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Smart Energy Meter Auditing with Power Demand Controller using Internet of Things

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Abstract

The concept of smart grid has been realized in the last few decades with the evolution of metering from mechanical meter to electronic meter and has progressed from Automated Meter Reading (AMR) to Advanced Metering Infrastructure (AMI). Smart grids are those networks that carry and deliver electricity based on specific smart technologies. Smart grid overcomes the limitations of conventional grids with the incorporation of smart meters in the grid through AMI. Smart meter can be defined as an energy meter that measures energy consumption with many incorporated smart features like demand side management, demand response, load control, load curtailment, etc. A smart meter forms the backbone of a smart grid imparting all of its smart technologies to the smart grid. The development of smart meter with Indian Standards is described in this paper.

Keywords: Smart grid, smart meter, AMI, AMR, energy meter, demand side management.

1. Introduction

A smart grid can be explained as an electricity network that incorporates smart technologies to monitor, control and supply electricity to consumers. It generates a platform for observing, analyzing, controlling and communication within the network for reducing energy consumption and cost, improving efficiency, maximizing the transparency and increasing reliability of the energy supply. The worldwide realization of smart grid has accelerated with the technological advancements in Advanced Metering Infrastructure (AMI). AMI forms the backbone of smart grid technology [1]. AMI can be defined as an infrastructure that contains a specified number of smart meters connected centrally through a Data Concentrator Unit (DCU) to the Head End System (HES) or directly from smart meters to the HES.

Smart meter is the state-of-the-art energy meter that measures consumption of electrical energy with in build smart technologies that distinguishes it from a normal conventional meter. Smart meters are designed in such a way that it incorporates the requirement of the utility companies as well as the customer. Integration of smart meters into electricity grid involves implementation of wide range of hardware and software technologies. Smart meter forms the core of smart grid implementation mainly concerned with providing data and information on request to the Head End System (HES) [2].

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Smart meter secures the utility by providing instantaneous information on circumstances like power theft detection, tampering, etc. This in turn made the smart meter to gain momentum worldwide. In India, smart meter implementation is still in the infancy stage. But, smart meters have already been implemented in large scale in many developed countries such as Australia, Canada, USA, and UK.

In India, the standards for smart meter are IS16444 (2015), IS15959 (Part I, 2011) and IS15959 (Part II, 2016). Since these standards are released recently and still amendments are occurring, Centre for Development of Advanced Computing (CDAC) has developed smart meter that adheres to the Indian standards and are capable of inclusion of forthcoming amendments, if so. The peculiar feature of smart meter includes bidirectional energy flow measurement as well as bidirectional communication between utility and consumer. The import energy from utility to consumer and export energy generated by the consumer through solar power plants or other distributed generation methods can be measured simultaneously. The bidirectional communication enables the utility to read the data measured by the meter, which depicts the outward communication, as well as establish various configuration programs to the meter, which depicts the inward communication.

The salient features of smart meter are its demand side management and load limiting [4]. By regular monitoring and analysis of smart meter data from the HES, the utility can obtain the trend in energy usage for a particular customer. This allows the utility to arrange sufficient amount of energy beforehand without causing tripping of transformers that leads a neighborhood powerless 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.

2. Smart Meter Architecture

The architecture of smart meter developed by CDAC is illustrated in Fig. 1.

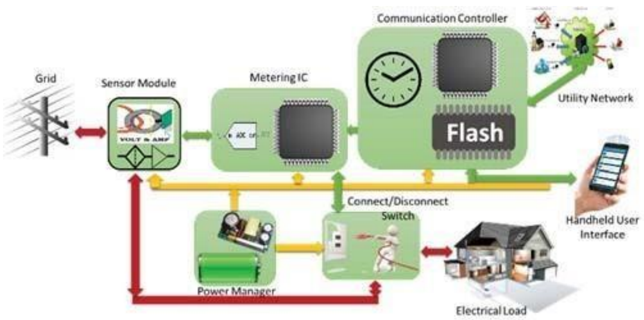

Figure 1 Smart Meter Architecture

Each block in Fig. 1 has dedicated operation that is detailed below.

2.1 Sensor Module

The electrical parameters like voltage and current from grid is fed into the sensor modules of smart meter. The sensors include current transformer and potential divider for current and voltage measurement respectively.

2.2 Metering IC

The metering IC employs its inbuilt Analog to Digital Converter (ADC) for acquisition of voltage and current signals, computes the metering parameters and stores the information in specified registers dedicated to each parameter.

