Advancement of domestic Smart Energy Meter as per Indian Standards for Smart Grid

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Abstract — The smart grid concept has been realized in the last few decades with the evolution of metering from mechanical meter to electronic meter and advanced from Automated Meter Reading (AMR) to Advanced Metering Infrastructure (AMI). Smart grids are networks that transmit and deliver electricity based on specific smart technologies. A smart grid overcomes the limitations of conventional networks by incorporating smart meters into the grid through AMI. A smart meter can be defined as an energy meter that measures energy consumption with many embedded smart functions such as demand management, demand response, load management, load curtailment, etc. Smart meters form the backbone of a smart grid and transmit all its smart technologies to the smart grid. This article describes the development of a smart meter with Indian standards.

Keywords: Smart Grid, Smart Meter, AMI, AMR, Energy Meter, Demand Side management,

I. Introduction

A smart grid can be explained as an electrical network that includes smart technologies for monitoring, controlling and delivering electricity to consumers. It creates a platform for observation, analysis, control and communication within the network to reduce energy consumption and costs, improve efficiency, maximize transparency and increase the reliability of energy supply.

Global smart grid implementation has accelerated with technological advances in Advanced Metering Infrastructure (AMI). AMI forms the backbone of smart grid technology [1]. An AMI can be defined as an infrastructure that contains a number of smart meters connected centrally through a Data Concentrator Unit (DCU) to a Head End System (HES) or directly from the smart meters to the HES.

Smart meter is a state-of-the-art electricity meter that measures electricity consumption using built-in intelligent technologies that differentiate it from a regular conventional electricity meter. Smart meters are designed to include both utility and customer requirements. The integration of smart meters into the electricity grid involves the implementation of a wide range of hardware and software technologies.

The smart meter forms the core of the smart grid implementation, which is primarily concerned with providing data and information on demand to the Head End System (HES) [2].

Smart meter provides utility by providing instant information about the circumstances like detection of power theft, tampering etc. Due to this, smart meter has grown in popularity worldwide. In India, the implementation of smart meters is still in its infancy. However, smart meters have already been implemented on a large scale in many developed countries such as Australia, Canada, the US and the UK.

In India, the smart meter standards are IS16444 (2015), IS15959 (Part I, 2011) and IS15959 (Part II, 2016). Since these standards have been released recently and are still being modified, the Center for Development of Advanced Computing (CDAC) has developed a smart meter that adheres to Indian standards and is able to incorporate upcoming changes, if any.

A special feature of the intelligent electricity meter is the two-way measurement of the energy flow and also the two-way communication between the supplier and the consumer. The import of energy from the public grid to the consumer and the export of energy generated by the consumer through solar power plants or other methods of distributed generation can be measured simultaneously. Two-way communication allows the utility to read data measured by the meter, which shows the external communication, as well as create various meter configuration programs that show the internal communication.

The main features of a smart meter are its demand-side management and load limitation [4]. By regularly monitoring and analyzing smart meter data from HES, the company can obtain a trend in energy consumption for a specific customer. This allows the plant to secure sufficient power in advance without tripping transformers that leave the surrounding area without power. If a particular customer's energy consumption rises above the permitted load, the power company can remotely disconnect that particular supply through a smart meter directly without disturbing the surroundings. This kind of demand management is only possible with the help of strong analytical methods used in HES. In this way, the energy company can achieve better management and monitoring of the smart grid, which in turn improves its efficiency and reliability.

The programmable tariff zones feature in smart meter enables the utility to set higher pricing at peak hours which helps in flattening of demand curve. As an additional feature the consumers can be made to access their energy consumptions from smart meter readings which enables them to make use of those readings to reduce their energy consumption according to tariffs. Smart meter also forms the integral component of smart homes which aids in house energy management.

II. Smart Meter Architecture

The smart meter architecture developed by CDAC is shown in Fig. 1. Each block in Fig. 1 has a dedicated activity, which is described in detail below.

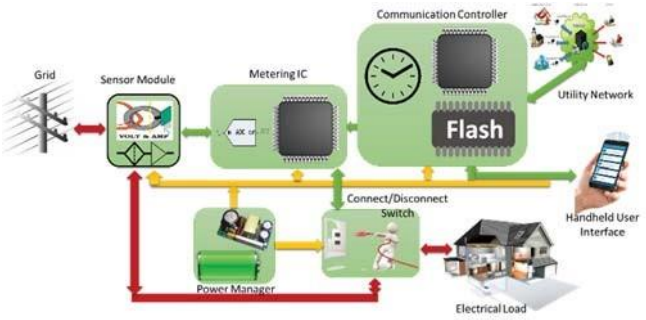

Fig. 1. Smart Meter Architecture

A. Sensor module

Electrical parameters such as voltage and current from the network are fed to the sensor modules of the smart meter. The sensors contain a current transformer and potential divider for measuring current and voltage.

