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Advance Metering Infrastructure and DLMS/COSEM Standards for Smart Grid

Divyang D. Vyas and Dr. H. N. Pandya

***Abstract*— There is an increasing interest in making utility services, more efficient, reliable, safe and with enhanced control so as to meet the challenges and requirements of modern days. The solution to this is identified in terms of intelligent utility network popularly called Smart Grid. However, to achieve the goals of smart grid set-up of Advance Metering Infrastructure (AMI) incorporating advanced two-way communication and distributed computing capabilities is essential. A lot of ideas and techniques concerning to AMI have been proposed and attempted, however there was no unique and generally accepted protocol for a long time. DLMS/COSEM has emerged out as one of the most widely accepted standards that are closest to meet the needs of AMI. In the paper, basic functionalities expected from an AMI have been identified and required system architecture is discussed. Overview of the DLMS/COSEM standard is presented with detailed discussion on communication profile proposed in it. Various communication technologies that can be used for various interfaces in AMI are proposed and their characteristics are reviewed.**

***Index Terms*—Smart grid, Embedded system, Communication technologies, Remote monitoring and control**

I. Introduction

ONE of the fastest upcoming paradigms in distribution and management of utility services, particularly in power sector, is Smart Grid. Smart grid basically represents an intelligent utility network that incorporates two-way communication and distributed computing capabilities for improved control, efficiency, reliability and safety. The first step towards realizing smart gird is to setup Advance Metering Infrastructure (AMI) that has added intelligence and communication facilities compared to current metering infrastructures. For realizing AMI it is necessary for the power market to change from monopoly market to more open and standardized market [1]. Device Language Message Specifications (DLMS) and Companion Specification for Energy Metering (COSEM) is suite of standards developed and maintained by DLMS User Association for the said purpose. These standards has been co-opted by International Electotechnical Commission (IEC) under IEC 62056 series of standards. Though lot of communication standards and techniques concerning to AMI are already in use, none of them stands out as a well designed layer of intelligence that completely covers the scope of smart gird. The DLMS seems to be closest current solution and has become the standard of choice among many countries and meter designers to achieve interoperability among metering systems involved in metering of most energy types (electricity, gas, heat and water), used at multiple application levels (residential, transmission and distribution) [2].

Divyang D. Vyas, Research Scholar of Department of Electronics, Saurashtra University, Rajkot-360 005, India. e-mail: vyasdd@yahoo.com).
Dr. H. N. Pandya, Head of Department of Electronics, Saurashtra University, Rajkot-360 005, India (e-mail: hnpandya@yahoo.com).

This paper is organized as follows. In Section II, primary functions that AMI is expected to support have been listed. This is followed by discussion on system architecture of AMI and role of each component in Section III. In Section IV, DLMS/COSEM standard is reviewed with emphasis on its communication profile. Various communication technologies that may be used for various interfaces in AMI has been identified and compared in Section V. This is followed by conclusion in Section VI.

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II. AMI System Functions

AMI is aimed to increase the level of observability and controllability of a complex utility service network like power system. In addition the infrastructure should support ease of interoperability and scalability. Following is the list of primary functions [3] that AMI is expected to support

- Meter registration to incorporate new meters in the gird.
- Remote tariff programming for updating parameters related to tariff, calendar, contract period etc.
- Remote meter reading (cyclic and on demand) for the purpose like billing.
- Remote disconnection and reconnection of electrical power to a customer on a designated date and time.
- Synchronization of the internal clock of metering equipment with the overall system clock.
- Remote firmware updation.
- Management of alarm and event over the gird
- Fraud detection.
- Remote access to system elements other then meters present over the gird.

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- Remote programming and gathering of load profile for energy management.
- Automatic adaptation to grid changes.
- Load management and energy balance through activation/ deactivation of the demand power control mode in meters.
- Device management at customer end and prepayment options
- Power quality management.

