like the one mentioned earlier on their FTTP, which offers the ability to deploy a cellular and mesh solution all in the meter. Cellular communication is for the backhaul to send the data back, and the mesh radio to collect the data from the rest of the network's neighbors. The cellular meters are deployed strategically throughout the system and the mesh does the rest. This solution, like all-cellular and the FTTP models, requires no additional AMI network equipment to be deployed or maintained.

Another metering solution includes a wi-fi enabled meter. The meter is added to a private, undiscoverable, secure network. There are some risks with what happens if the homeowner changes routers, but this approach may be a solution to supplementing a need for an ONT, especially where the utility has full control over the fiber network as well.

Edge Devices

As AMI expands into leveraging the backhaul or elimination of building proprietary networks, there are some vendors finding avenues to push data extraction and processing to the edge device. The declining costs for computer memory, storage and processors have given rise to more sophisticated features being added to electric meters.

Figure 3: Historical Price of Computer Memory and Storage



Source: Our World In Data[4]

While all the AMI vendors and meter manufacturers are increasing their compute and memory power in the meter, a fracture has occurred where a few of the vendors have split off and have added additional standardization to their next generation RF mesh systems. This is done in the way of Wi-SUN (and the Wi-SUN Alliance) and the IPV6 protocol.

Like the 3GPP, the Wi-SUN alliance is an industry consortium promoting interoperable wireless solutions for smart cities, smart grids, and other Internet of Things (IoT) applications. The difference is

[4] https://ourworldindata.org/grapher/historical-cost-of-computer-memory-and-storage

that their primary focus is on using open standards around the IEEE 802.15.4g (the standard for wireless communication that is designed for low-power networks, such as 900Mhz and 2.4 GHz systems).

Standardizing the AMI traffic is one component; the next is ensuring this network is communicating and can connect to a massive number of devices. Afterall, the Wi-SUN alliance is an open standard, so this would theoretically allow the interoperability of AMI hardware for any vendor that complies to it.

To do this, the AMI network needs to be an Internet Protocol or IP based type system. Unlike the IPv4, which is running out of unique device IDs, the AMI systems are using IPv6. This latest version offers a vastly larger address space and is crucial to supporting the growing number of meters, distribution automation equipment, and IoT devices on this type of network. IPv6 can support multicast communication, which allows for the efficient transmission of data to multiple devices simultaneously. This is useful in AMI networks for tasks such as software updates or sending broadcast messages to meters, but all endpoints in general. IPv6 also helps to ensure that devices from different manufacturers can work together within the same AMI network. It also aligns with international standards for smart grids, promoting global interoperability.

Moving to the IPv6enabled AMI system does a few things, some of which will inhibit the ability to propagate long distances. The impact to the distance is the requirements placed on the bandwidth of the network, causing a reduced communication distance. The consequence of having more network devices is a bolstered system because of the additional equipment. This also allows a shift in data and information collection. Rather than using the cellular or fiber networks to bring the data in as quickly as possible, IPv6 networks and systems are positioning themselves to use edge intelligence. The meter and the devices around them can contribute and feed information into one another. The meter can also act alone and gather data internally, process it onsite, bundle it into a single or few manageable packets, and send it up to the AMI system or other receiving application.

The additional add-on comes in the form of developed and downloadable applications to the meter. The applications, like a phone or tablet, can be designed by an AMI vendor or the utility and pushed to any number of meters. This could be an application devoted to monitoring voltage sags and, if a meter finds a violation, it then grabs the previous week’s one minute intervals voltage recording, saves the preceding week’s voltage readings, and then sends this all into the engineering department for analysis, byte by byte.

The devices are also sophisticated to the point of using the application and data to make decisions at the meter, as well as meters shared on the same transformers. The applications can be tailored to specific use cases. The meters and devices can also be used to communicate with each other, for monitor loading of transformer health. There is a lot of opportunity for information use and exception reporting when the edge device is the first line of defense. When properly deployed and utilized, the reaction and analysis have the potential to be much quicker than the traditional methods of sending all the data into the centralized systems.

In addition to the electric meter as the edge device, there is also an increase in putting AMI communication devices into other products. This could be the result of the Internet of Things and Wi-SUN alliance, or more than likely, it is that most AMI vendors are now owned by larger corporations that manufacture more than just communications for AMI systems. There are now options for EV chargers (RF, PLC, and Cellular) and circuit breakers. As the market expands and the companies mature, it is likely that there will be more and more options available within the AMI community. The practicality and consumer reception may yet to be seen though. Certainly though, the advantages of an AMI-enabled EV charger, in addition to the demand response capabilities, would also be the elimination of a secondary or sub-metering application.