B. Metering IC

The measurement IC uses its built-in analog-to-digital converter (ADC) to acquire voltage and current signals, calculate measurement parameters, and store the information in specified registers dedicated to each parameter.

C. Communication driver

The communication controller refers to the microcontroller in the smart meter that forms the control part of the system. It deals with the coordination and control of power management, memory storage, load management, profile generation and establishment of two-way smart meter communication. The metering data from the metering IC is read by the controller and used to generate various profiles such as block load profile, daily load profile, billing profile, event profile etc. These profiles are communicated to the HES on demand or whenever the meter is pushed. . The built-in real-time clock (RTC) of the controller is used for synchronized measurements with the time data with the service server. The microcontroller also handles load limiting with an on/off switch.

D. Communication modules

Communication modules include GSM, WiFi, Bluetooth and IRDA. GSM (2G/3G/4G), IrDA and WiFi can be used for utility purposes, while Bluetooth can be used on the consumer side. The communication module acts as a bridge between the meter data and the public network server. It creates a two-layer protocol, i.e. the first layer converts the meter data into a recommended Advanced Metering Infrastructure protocol such as IEC 62056 (Parts 21, 42, 46, 47, 53, 61 and 62), IS 15959 and the second layer converts the smart meter protocol compatible with the communication module protocol such as GSM/GPRS/WIFI. The Device Language Message Specification (DLMS) and the Companion Specification for Energy Metering (COSEM) protocol govern the communication of the smart meter with the HES.

E. Power Manager

A switched mode power supply (SMPS) forms the power manager that powers the electronics in the meter and converts the AC from the main line to the required DC voltages. A super-capacitor is also used in the smart meter to supply power to the entire system in the event of a main line failure.

F. Display

The user display, which is removable and optional, can be used for monitoring purposes. In addition to the liquid crystal display (LCD) in the meter, there is also a manual user interface, so the user can track their usage, analyze daily and weekly usage, etc.

III. Indigenous Smart Meter Development

Center for Development of Advanced Computing (CDAC) has developed single-phase and three-phase smart meters for AMI based on Indian Standards ISI6444:2015, IS 15959 (Part 1):2011 and 15959 (Part2): 2016. Fig. 2 shows a single-phase smart meter and Fig. 3 shows a three-phase smart meter developed by CDAC. The smart meter developed by CDAC consists of three pluggable PCBs. SMPS (Switched Mode Power Supply), SMCC (Smart Meter Control Card) and SMCM (Smart Meter Communication Module)

Fig. 2. Single phase smart energy meter developed by CDAC

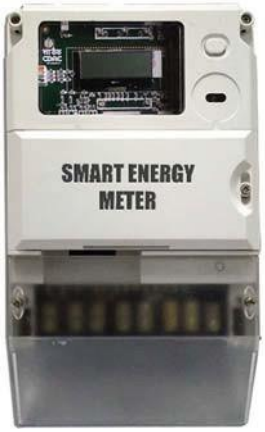

Fig. 3. Three phase smart energy meter developed by CDAC

A. SMPS

The SMPS of single-phase and three-phase smart meters is shown in Fig. 4 and Fig. 5. It operates from 60 V to 440 V AC between line and line to neutral. A three-phase SMPS is a 3-phase 3-wire SMPS and is capable of working with a 3-phase 4-wire as well. It can also work with one phase and one neutral or two phases or three phase without neutral, three phase with neutral, any of the four as required. The maximum output voltage rating is 6 V, 2 A. The SMPS is engaged in providing 5 V DC to other electronics embedded in the smart meter.

Fig. 4. Single phase SMPS

Fig. 5. Three phase SMPS

B. SMCC

The plug-in SMCC of single phase smart meter and three phase smart meter are shown in Fig. 6 and Fig. 7. Here PIC controller is used to control the overall operation of the system. A measuring IC integrated in the SMCC measures the required electrical parameters. An external flash memory is used to save the measured data.

