

## Implementation of AMI Systems in CFE-Distribution, Mexico

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**Abstract**—The Smart Grid concept has been conceived as the integration of the electrical grid (generation, transmission and distribution) and the communications network of an electric utility. Although, traditional communications interfaces, protocols and standards has been used in the electrical grid in an isolated manner, modern communications networks are considered as the fundamental enabling technologies within a Smart Grid environment. Emerging communications technologies, protocol architectures and standards can help to build a common communications network infrastructure for data transport between customer premises, power substations, power distribution systems, utility control centers and utility data centers. The Smart Grid will support traditional applications such as supervisory control and data acquisition (SCADA), distribution automation (DA), energy management systems (EMS), demand site management (DSM) and automated meter reading (AMR), etc., as well as new applications like advanced metering infrastructure (AMI), substation automation (SA), microgrids, distributed generation (DG), grid monitoring and control, data storage and analysis, among others. To make this possible, the Smart Grid requires a two-way wide area communications network between different dispersed areas, from generation to consumer premises. An AMI system uses communication technologies for smart meter reading several times a day to get data consumption of electricity, as well as sending outage alarm information and meter tampering almost in real time, from the meter to the control center. Currently, there are various communication technologies to implement AMI systems. This paper presents an overview of the most relevant communications technologies that can be used to implement AMI communications infrastructure such as neighborhood area networks (NAN), field area networks (FAN) and wide area networks (WAN) using different transmission media such as fiber optics, spread spectrum radio frequency, microwave, WiMax, Wi-Fi, ZigBee, cellular, and power line carrier. In addition, a review of the current state of various AMI projects around the world, including the progress in the implementation of AMI systems in Mexico, besides the evaluation performance of CFE's AMI networks.

**Keywords**-Advanced Metering Infrastructure, AMI systems, Automated Meter Reading, Communications Technologies, Smart Grid.

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### I. INTRODUCTION

An AMI system aims to incorporate the metering data collected from consumers to a management information system, located at the control center of an electric utility. This is done through a two-way communication system (from consumer to the electric utility and vice versa) where the exchange of information in real time is achieved, providing the customers the possibility to have great benefits such as differentiated tariffs and records of demand; for the electric utility, more efficient management of the electricity. The functionality of this new technology goes beyond simply getting a monthly meter reading, AMI is a system is capable of capturing real-time energy consumption, demand, voltage, current, and transmitting information independently of states and events recorded by the meter. An AMI system allows the deployment of new applications such as remote meter reading and consumption, remote connection and disconnection, break detection, early identification of possible fault events and losses, theft detection, time of use, monitoring and power management, among others.

An AMI system generally consists of three main components: smart meters, communication networks and measuring data management system (MDMS). Currently, there are new measuring devices called "smart meters", which presents best features of accuracy, precision, control, memory, interfaces and communication protocols. An AMI system uses communications networks that are able to read smart meters several times a day, to obtain data consumption of electricity, as well as sending outage alarm information, meter tampering, almost in real time from the meter to the control center. These networks are the main part of an AMI system and generally use

different architectures including meters, collectors/data concentrators, and software applications to collect metering data (reading of consumption, disconnection and reconnection, alarm generation, theft reports, among others) in a management system. The main purpose of communications technologies is to provide a common communications infrastructure to the new smart grid, and in particular to AMI systems.

### II. STANDARDS

The Smart Grid is based on the concept that all components of the electric grid are capable of communicating and supporting smart grid applications such as real-time energy consumption status, and remote controlling of appliances. The adoption and use of standards-based networking technologies will bring a wide range of opportunities for the development of AMI systems. They will enable electric utilities to integrate products ensuring interoperability across intelligent electronic devices, networking technologies, and backhaul communication links endpoints. Moreover, international, regional and national standards will enforce the integration of equipment from multiple vendors. The electric power industry is working on establishing open standards and has been driving the completion of standards in the United States and in Europe through international standardization bodies such as NIST [1] and IEC [2]. Currently, the National Institute of Standards and Technology (NIST) have published reference architecture for smart grids, along with recommendations for the adoption of 72 existing and developing standards from several organizations. Also, European groups are working on smart grid standards, including the European Industrial Initiative on

electricity grids under the European Technology Platform (ETP) Smart Grids [3], and the European Utilities Telecom Council (EUTC) [4].