Data Value Mining

We have the edge devices doing analysis, cellular and fiber backhaul, pushing up information as quickly as the end device can deliver it, and yet there is still this need for data storage and access to information. The data needs to be organized, reported, and delivered in a way that creates a call to action or to emphasize a point. However the utility chooses to use the data, there are mechanisms in place to help leverage the amount and cache of data.

The first place to start is in the AMI system itself. But, this can have a limited viewpoint and an expiration date. Not all AMI systems are designed or provided to be long- or even short-term data repositories. In some cases, 60 days of reporting data is all you will get out of your AMI system and then it is gone. Now, as illustrated previously, not all AMI systems are the same. At the other end of the spectrum, there are AMI vendors who allow unlimited data storage, so long as your maintenance and data storage fees are paid. The trick will be in getting the retrieval of that data out any of those AMI databases (and not in having to run tedious and repetitive data exports).

In most cases, the information and data are shifted and moved to long-term storage, such as a Meter Data Management System (MDMS). Depending on the software vendor of choosing (and cost), these systems come with a range in features and functions. When boiled down to the fundamental core of their purpose, it is to store and report on large amounts of information that the AMI system does not keep. It also connects to additional systems to pull in other sources of information, such as customer information or rate class. The MDMS structure still appears to be the main go-to place for information storage and retrieval, for now.

In the last few years, there have been additional options available at cost points, which are making it easier for utilities (and other industries) to harness their ability to data value mine. With cloud storage facilities, one can store large amounts of data for long periods of time and be able to pull this information back out as needed. AWS, Google, and Azure are just a few of these options. There are also services where you can store data and purchase on-demand resources for running through huge data sets in a few minutes or seconds. Purchasing idle compute power to making a report generate faster or to get closer to real-time reporting is available. The storage may be getting inexpensive, but the on-demand resource model can get costly if one is not careful. In the analytics space, we are talking about data lakes and data warehouses.

Data Lakes and Data Warehouses

Picture a vast body of water, say Lake Superior. There are ships, boats, buoys, islands, and all sorts of different items and things. Just like a real lake, a data lake is a centralized repository of structured data (like boats at a marina), semi-structured data (more like ships moving through their shipping lanes), and unstructured data (everything else that gets added to the lake over time). Data lakes are where a utility can store all of that AMI, outage, and billing information, or whatever else it may be. Data lakes allow for exploration of the data and starting the process of cleaning it up for analysis and actual use.

A data warehouse is where we move the information. The information in the data lake is explored and converted into an organized and highly structured format. This is the data that we can report and from which we can get visualizations. The data warehouse is a critical step that is most often overlooked. Structured data is the unsung hero of good reporting. A data warehouse is more like Costco, Amazon, or even your own inventory warehouse. Everything has its place, it is neat and organized, and there is structure. There are also places where items and materials may be linked together, but again, it is all neat and orderly.

From the data lake and data warehouse, we get what most of us are familiar with seeing, the dashboard or visualizations. They are the stories and reports created from the data warehouse to provide insights using either single, but often multiple, data sources linked together in a purposeful manner. These dashboards, when used with data warehouses (data lakes are not *always* needed) can provide valuable data insights which are not available through traditional means and can be tailored to or customized to a utility's needs without having to have a custom code or request made. PowerBI and Tableau are a couple of the more well known dashboarding and visualization tools available today. Examples of dashboards are provided in the following figures.