III. AMI System Architecture and Components

AMI system architecture [3] is shown in Figure 1. It represents the reference frame work that satisfies the functional, technical and other general requirements of AMI. Though initiatives towards AMI have been dominantly taken up by the power utility sector, the architecture supports multi-utility metering. However, compared to other utility meters, electricity meters are directly connected to the electricity network, which may conveniently be used as a media for data exchange. Thus, it is expected that the largest penetration and the back-bone of AMI for multi-utility metering will be in electrical network. The main components of AMI system are discussed as follows.

A. Electricity meter and Communication HUB

This module performs two basic functionalities. First to measure and record electrical energy consumed/produced and related parameters of interest, and second to act as a communication hub. There can be more than one form in which electricity meter and communication hub may exist. In new installations a single smart meter performing both the functions of metering and communication is possible. On the other hand, for installations where old electricity meter are not to be replaced, then a communication hub can be as a separate ad-on unit. In multi-utility metering, meters for different utilities can be different which may all be connected to a common communication hub. Further, interfacing devices other then meters may also be connected to the communication hub.

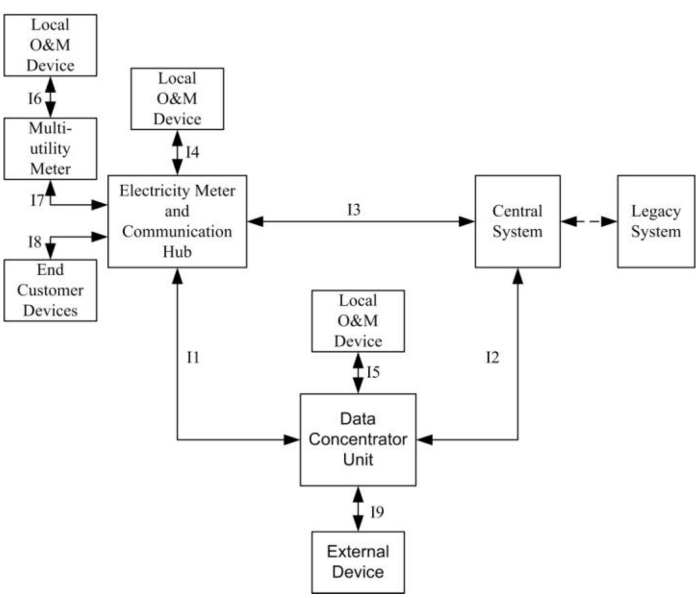

Fig. 1: AMI system architecture.

Communication hub provides additional processing capabilities, memory and communication means for storage and transmissions of data to the electricity meter. It facilitates data transfer between in-home network devices and the external AMI network. It may be directly connected to the Central system or may be connected through Data concentrator unit (DCU). In either of the cases, Communication hub may operate in two different modes viz. as a Gateway or a Proxy Gateway. The later is more suitable as most of the units that are connected to communication hub namely Multi-utility meter and interfacing devices generally are battery operated and "always on" status may not be possible for them. Thus, spontaneous interaction with these devices may not be possible, which makes pure Gateway function less suitable. As a Proxy Gateway, Communication hub buffers the periodic data received from connected devices and forward it to higher level on demand. Similarly, commands received from higher level are buffered in Proxy Gateway before being delivered to the connected devices. Additionally, Communication hub may also have a facility of local interface.

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B. Data Concentrator Unit

This module acts as an intermediate element between Communication hub and the Central system. Communication hub may be directly connected to the Central system; however this may not be always efficient particularly towards the tail of distribution network. In such a scenario number of Communication hubs may be connected to a single DCU. Function of DCU will be to manage two way data exchange. It will collect and mange information received from various Electricity meters and Communication hub and sent it to Central system and will also transfer commands received from Central system to Electricity meter and Communication hub.

Similar to Communication hub, functioning of DCU may be as a Proxy Gateway. It may also support facility of local interface for local access of data. Further, it may optionally also feed to systems other then Central system on the network like SCADA.

C. Central System and Legacy System

Central system acts as a central server responsible for the management of all information and data related to smart metering. It is also responsible for the configuration and control of all system components and responding to all events and alarms over the network. It is possible that Central system may delegate part of its operation to DCU or Communication hub so that some operations may be performed at lower level in hierarchical structure.