### III. COMMUNICATIONS TECHNOLOGIES

The main goal of communication technologies is to contribute to the development of smart grids, and in particular the implementation of advanced metering infrastructure systems. AMI networks require the use of various types of communications technologies public and private, wired and wireless, licensed and unlicensed based on open standards and proprietary technologies. Several communications and networking technologies can be used to implement home area networks, neighborhood area networks, field area networks and wide area networks, including fiber optics systems, cellular, satellite, trunked radio, WiMax, power line carrier, broadband over power lines (BPL), and IP, as well as in-home technologies such as Ethernet, Wi-Fi, HomePlug, ZigBee, RF Mesh, etc. Next, an overview of the most relevant technologies to implement the communications infrastructure of AMI systems is presented.

#### A. ZigBee

ZigBee is the only standards-based wireless technology designed to address the unique needs of low-cost, low-power wireless sensor and control networks. ZigBee is a specification for a suite of high-level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs) [5]. The ZigBee protocol enables communication using multiple network topologies, including star, tree and mesh. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted to RF applications that require a low data rate, long battery life, and secure networking. ZigBee uses the ISM band for industrial, scientific, and medical applications, namely 868 MHz in Europe, 915 in the US and 2.4 GHz in the rest of the world. The primary attractiveness of ZigBee is its open standard platform that promises interoperability among multiple products and systems [6]. ZigBee now has a Smart Energy Application Profile specifically designed for utility applications within the HAN such as Demand Response, Dynamic Pricing Response, Plug-in Hybrid Electric Vehicle (PHEV), smart charging, etc. The ZigBee Smart Energy 2.0 was selected by the U.S. Department of Energy and the NIST, as an interoperable standard for HAN devices.

#### B. Wi-Fi

Wi-Fi (Wireless Fidelity) is a technology intended for use more in enterprises and in industry, including in the Smart Grid. Wi-Fi is commonly used as the abbreviation of 802.11b standard. It supports bandwidth up to 11 Mbps, comparable to traditional Ethernet. The 802.11b standard also uses DSSS as modulation technique in the 2.4 GHz band as the original 802.11 standard [7], where Wi-Fi devices communicate to each other at data rates up to 11 Mbps. Currently available technologies based on IEEE 802.11a and IEEE 802.11g, can provide data rates up to 54 Mbps. The IEEE 802.11a standard operates in the frequency band of 5.8 GHz using orthogonal frequency division multiplexing (OFDM), while IEEE 802.11g operates in 2.4 GHz using DSSS modulation technique. In addition, the new IEEE 802.11n based on multiple-inputs multiple-outputs (MIMO) antenna technology, was designed to increase the data transmission up to 600 Mbps. Recently, the

Wi-Fi Alliance has created a new task group to determine which standards should be modified to take advantage of the smart grid. The alliance has issued a report that looks at areas in the smart grid environment where Wi-Fi can play a role [8]. This includes smart meters, home area networks and the collaboration between smart grids and cellular networks. In addition, the Wi-Fi Alliance and the ZigBee Alliance have announced an agreement to collaborate on wireless HAN for smart grid applications. The Wi-Fi technology could support the communications infrastructure of AMI systems due to its robustness, manageability, performance, and security.

#### C. WiMax

WiMax (Worldwide Interoperability for Microwave Access) is a wireless technology that provides high-throughput broadband connections over long distances. It can be used as point-to-point or point-multipoint for providing mainly Ethernet/IP-based data services as a shared medium to locations where neither copper nor fiber is available or mobility is required. WiMax can provide long distance communications beyond 16 km and in some instances beyond 48 km at data transfer rates of 75 Mbps. WiMax, using the IEEE 802.16 standard [9], [10] allows seamless communication with multiple vendors. In addition, WiMax can communicate out of sight via IEEE 802.16e and can communicate with moving trucks or cars. It can serve as the backbone of a transmission and distribution communication system supporting Wi-Fi applications for substation or distribution automation, as well as provide a backhaul infrastructure for AMI systems.