Fig. 6. Single Phase Control Card

Fig. 7. Three Phase Control Card

C. SMCM

Single-phase and three-phase module plug-in SMCMs are shown in Fig. 8 and Fig. 9. For GPRS, network coverage may vary from location to location. The module is pluggable so SIM (Subscriber Identity Module) networks can be changed to suit the network with maximum coverage in a particular area. In areas that do not support any kind of network coverage for GPRS, any RF modules like LoRa, Bluetooth, WiFi etc. can be plugged into the same socket without any hardware modification in SMCC & SMPS.

The developed meter establishes two-way communication between the grid and the smart meter through the Device Language Message Specification (DLMS)/ Companion Specification for Energy Metering (COSEM) protocol. DLMS/COSEM is a standard specification that provides an interoperable environment for structured modeling and gauge data exchange. DLMS is designed to support messaging to and from power distribution facilities in a computer-integrated environment. COSEM is an interface model of communicating devices for energy measurement, which sets rules for data exchange based on existing standards. Security of meter data is ensured using cryptographic techniques. The electricity meter has communication modules for GPRS, WiFi, Bluetooth and IrDA, which can be configured depending on the utility's requirements.

Fig. 8. Single phase Communication Module

Fig. 9. Three phase Communication Module

The developed meter has a facility for remote load connection/disconnection. It also has tamper detection capability. The meter's firmware can be upgraded remotely, enabling Firmware Over-The-Air (FOTA) technology. In addition, password protected user login and parameter setting, net metering i.e. energy import and export metering are prominent features of this meter. Another feature of this meter is an Android-based app that allows customers to view energy consumption.

IV. Challenges in Indigenous Development

Unlike other developed countries where people can afford to buy a smart meter regardless of the price range, Indian conditions are tied to the cost of smart meters [3]. Therefore, the main challenge in developing a smart meter was to make it cost-effective.

The PIC driver is chosen to have a built-in LCD driver and driver, RTC, IrDA driver, etc. So no separate ICs/modules were needed. The segmented LCD used in SMCC is very cheap. Also, the measurement IC in SMCC is low cost and conforms to the standard.

Each of the three printed circuit boards used is double-layered, which makes it convenient even for printed circuit board manufacturers with minimal production technology.

The modules are pluggable, so if a particular module is malfunctioning, only that module needs to be replaced and not the entire meter itself. Also with communication modules, the module can be disconnected from the meter and the SIM card operator can be changed if the meter does not communicate for a specific network in a certain area. If a specific region does not support GPRS, an RF module such as LoRa, WiFi, etc. can be connected to the same connector without any hardware modification.

The system uses both a shunt and a current transformer for current measurement. A current transformer in one line ensures isolated measurement.

The remaining components used in the development of a smart meter are commonly and cheaply available in the markets.

When developing the software technology, the DLMS protocol suite was expensive, but it was a necessary part of smart meter development to enable interoperability between different manufacturers. CDAC has successfully developed, tested and validated a proprietary and independent DLMS protocol stack in C that can be ported to any microcontroller.

V. Observations and Test Results

The accuracy test results of the developed Class 1 single-phase meter are shown in Table I.

The percentage error in active energy when the current flows only through the phase line and the neutral line individually was observed for unity power factor, 0.5 lagging power factor and 0.8 main power factor at currents of 0.1 A and 60 A, setting the conditions in a standard calibration bench accuracy class 0.1.

The results of compliance test of DLMS communication protocol of CDAC Smart meter conducted at CPRI, Bangalore are reproduced as shown in Fig. 10. The above test includes testing of different layers – HDLC, Application layer, COSEM layer and Symmetric Key Security (SYMSEC) layer).

TABLE I. Accuracy Test Results of CDAC Smart Meter

Current (in A)	Error Percentage					
	Unity Power Factor		*0.5Lagging Power Factor*		*0.8 Leading Power Factor*	
	Phase	*Neutral*	*Phase*	*Neutral*	*Phase*	*Neutral*
0.1	0.379	-0.037	-0.016	0.354	-0.7	-0.258
60	-0.01	-0.015	0.401	0.283	-0.196	-0.129

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TYPE   TOTAL   SKIPPED   INAPPLICABLE   INCONCLUSIVE   PASSED   FAILED
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HDLC   36      0         3              0              33       0
APPL   63      0         12             0              51       0
COSEM  991     0         3              69             919      0
SYMSEC 64      0         23             0              41       0

Communication profile:          HDLC

Application context names:      LONG_NAMES,LONG_NAMES_WITH_CIPHERING

Security mechanisms:            NO_SECURITY,LOW_LEVEL_SECURITY
                                HIGH_LEVEL_SECURITY_GMAC