Legacy System represents the commercial or technical systems of a system operator. This may be more than one depending on the number of different utility system operators operating on common grid. It is responsible for the

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management of business processes such as meter registrations, remote meter reading, tariff adjustment, remote connect/disconnect, billing, outage management, customer care etc. Legacy system is purely to support operational and business processes and operates independent of type of metering infrastructure and communication technologies. Central system will execute the received request from the Legacy system over the network and also conveys back the response received from meters thus completing the business process.

D. Local Operation and Maintenance (O&M) Devices and External Devices

These are portable devices used by the system operator's service personnel to locally configure, operate and maintain various elements over the network. Local O&M facility is made available with Electricity meter and Communication hub, Multi-utility meters and DCU. Local O&M facility is useful particularly at the time of installation and later to perform maintenance or reconfiguration if not possible remotely by Central System. O&M facility may also help to retrieve meter data as a redundant measure in case of sustained communication failure.

External devices refer to auxiliary equipments that may be optionally connected to the DCU which utilizes network facilities to support objectives of AMI. Example of such facility can be SCADA system or other similar system related to substation automation.

E. Multi-utility Meters and End Customer Devices

Multi-utility meter represents smart metering devices that can measure utility services such as gas, water etc. These are expected to be battery operated and not connected to mains power.

End customer devices are auxiliary equipments connected to the meter installation that enables the customer to interact with the utility meters and/or load devices with in customer's premises. These as such are not the part of AMI but can be optionally given as an additional facility to customer. Simple example of an End customer device can be a display unit that gives details of consumption, current tariffs etc. On the other hand, example of smarter End customer device can be of a device that enables customer to manage operation of specific loads from single user interface using in-home network.

IV. DLMS/COSEM STANDARD

DLMS is a suite of open standards developed and maintained by the DLMS User Association [4]. COSEM is part of the DMLS protocol stack [5]. DLMS primarily covers two protocols viz. Application protocol and Transport protocol that define the standard method to model and transfer metered data and other classified functions of the energy meter. These protocols are officially endorsed and registered by the International Electrotechnical Commission (IEC) under IEC 62056 [6]. DLMS standards are published as set of colored books details of which is shown in Table 1.

TABLE I.
DLMS//COSEM STANDARDS AND ITS EQUIVALENT IEC STANDARDS

DLMS User Association	IEC	Standards about
Blue Book	IEC 62056-61 IEC 62056-62	COSEM meter object model and object identification system (OBIS)
Green Book	IEC 62056-21 IEC 62056-42 IEC 62056-46 IEC 62056-47 IEC 62056-53	Architecture and protocol to transport the model
Yellow Book	--	Conformation testing process
White Book	--	Glossary of DLMS/COSEM terms

DLMS protocol is based on OSI (Open System Interconnection); however 7 layers of OSI are primarily collapsed in to 4 layer structure which are physical, data link, transport and application. The physical layer defines the transfer method and a communication parameter to transfer information with the meter. The data link layer provides the communication with the meter and the messaging method to change data. The transport layer enables data transfer using IPv4 network. The application layer defines the energy meter functions as objects so that the application program can access it.

COSEM defines standards to model metering equipment as a set of logical devices, hosted in a single physical device. Each logical device models a subset of the functionality of the metering equipment in terms of attributes and methods and is called COSEM objects. Various COSEM objects that have same structure are covered under a common COSEM interface class. OBIS (Object Identification System) naming is used to identify COSEM objects to make them self-describing. A full list of standard OBIS codes [7] and valid combinations of standard values in each group is maintained by the DLMS User Association. Such a hierarchical structure defined by COSEM helps to combine standardized building blocks to model any complex metering system and that to independent of utility type and communication media.

DLMS/COSEM is based on client-server paradigm [4], where metering equipment plays the role of the server and data collection system like DCU or Central system, plays the role of a client. In cases of events or alarms, server can also execute an unsolicited service to notify clients. The communication protocol stack, called a communication profile, is completely independent of the application layer so servers and clients may independently support one or more communication profiles to communicate over various media. The COSEM model, used for modeling the application process and the application layer, remain the same. When a meter is read, the necessary attributes of described objects are accessed using an xDLMS (Extended DLMS) service and transformed into a series of bytes, called APDUs (Application Protocol Data Units).