#### D. GPRS

GPRS (General Packet Radio Service) technology is the evolution of the second-generation GSM networks towards 3G networks and cellular technologies, known as 2.5G. The important step taken with GPRS is that it uses the radio channel in a more efficient manner, using packet switching and the IP protocol. New applications introduced over GPRS allow users to experience an increase in speed. GPRS offers a data packet service for cellular networks based on GSM technology [11], [12]. In addition, the packet switching technology fundamentally enables the sharing of resources. A GPRS user will only use the network when sending or receiving a data packet. All the time that the network is idle, other users may use it. GPRS can be used to implement AMI systems in the distribution network.

#### E. PLC

PLC (Power Line Carrier) technology provides connectivity over existing power lines as a communication medium [13]. There are different technologies associated with power line communications for various applications such as: home automation and Internet access. Narrowband PLC (3-500 kHz) provides speeds from a few bits per second up to 100 kbps, covering distances of several kilometers. The major disadvantages of this technology are transmission errors due to attenuation and electromagnetic interference [10]. It is often used to connect smart meters in the low voltage of distribution transformers. The PLC technology can be used to implement neighborhood area networks (NAN), and home area networks (HAN).

#### F. BPL

BPL (Broadband over Power Lines) is a technology that carries broadband Internet traffic over medium voltage power lines. Access BPL systems carry high-speed data and voice

signals over the medium voltage power lines from a point where there is a connection to a communications network [14], [15]. This point of connection may be at a power substation or at an intermediate point between substations, depending on the network topology. BPL systems can be used to provide high-speed Internet access and other broadband services to homes, as well as provide electric utilities with a means to more effectively manage their electric power distribution operations. In addition, BPL can be used as a communications medium for the delivery of last mile broadband services in AMI systems.

#### G. RF

The RF (Radio Frequency) technology allows the implementation of wireless networking topologies such as point-to-point, point-multipoint, or mesh. RF radio using spread spectrum modulation is a technology currently in use that operates in the 902-928 MHz unlicensed band, achieving RF data rates up to 154 kbps over medium distances (~ 100 km). RF Mesh is a technology that allows meters and other sensing devices to access the network by securely routing data via nearby meters and relay devices. Mesh networks typically consist of radios, routers and gateways. RF mesh forms a network topology by using mesh or star configurations. Any node not in direct communication range of its target destination will have its data relayed by another node in the mesh [16]. This technology supports bidirectional communication between smart meter networks and the power utility, offering high availability. Most current systems operate in the 900 MHz unlicensed band. However, there are systems operating in 2.4 GHz or 5.8 GHz as is the case of wireless networking systems based on the IEEE 802.11a/b/g/n, IEEE 802.15, and IEEE 802.16 standards. New technologies based on RF mesh networking promise an ideal solution with high functionality and low cost. RF mesh networking of multiple sensors in a facility may enable industrial and commercial customers to reduce energy costs through profiling energy usage and developing plans that help to avoid demand charges, reduce energy consumption, and improve business processes. RF mesh networks provide good flexibility, scalability, reliability and redundancy and can be used to implement AMI systems, particularly field area networks (FAN) [8].

#### H. Optical fibers

Optical Fibers technology can be used to implement wide area networks (WAN). Power utilities have installed their own fiber cables on the electrical power lines, taking advantage of rights of way to implement their own private networks. This is generally used to interconnect its main electrical substations with dedicated fiber. Optical fibers provide very high transmission capacity of 10Gbps using a single wavelength and 40Gbps to 1600 Gbps using wavelength division multiplexing (WDM) [10]. They also offer high performance and high reliability using technologies such as SONET or DWDM [17]. The SDH technology has been in use by service providers, as well as utilities to implement its data transmission backbone. SDH provides high reliability and short times (less than 50 ms) for network restoration, in case of errors. Meanwhile, networks based on DWDM technology can transmit different types of data traffic in multiple formats such as IP, ATM, SONET/SDH, and Ethernet at different speeds along an optical channel.

## IV. PROGRESS IN THE IMPLEMENTATION OF AMI PROJECTS

Derived from the need to know the current status of the various AMI projects and technologies applicable to AMI communications systems, this section provides an overview of the ongoing efforts by major power utilities to implement their AMI communications infrastructure. Then, several cases of AMI projects that are in development by various electric utilities worldwide are presented.