2.3 Communication Controller

Communication controller refers to the microcontroller in the smart meter that forms the supervisory part of the system. It is concerned with the coordination and control of power management, memory storage, load management, profile generation and establishing bi-directional communication of smart meter. Metering data from the metering IC is read by the controller and is used for generation of different profiles like block load profile, daily load profile, billing profile, event profile etc. These profiles are communicated to the HES on request or whenever a meter push occurs. The inbuilt Real Time Clock (RTC) of the controller is used for time stamped synchronized measurement with utility server. The microcontroller also handles load curtailment through connect/ disconnect switch.

2.4 Communication Modules

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

2.5 Power Manager

Switched-mode power supply (SMPS) forms the power manager, which provides power to the electronics in the meter, converting AC from the main line to the required DC voltages. A super capacitor is also employed in the smart meter that supplies power to the whole system in case of main line power failure.

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2.6 Display

The user display, which is detachable and optional, can be used for monitoring purposes. In addition to Liquid Crystal Display (LCD) in the meter, a handheld user interface is also provided; so that a user can monitor his/her usages, analyze daily and weekly usages etc.

3. Indigenous Smart Meter Development

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

Figure 2 Single phase smart energy meter developed by CDAC

3.1 SMPS

The SMPS of single phase and three phase smart meters is shown in the Fig. 3 and Fig. 4. It operates from 60 V to 440 V AC line to line as well as line to neutral connection. The three phase SMPS is 3 phases 3 wire SMPS and is capable of working on 3 phase 4 wire as well. It can operate on even a single phase and one neutral or two phases or three phases without neutral, three phase with neutral, any of four as desired. The maximum output rating is 6 V, 2 A. The SMPS is concerned with providing 5V DC to other electronics incorporated in the smart meter.

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Figure 3 Single phase SMPS

Figure 4 Double phase SMPS

3.2 SMCC

The pluggable SMCC of single phase smart meter and three phase smart meter is shown in Fig. 5 and Fig. 6. Here a PIC controller is used to control the overall functioning of the system. The metering IC incorporated in SMCC measures the required electrical parameters. External flash memory is used to store the data measured.

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Figure 5 Single phase control card

Figure 6 Three phase control card

3.3 SMCM

The pluggable SMCM of single phase and three phase modules are shown in Fig.5 and Fig. 6. For GPRS, the network coverage may vary from place to place. The module is made pluggable so that the Subscriber Identity Module (SIM) card networks can be changed with respect to the one having the maximum coverage in that particular area. In those areas that do not support any kind of network coverage for GPRS, any RF modules like LoRa, Bluetooth, Wi-Fi etc. can be plugged in the same socket without making any hardware modification in SMCC & SMPS.

The developed meter establishes bi-directional communication between utility and smart meter via Device Language Message Specification (DLMS)/ Companion Specification for Energy Metering (COSEM) protocol. DLMS/COSEM is a standard specification to provide an interoperable environment for structured modeling and meter data exchange. DLMS is designed to support messaging to and from energy distribution devices in a computer-integrated environment. COSEM is an interface model of communicating energy metering equipment, which sets the rules for data exchange, based on existing standards. Security of data from meters is ensured via cryptographic techniques. The meter has communication modules for GPRS, Wi-Fi, Bluetooth and IrDA which can be configured

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depending on utility's requirement.

The developed meter has the facility to connect/disconnect load remotely. It also has provision for tamper detection. The firmware for meter can be remotely upgraded, enabling Firmware Over-The-Air (FOTA) technology. Moreover, password protected user login and parameter setting, net metering i.e., metering both import and export energy, are prominent features of this meter. An android based application for customers to view their energy usage is another feature of this meter.

Challenges in Indigenous Development

Unlike other developed countries where people can afford to buy smart meter irrespective of price ranges, Indian conditions are bound on cost of smart meters [3]. Therefore, the main challenge involved in the development of smart meter was to make it cost effective. The PIC controller is selected in such a way that it has inbuilt LCD driver and controller, RTC, IrDA driver, etc. Hence no separate ICs/modules were required. The segmented LCD used in the SMCC is very cheap. Also, the metering IC in the SMCC is of low cost and meets up the standard. Each of three PCBs used are 2 layered which makes it comfortable even for a PCB manufacturer with bare minimum technology for fabrication. The modules are made pluggable such that if a particular module doesn't work properly, only that module needs to be replaced and not the complete meter as such. Also, for the communication modules, the module can be unplugged from the meter and the SIM card operator can be changed if the meter fails to communicate for a particular network at a particular region. If a particular region doesn't support GPRS network, an RF module like LoRa, Wi-Fi, etc. can be plugged in at the same connector without making any hardware modifications. The system use both shunt resistor and current transformer for current measurement. Current transformer in one line ensures isolated measurement. The remaining components used in the development of smart meter are commonly and cheaply available in the markets. In the development of software technology, DLMS protocol stack was costly but has been an essential part of smart meter development in order to enable interoperability among different manufacturers. CDAC has successfully developed, tested and verified an indigenous and independent DLMS protocol stack in C language that can be ported to any microcontroller.