Various DLMS communication profiles as shown in Figure 2 are discussed below [4].

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1) *3 layer correction oriented High-level Data Link Control (HLDC) based communication profile:* This comprises of COSEM application layer, HDLC based data link layer and the physical layer for correction oriented asynchronous data exchange. It supports data exchange via a local optical or electrical port, leased lines and PSTN or the GSM network.

2) *TCP-UDP/IP based communication profile:* These profiles support data exchange via the Internet over various physical media like Ethernet, ISDN, GPRS, UMTS, PSTN/GSM using PPP etc. In these profiles the COSEM application layer is supported by the COSEM transport layer(s), comprising a wrapper and the Internet TCP or UDP protocol. Lower layers can be selected according to the media to be used as the TCP-UDP layers hide their particularities.

3) *S-FSK PLC based communication profiles:* These profiles support data exchange via power lines using S-FSK modulation. In these profiles, the COSEM application layer is supported by the connectionless Logical link control (LLC) sublayer as specified in IEC 61334-4-32, or the LLC sublayer using the data link layer based on the HDLC protocol as specified in IEC 62056-46. The MAC and the Physical layers are as specified in IEC 61334-5-1.

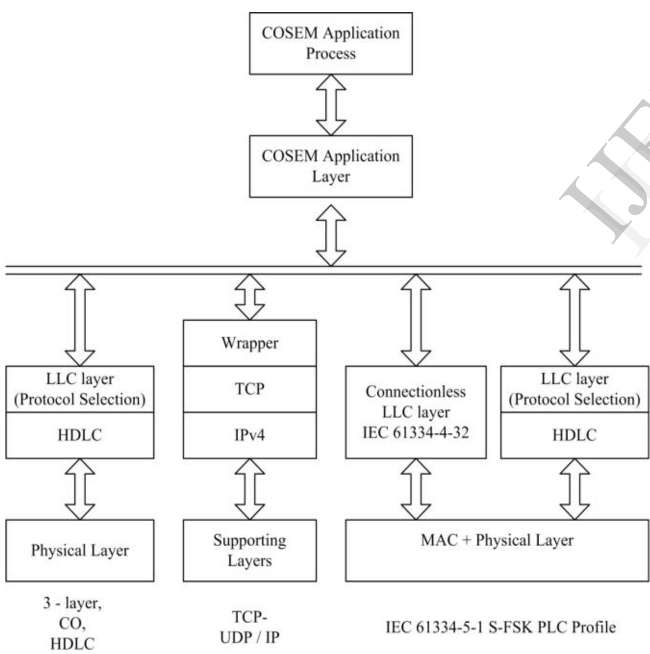

Fig. 2. DLMS/COSEM communication profile.

V. COMMUNICATION TECHNOLOGIES FOR AMI

Communication technologies used for various interfaces in AMI should be evaluated against number of factors like bandwidth, latency in communication, network coverage, reliability against failure, security and installation and operational cost. For the AMI architecture discussed in previous section, communication technologies that can be proposed to be used for interface between various elements is given in Table. 2. As Legacy system works almost independent of the communication technologies used in interface of other elements in AMI, the interface between Central system and Legacy system can have number of options and hence not mentioned in the Table.

A. *IEEE 802.11 Standards*

IEEE 802.11 is a set of IEEE standards that govern wireless networking transmission methods [8]. They are commonly used today in their 802.11b, 802.11g, and 802.11n versions to provide indoor wireless local area network (WLAN) and home area network (HAN). They can be used in AMI for HAN and home automation. Use of these standards supports design of low cost application devices to be used at consumer end. Use of this however is up to 100m and security issues arising due to multiple networks operating in the same locations has to be resolved.