### A. Italia-Enel

The Italian electricity company ENEL, through the Telegestore project Automated Meter Management (AMM) system installed by the end of 2013, 32 million of smart meters in Italy, representing 90% [18]. It is noteworthy that the timetable set by the European Commission is at least 80% of smart meters installed by 2020, making it one of the most advanced companies in the world. The Telegestore AMI infrastructure consists of the following main elements: smart meter units, concentrators (collectors), communications networks (PLC and cellular) and a central meter management system. Smart meters include integrated metering functions, data transmission and management equipment. The concentrators, transmitting data to and from the smart meters installed in the MV/LV substations, and other functions such as: calculations, remote operations on meters, alarm signal detection and remote firmware download. The central system for management of meters handles billing information and quality of service monitoring (minutes of interruptions per year). Communication networks are implemented in two levels: at level 1 uses PLC between smart meters and concentrators, and level 2 uses GPRS mobile data communication via a public GSM cellular network between concentrators and the AMM control center.

### B. Sweden-Vattenfall

The Swedish utility Vattenfall Distribution, through the "AMR/AMI and Advanced Meter Management System" project, from 2003 to 2009 installed 860,000 smart meters in its first phase. The full scope of the project consisted of three stages (AMR1, AMR2 and AMR3) and currently the deployment of smart meters is close to 100% [18]. The AMR/AMI infrastructure consists of the following elements: smart meters, concentrators, collection systems, communications networks (PLC, radio, cellular and fiber), and a central meter management system. Smart meters include integrated measurement functions, data transmission and device management. The concentrators perform data transmission and reception functions with the smart meters. Communication networks are implemented on 3 levels. At level 1, uses low power radio communication "LPR" (30%) or PLC (50%) between smart meters and data concentrators. At level 2, between concentrators and AMR collection systems uses GPRS (15%). Also, there is the possibility of using point-to-point GPRS communication via a cellular network, bypassing the data concentrators. At level 3, between the AMR collection systems and the central meter management system uses four communication alternatives: GPRS (70%), public telephone network (20%), short wave radio "SWR" (5%), and private fiber optic or copper pairs (5%). The central management system performs meter billing information service.

C. Canada-Ontario

Canada, through the "Ontario Smart Meter Deployment" project, from 2004 to 2012 installed 4.8 million smart meters for all 4.5 million residential and commercial customers in the province of Ontario, ending its program [18]. Each local distribution company was responsible for installing their own infrastructure and all AMI systems were integrated into a central meter data management repository (MDM/R), through an independent operator in its role as Smart Metering Entity. The MDM/R, management system is responsible for processing the billing information hourly and sends it to the associated distribution companies, for issuance and delivery of billing receipts to all customers [19].

D. Austria

Austria, through the "Energie AG Smart Metering" project AMIS installed by the end of 2013 100,000 smart meters in Northern Austria. Austria, through the "Energie AG Smart Metering" project AMIS installed by the end of 2013 100,000 smart meters in Northern Austria. The full scope of the project is to deploy a total of 600,000 smart meters in 2019 as required by the Austrian law [18]. It is worth mentioning that users who do not have smart meters, must consult their readings through a web portal or through their receipt of consumption. The infrastructure of the AMIS system consists of the following elements: smart meters, communication networks (radio, optical fiber and cellular) and a central meter management system. Smart meters include integrated measurement functions, data transmission and device management. Concentrators perform data transmission and reception with the smart meters. Communication networks are implemented in 2 levels. At level 1 uses PLC between smart meters and concentrators. At level 2, between data concentrators and control centers use three alternative media: radio (66%), fiber (33%) and GPRS (4%). The central control system is responsible for processing the billing information.

E. Netherlands

The Netherlands, through the "Smart Meter Deployment" project, from year 2012 to 2014 installed 500,000 smart meters in its first phase. The full scope of the project is to have a smart meter installed in at least 80% of each household and small business by year 2020 [18]. Communication networks are implemented in 2 levels. At level 1 uses PLC between smart meters and concentrators. At level 2, between data concentrators and the control central uses PLC. Another alternative is to use GPRS directly between smart meters and the control center, bypassing data concentrators [20].