4. Observations And Test Results

The accuracy test results of the developed Class 1 single phase meter is given in Table 1. The error percentage in active energy when current flows through phase line only and through neutral line individually was observed for unity power factor, 0.5 lagging power factor and 0.8 leading power factor at currents 0.1A and 60A, by setting conditions in a standard calibration bench of accuracy class 0.1. The DLMS communication protocol Conformance test results of CDAC Smart meter conducted at CPRI, Bangalore is reproduced as shown in

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Fig. 10. The above said test covers of various layers – HDLC, Application layer, COSEM layer and SYMSEC (Symmetric Key Security) layer.

5. Benefits of Smart Meter

Smart metering enables continuous monitoring of energy at household level, accurate billing etc. AMI communicates the smart meter data to utilities but also has the ability to inform the consumers regarding their usage, peak demand, bill dues, cost of energy consumption etc.

The benefits of smart meter can be categorized as follows.

6.1 For Utilities

Testing Demand Side Management enables the utility to have complete control over its energy distribution through load limiting thereby avoiding transformer tripping and preventing local power shut down. Demand analysis helps the utility to prearrange adequate power to be supplied for a particular locality

- As the meter communicates data to utility, there is no need for monthly meter readings by meter reader Expenses for meter reading can be eliminated
- Collection of meter data over the air avoids the need of back office billing calculations and account keeping
- Utility can request and collect data from meter at any instant of time and can use this data to balance loads
- The system can be monitored in quick and detailed manner
- Utility can remotely connect and disconnect loads.
- Meter tampering and theft can be detected so that energy usage does not go unmetered.
- Messages regarding power outages will reach utility instantly.
- Utility can enforce dynamic pricing, by which cost of electricity raises or lowers depending on demand
- Different tariff zones can be enabled for pricing
- Customer safety gets ensured. Customer complaints and service calls can be reduced to minimum.
- Data from each meter can be easily accessed and can be analyzed for further studies
- Optimizes energy from existing plants, expenditure on building new plants gets eliminated

6.2 Advantages for Electricity customers

- Smart meters offer the following benefits to electricity customers:
- Electricity bills becomes more accurate and timely
- Customers can attain more detailed information regarding energy usage
- Power outage restoration gets much faster

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- Consumers can reduce consumption during peak hours by analyzing usage to reduce electricity bills
- Net metering generates a platform for the consumers to get payment for the energy generated by them through solar power plants or other distributed generation methods

6.3 Environmental advantages

- Net metering encourages distributed generation from renewable energy sources like grid tied solar power inverter
- Less impact on environment as efficient demand side management reduces costs and carbon emissions involved in electricity production.

6. Smart Meter Future in India

According to 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 of data concentrator units/gateways as it becomes possible to upload data from smart meters directly to internet which can be downloaded at Head End System at any instant. Also the Government of India aims to implement 250 million smart meters, replacing conventional meters, eyeing its technological advantages [6]. Smart meters can be connected to a Wi-Fi network in the home or building or neighborhood which links the meter with broadband internet to send meter data. The Head End System and the Meter Data Management System (MDMS) can aggregate data by connecting to internet. Also, data can be sending to utility applications and consumer’s application on their smart phones eliminating the need for In-Home Displays.

7. Conclusions

Smart meter made a revolution over conventional meters through its intelligent inbuilt technologies. It had gained momentum worldwide as it favors both utility and consumer with its smart abilities. Smart meter paved the way for smart grid realization through AMI. CDAC could successfully develop smart meter that is in accordance with Indian standards released by Bureau of Indian Standards (BIS). Since the development started from scratch, complete know-how of smart meter could be achieved in hardware as well as software technologies. CDAC smart meters are adapted to amendments in the Indian standards that can occur in future. These in turn help to get rid of any foreign agencies to intervene our system by any means that can pose a threat to the grid security or can bring up high maintenance costs for the utility. Thus indigenous development of smart meter paves the path with full authority and control for the revolution of smart grid realization through AMI.

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