Figure 4: Example of a Dashboard

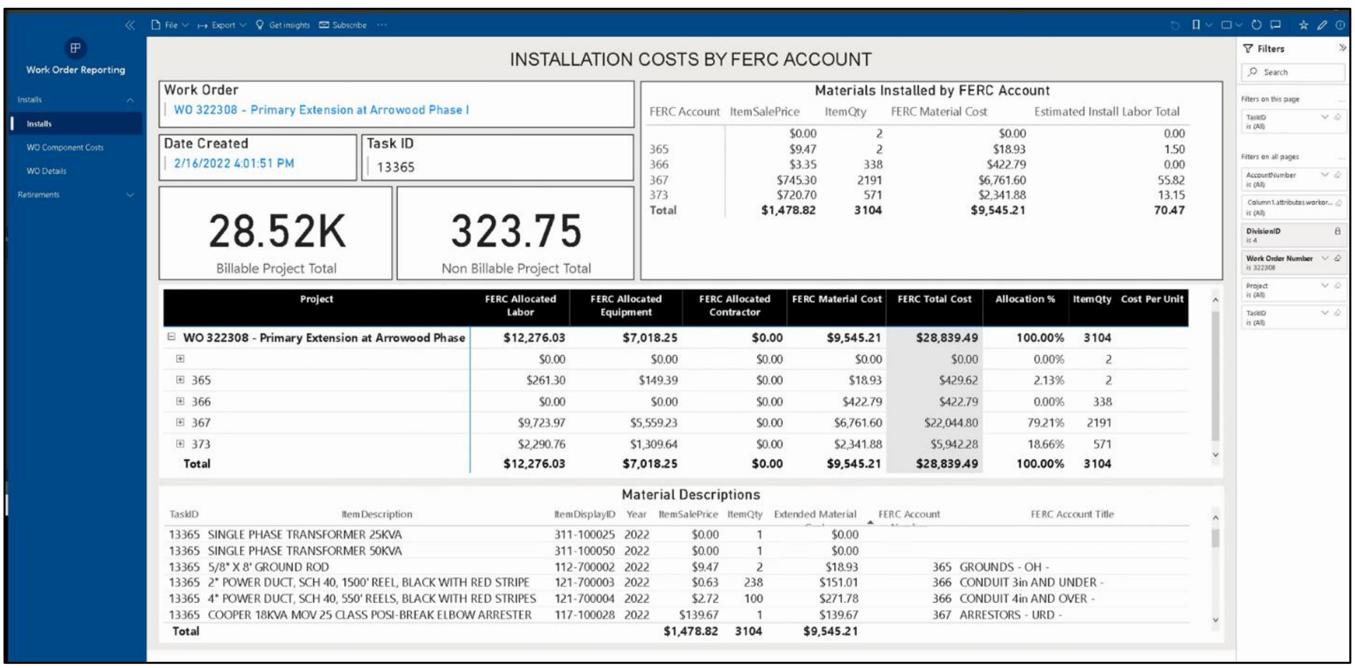
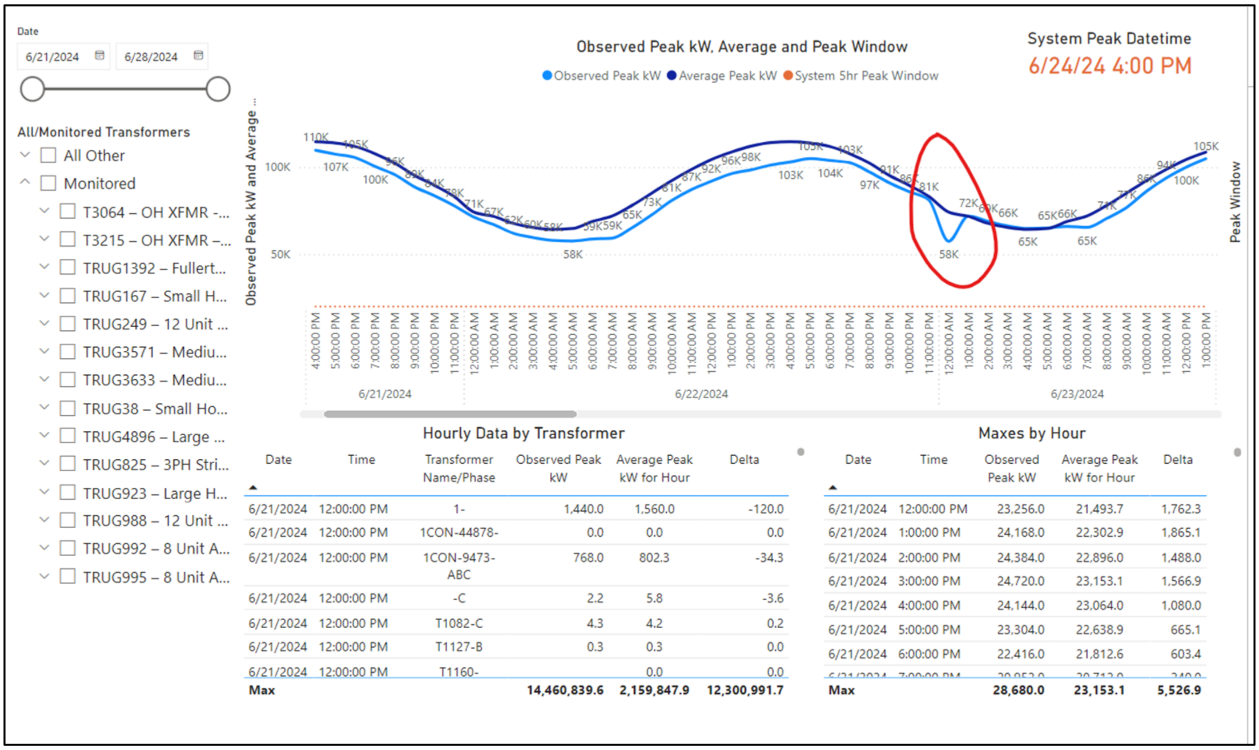