F. USA-California

In the United States, across its territory were installed more than 37 million AMI smart meters and over 45 million AMR meters at the end of 2013. Over 10.5 million of those AMI meters have been installed in the State of California, with another 0.5 million AMR meters primarily by four utilities: Municipal Sacramento Utility District (SMUD), Glendale Water and Power (GWP), Burbank Water and Power (BWP) and San Diego Gas and Electric (SDG&E). SMUD has deployed 617,502 AMI meters, GWP 85,349 AMI meters. The BWP utility has installed 52,163 AMI meters and SDG&E 1,093,312 AMI meters [18]. These four utilities serve about 2.2 million of the 15 million customers in California. Each of these developments includes smart meters and the associated

communications networks, remote reading and control, data management systems, web portal customer interaction, and dynamic pricing schemes. Related to communications infrastructure, BWP deployed and integrated two network types: a Cisco fiber optic network and a city-wide secure Tropos/ABB wireless mesh network, as well as a Trilliant/General Electric smart meter system, and a meter data management system. The fiber optic Ethernet network allows for monitoring and control of the electric distribution system. The smart meters transmit data through the wireless mesh network [21].

V. IMPLEMENTATION OF AMI SYSTEMS IN CFE-MEXICO

In Mexico, CFE has developed a general architecture for implementing AMI communication systems, for its various divisions and zones. Figure 1, shows the proposal to implement the AMI communications systems.

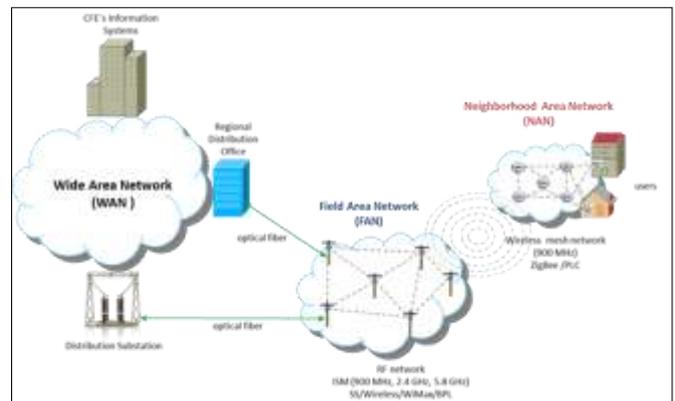


FIGURE 1. ARCHITECTURE PROPOSAL FOR CFE'S AMI NETWORK

CFE has used various communications technologies for their AMI systems. To implement neighborhood area networks (NAN), generally uses PLC technology or ZigBee at 900 MHz wireless mesh-networking. To deploy field area networks (FAN), generally uses point to multipoint spread spectrum wireless technologies operating in the ISM frequency band (900 MHz) or general radio packet service (GPRS) via public cellular networks. To implement wide area networks (WAN), generally uses the CFE's Intranet based on optical fiber technology which forms the national communications network [22]. Table 1, shows the communication technologies used by AMI pilots for several CFE's Distribution divisions, nationwide.

TABLE I. CFE'S AMI SYSTEMS AND USED TECHNOLOGIES

Distribution division	AMI pilots	Communication Technologies		
		HAN	FAN	WAN
Centro Sur	Acapulco	PLC	Optical fiber	Optical fiber
Valle de México Centro	Polanco	ZigBee	Spread Spectrum	Optical fiber
Peninsular	Mérida, Cancún y Riviera Maya	ZigBee	Spread Spectrum, GPRS	Optical fiber
Jalisco	Metropolitana Reforma y Vallarta.	ZigBee	Spread Spectrum	Optical fiber

Distribution division	AMI pilots	Communication Technologies		
		HAN	FAN	WAN
Golfo-Norte	Metropolitana Norte y Poniente.	ZigBee	Spread Spectrum	Optical fiber

### A. Evaluation of AMI Communications Systems

In order to obtain information related to the performance of communications networks of AMI systems currently in operation in different zones of CFE-Distribution; it was required to measure their operating characteristics to establish guidelines that will generate technical recommendations for future implementation of AMI projects. To make the above, five sites with AMI systems were chosen in order to assess the performance of traffic of communication networks. The facilities considered for the evaluation were:

- Zona Polanco de la División Valle de México Centro
- Zona Acapulco de la División Centro Sur
- Zonas Cancún y Riviera Maya de la División Peninsular
- Zona Metropolitana Reforma y Vallarta de la División Jalisco.
- Zonas Metropolitanas Norte y Poniente de la División Golfo Norte.