ACSE and xDLMS features:        ACTION,GET,SERVICE_SPECIFIC_BLOCK_TRANSFER
                                SET

Security features:              ACTIVATE_SECURITY_POLICY,KEY_TRANSFER
                                SERVICE_SPECIFIC_GLO_CIPHERING

Logical device(s) found:
                                SAP = 1 is "4954502D4C5431302D36305665723033" (ITP-LT10-60Ver03)

COSEM classes tested:           1,3,4,7(1),8,9,15(1),18,20,22,23(1),41,48
                                64,70,71
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Fig. 10. DLMS Conformance Test Results

VI. Benefits Of Smart Meter

Smart metering enables continuous energy monitoring at the household level, accurate billing, etc. AMI communicates data from smart meters to utilities, but also has the ability to inform consumers about their usage, peak demand, charges, energy consumption costs, etc.

The benefits of a smart meter can be categorized as follows.

A. *For Utilities*

- Demand Side Management allows the supplier to have full control over power distribution through load limiting, preventing transformer tripping and local power outages.
- Demand analysis helps the power plant ensure adequate energy supply for a specific location in advance
- Since the meter transmits data to the grid, there is no need to take monthly meter readings with a meter reader Meter reading costs can be eliminated
- Collecting data from meters over the air eliminates the need for billing calculations and back office accounting
- The utility can request and collect data from the meter at any time and can use that data for load balancing
- The system can be monitored quickly and in detail
- The tool can connect and disconnect loads remotely.
- Meter tampering and theft can be detected so that energy consumption is not left unmeasured
- Messages related to power outages immediately reach the network

• Energy can force dynamic pricing, whereby the cost of electricity increases or decreases depending on demand

• Different tariff zones can be enabled for pricing

• Customer safety is ensured. Customer complaints and service calls can be kept to a minimum.

• Data from each meter is readily available and can be analyzed for further studies

• Optimizes energy from existing plants, eliminates expenses for the construction of new plants

B. Advantages for Electricity customers

- Smart meters offer electricity customers the following benefits:
- Electricity bills are more accurate and timely
- Customers can get more detailed information about energy consumption
- Power outage recovery is much faster
- Consumers can reduce consumption during peak hours by analyzing usage to reduce electricity bills
- Net metering creates a platform for consumers to get paid for the energy they produce through solar power plants or other distributed generation methods

C. Environmental benefits

- Grid metering supports distributed generation from renewable energy sources such as a grid-tied solar inverter
- Less impact on the environment, as effective demand management reduces the costs and carbon emissions associated with electricity generation.

VII. Smart Meter Future in India

According to the India Smart Grid Forum (ISGF), by 2020, almost every building in urban and semi-urban areas on Earth will have broadband Internet connectivity [5]. This can eliminate the need for data concentrator units/gateways as it is possible to upload data from smart meters directly to the internet which can be downloaded at any time at the Head End system. Also, the Indian government aims to introduce 250 million smart meters to replace conventional meters, pursuing its technological advantages [6].

Smart meters can be connected to a home or building or neighborhood Wi-Fi network that connects the meter to the broadband internet to send data from the meter. Head End System and Meter Data Management System (MDMS) can aggregate data by connecting to the Internet. Data can also be sent to utility and consumer applications on their smartphones, eliminating the need for home displays. Govt. India was running a National Optical Fiber Network program to provide broadband to 250,000 villages, which was set to expand to 600,000 villages under the Digital India program to provide universal broadband access to all [5].

These systems can bring broadband access to most parts of the country and will create a dedicated fiber optic backbone for India's power system.

VIII. CONCLUSION

The smart meter has revolutionized conventional electricity meters thanks to its intelligent built-in technologies. It has gained momentum globally as it prioritizes utility and consumers with its smart capabilities. The smart meter has paved the way for the realization of a smart grid through AMI. CDAC could successfully develop a smart meter that complies with the Indian Standards issued by the Bureau of Indian Standards (BIS). Since the development started from scratch, it was possible to achieve complete smart meter know-how in both hardware and software technologies. CDAC Smart Meters are adapted to changes in Indian Standards that may occur in the future. These in turn help to get rid of any foreign agencies that would interfere with our system by any means that may pose a threat to network security or cause high maintenance costs for the company. Homegrown smart meter development thus paves the way with full authority and control to revolutionize the realization of smart grids through AMI.

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