Figure 5: Example of a Dashboard



Right now, we are not seeing data lakes or warehouses replace the role of an MDMS, but rather supplementing the MDMS or other data storage with additional tools. In situations where there is not an MDMS in place, some who may have felt the costs were too great are now finding an opportunity to explore custom data infrastructure to meet their data mining goals.

The Big Picture

The AMI landscape on the surface is still the same when it comes to a simple goal: get data from the meter to the utility. Most importantly, it needs to be used for billing and the system needs to be reliable. Gone is the need for manual reads. Moving beneath the top layer, there are still innovations and technologies being developed or deployed to take advantage of the opportunities available to us today: the build out of the cellular networks across the country; the implementation of fiber to the premises (FTTP); the ability to have devices communicate locally to share information in more real-time to make decisions faster than trying to send it all back, analyze it, and then return it back out to the field with a command. There is also a shift in the way electricity is produced and delivered. Good or bad, it is changing, and that is affecting the way data is not only collected, but used and reported. There are more options and hybrid deployment techniques and other permeations for AMI. In the end, seek the best fit system for your needs today, with an eye to the future for as long out as one can possibly see.

About the Author

Kyle Kopczyk, Manager of Utility Automation, Power System Engineering

Mr. Kopczyk earned a BS degree in Electrical Engineering from Michigan Technological University at Houghton, Michigan and an MBA from the Minnesota School of Business. He has 15 years of experience in the utility industry focusing on Data Analytics, AMI/AMR, Demand Response, and Integration/Interoperability. Kyle also works closely on technology strategy planning, business cases, and project deployment/management. Kyle is a subject matter expert in PSE's Utility Automation practice areas.

Contact for Questions or Comments

David Pinney, Principal Analytical Tools & Software Products, Business and Technology Strategies: David.Pinney@nreca.coop

To find more resources on business and technology issues for cooperatives, visit our **website**.

Analytics, Resiliency and Reliability Work Group

The **Analytics, Resiliency and Reliability (ARR) Work Group**, part of NRECA's Business and Technology Strategies department, is focused on current and future data and research required to provide prompt technical and economic support to the NRECA membership. Specifically focused toward the electric co-op community, ARR products and services include: development and maintenance of a portfolio of energy analytics products and services; collection and analysis of data; and provision of additional products and services in the areas of the data collection, IT architecture, sensors, and energy markets. For more information, please visit **www.cooperative.com**, and for the current work by the Business and Technology Strategies department of NRECA, please see our **Portfolio**.

Legal Notice

This work contains findings that are general in nature. Readers are reminded to perform due diligence in applying these findings to their specific needs, as it is not possible for NRECA to have sufficient understanding of any specific situation to ensure applicability of the findings in all cases. The information in this work is not a recommendation, model, or standard for all electric cooperatives. Case studies are provided as examples only to illustrate how various rate designs and related practices have worked in some cooperatives. NRECA is committed to complying fully with all applicable federal and state antitrust laws. Electric cooperatives are: (1) independent entities; (2) governed by independent boards of directors; and (3) affected by different member, financial, legal, political, policy, operational, and other considerations. For these reasons, each electric cooperative should make independent business decisions on whether and how to use this information and on what rate designs are appropriate for the cooperative's own circumstances. Neither the authors nor NRECA assume liability for how readers may use, interpret, or apply the information, analysis, templates, and guidance herein or with respect to the use of, or damages resulting from the use of, any information, apparatus, method, or process contained herein. In addition, the authors and NRECA make no warranty or representation that the use of these contents does not infringe on privately held rights. This work product constitutes the intellectual property of NRECA and its suppliers.