Bandwidth measurements were conducted between two AMI collectors in various sites to characterize the quality of the PLC and RF links. The assessment of bandwidth, latency and availability were carried out on five AMI systems at different sample periods. Tables II and III, show the results of the measurements of the AMI communication links.

TABLE II. TEST RESULTS OF BANDWIDTH

Site	Period (hrs)	Input traffic (kbps)	Output traffic (kbps)
Zona Polanco	39	7.50	2
Zona Metro Guadalajara	13	20	10
Zona Vallarta	23	13.33	5
Zona Metro Norte	49	10	1
Zona Metro Poniente	6	1	1
Zona Acapulco	24	20	20
Zona Cancún	24	10	10
Zona Riviera Maya	24	20	10

TABLE III. TEST RESULTS OF LATENCY AND AVAILABILITY

Site	Period (hrs)	Latency (ms)			Availability (%)
		Min	Max	Avg	
Zona Polanco	24	23.65	1650	257	84.5
Zona Vallarta	23	5.5	154.01	130.14	98.1
Zona Metro Norte	19	294.29	1019.41	656.85	61.16
Zona Metro Poniente	7	368.95	803.86	582.61	58
Zona Acapulco	24	5.4	20.6	6.2	100
Zona Cancún	24	80.8	1070.88	322.04	84
Zona Riviera Maya	24	78	426.96	187.81	95

## VI. RESULTS

As a result of the work carried out, it was found that the most advanced countries in the deployment of AMI systems worldwide are Italy, Sweden and Ontario, whose penetration

rates have reached 99% of all customers. Italy is the most experienced country in AMI deployment and operation in the world. In Europe, the electricity company ENEL currently has 37 million AMI meters installed throughout the country. Ontario is a good example in North America as the most advanced region on AMI deployment. USA shows a progress about 40-50% on average over the continent. California shows a higher rate of deployment compared to other regions reaching around 60%, followed by Austria with 20%, and Holland with less progress, around 10%. Korea is still in the beginning stage of AMI deployment. On the other hand, China is expected to see the greatest number of smart meters installed by 2020, with over 435 million devices, United States 132 million devices, Japan 58.7 million devices, France 35 million devices, and the UK is expected to have installed 53 million smart meters by 2020. In summary, the global smart meter installation figure is set to reach almost 800 million by 2020 [23]. Mexico and other countries like Ireland and France are still in the pilot/demo stage to test the feasibility of implementing smart meters at short and medium scales, as reported by the International Smart Grid Action Network, "ISGAN" [18]. From the results of the assessment of bandwidth, latency and availability of the AMI communications links; we observed that for the AMI system based on PLC technology, the maximum bandwidth was 20 kbps compared to 10 kbps obtained with RF technology. The average latency obtained was 6.2 ms for PLC, and 255.6 ms for RF technologies. The average availability found was 100% for PLC, and 83% for RF technologies. This was expected, because PLC technology is only used to implement the neighborhood area network (NAN) while optical fiber is used for the field and wide area networks (FAN and WAN). RF technology uses mesh networking for NAN, spread spectrum for FAN and optical fiber for WAN. In general, the RF technology showed the lowest performance, compared to PLC.

## VII. CONCLUSIONS

Currently, there are a number of communications technologies that can be used to implement the infrastructure of AMI systems. The common communications technologies used by most of countries to implement their AMI infrastructure are: PLC, wireless (ZigBee), GPRS, spread spectrum radio, wireless mesh, and optical fiber networks. One interesting technology for distribution networks is to use GPRS communications, via public cellular networks. The advantage of using GMS/GPRS is that mobile networks offer high-speeds, and also include several security issues such as encryption, VPN, firewalls etc., making them secure and reliable. The disadvantage is that it introduces long run high operational costs. From the review of the current state of progress in the implementation of AMI projects around the world, it is concluded that the most advanced countries in the deployment of AMI systems worldwide are Italy, Sweden and Ontario, who have met the goals set by the European Commission. Italy is the most experienced country in AMI

deployment and operation in the world. Ontario is a good example in North America as the most advanced region on AMI deployment, followed by USA. Korea is still in the beginning stage of AMI deployment. Mexico and other countries like Ireland and France are still in the pilot/demo stage.

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