IEEE 802.11s is amendment to IEEE 802.11 for mesh networking in WLAN, popularly known as wireless mesh network (WMN). This consists of radio nodes organized in a mesh topology. In AMI this can be an option for defining how wireless devices can interconnect to create a WLAN mesh network, which may be used for static topologies and ad-hoc networks. This can act as an AMI backhaul particularly at distribution end supporting automation, demand response and remote monitoring. It is easily scalable and allows improved coverage around obstacles, node failures and path degradation.

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TABLE II
COMMUNICATION TECHNOLOGIES FOR VARIOUS AMI INTERFACES

Interface Tag in Fig. 1	Technology Type	Proposed appropriate Technology and lower layer protocol
I1	Wired	PLC IEC 61334
I2, I3	Wireless and wide area	GPRS/UMTS TCP-UDP/IP
I4,I5,I6, I7, I8	Wireless and local area	ZigBee, Wi-fi IEEE 802.15.4 IEEE 802.11
I9	Wireless and local area	ZigBee, Wi-Fi, Substation Automation IEEE 802.15.4 IEEE 802.11 IEC 61850

B. *IEC 61334*

IEC 61334 is a standard for low-speed reliable power line communications. It is also known as S-FSK (Spread Frequency Shift Keying). A typical PLC system in AMI may consist of a backbone-coupled DCU close to a MV/LV transformer. All traffic on the line is initiated by the DCU, which acts on behalf of Central system. More recent narrowband PLC technology include sophisticated techniques such as OFDM (Orthogonal Frequency-Division Multiplexing) to provide higher data rates, and focuses on broadband solutions operating in the 1-30 MHz band [9]. Further, installation of filters highly improves SNR ratios. Despite the difficulties, PLC technologies are at a clear advantage for utility companies as no separate communication channel is required and it can prove to be relatively cheaper [10].

C. ZigBee

ZigBee is a low-cost, low-power communication standard maintained and published by ZigBee Alliance [11] and is suitable particularly for personal area network. It is based on based on IEEE 802 standard and works in industrial, scientific and medical (ISM) radio bands. One of the important advantages of ZigBee is that it supports mesh-networking. This provides high reliability and more extensive range. For AMI, ZigBee is very suitable for realizing Home Area Network (HAN) that includes interface between the Electric meter and communication hub with other elements like Multi-utility meter, Local O&M device, End customer device etc. Currently, under ZigBee Smart Energy profile [12], number of agencies is jointly working to develop a standard for interoperable products that monitor, control, inform and automate the delivery and use of energy to support goals of smart grid.

D. IEC 61850

IEC 61850 [13] is primarily designed for intra-substation communication for substation automation. The standard defines the application layer and is thus independent of the underlying communication medium. All services and models are designed in an abstract form called ACSI (Abstract Communication Service Interface) which then can be mapped to protocols such as MMS (Manufacturing Message Specification) and TCP/IP over Ethernet. Typical use of this standard in AMI is for interface between DCU and External devices e.g. a SCADA system.

E. Cellular Technologies

For data communication over a large geographic area (Wide Area Network) cellular technologies are one of the best available options. With evolution of cellular technology from 2G (GSM) to 3G (GPRS/UMTS) and presently towards 4G (LTE) it has became possible to achieve higher data rates, better security and wide coverage [14]. Scalability is another important advantage that these technologies provide. These technologies can be used for interface between DCU and Central system or where Electricity meter and communication hub is directly connected to Central system. Because of continuous rapid growth in this domain the major concern in use of these technologies is their life span.

VI. CONCLUSION

In this paper key functions and system architecture for AMI has been discussed. DLMS/COSEM standards, which is the closest current solution to the requirements of AMI and smart grid is studied. Method to model the metering equipment and OBIS naming is studied. Communication profile proposed based on client-server architecture proposed in DLMS standards is reviewed. Various communication technologies that can be used for different interfaces in AMI has been discussed and evaluated. The study reveals that enough opportunities lie for the researchers and market in general in the mammoth work of smart grid implementation as it requires a heterogeneous solution that allows integrating various existing open technologies and achieving interoperability and co-existence of various communication protocols.

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