SMART METERS AND ADVANCED METERING INFRASTRUCTURE

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ABSTRACT

Reducing the power supply-demand gap and increasing reliability of power supply are the challenges of current energy management. Implementation of smart grid, smart meters and smart metering can be a possible solution for power demand reduction, efficient power supply management, and optimization of management resource usages. Purpose of the paper is to discuss and analyze Smart meters. Smart meters include sophisticated measurement and calculation hardware, software, calibration and communication capabilities, particularly explain its need and basic idea behind it. Further, different characteristics features are explained in this work we discuss smart meter and various elements of smart metering, current state of the technologies related to smart grid, smart meter, advanced metering infrastructure (AMI). As a result, it is concluded that smart grid development will allow consumers to use energy effectively and thus help in security energy needs.
Keywords- Smart Grid, Smart Meter, Advanced metering infrastructure

I. INTRODUCTION

Electricity is essential for modern society as it powers everyday life devices (e.g., computers, televisions, and telephones) as well as it powers commercial buildings, industries, Internet, etc. The demand for electric power is increasing at a high rate particularly at urban areas[1]. The target period for reaching the maximum capacity can be prolonged, if the growth of the peak demand can be slowed and the efficiency of power usages can be increased. Modern society depends tremendously on electricity, and power supply interruptions and outages have significant negative impact on the quality of lives. The great majority of electric consumers in developing countries own or lease an electromechanical meter to allow the measurement and determination of their energy bill in a given period. The meter operation is based upon a disk that rotates due to the application of a magnetic field, caused by the flow of electric current, thus being able to meter the total energy consumed. For billing purposes, electricity consumption for a given period is calculated as the difference between the current and previous meter reading. This type of meter is massively used, mainly associate in the residential and small commercial customers. Since the inception of electricity of electricity deregulation and market-driven pricing throughout the world, utilities have been looking for a means to match consumption with generation. Traditional electrical and gas meters only measure total consumption, and so provide no information of when the energy was consumed at each metered site. Smart meters provide a way of measuring this site specific information, allowing price setting agencies to introduce different prices for consumption based on the time of day and the season. Smart meters may include measurements of surge voltages and harmonic distortion, allowing diagnosis of power quality problems. Smart metering essentially involves an electronic power meter supplemented by full remote control, diagnostics, power peak and consumption analysis, anti-tampering mechanisms, fault alert, time-variable tariffs, and many more possibilities.

II. SMART METER AND SMART METERING

A. Smart Meter

Smart meters are powerful tools and are electronic measurement devices used by utilities to communicate information for billing customers and operating their electric systems[2]. It is usually an electronic device which records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes. Smart meters enable two-way communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an advanced metering infrastructure (AMI) differs from traditional automatic meter reading (AMR) in that it enables two-way communications with the meter. When an Advanced Metering Infrastructure (AMI) is in place, smart meter can measure and record actual power usage during a day at certain time interval. These collected data are sent to a central data management system over a secure network via wireless communication. In addition, these sensors can be used by the utilities to detect fault and send outage or restoration notifications. Use of this information allows the utilities to provide more reliable power supply. It also allows better planning, operation, and faster outage response of the grid. These meters also allow increased resolution of data on various measurement parameters across the grid and these data can be used by utilities for the following applications :

a. Faster outage detection, response, and restoration by providing data to the field operations timely.

b.Keeping customers better informed about the status of power grid. Utilities can communicate relevant information, e.g., cause of outage, field-estimated restoration time, and public safety notice.

c. Improving resilience against disruptions, reducing potential outages, reducing frequency and duration of outages by enhancing accuracy of the grid asset planning and management.

B. Smart Grid

Smart grid is a cyber-physical system which includes communication system with the power flow structure, to gain intelligence and automated control [3]. As a result, it deals with not only the power flow but also information flow. The communication support schemes and real-time measurement techniques of smart grid enhance resiliency and forecasting as well as offer protection against internal and external threats[7]. Smart grid is a synergistic combination of the existing technologies and the emerging technologies. Smart grid uses advanced metering infrastructure (AMI) for collecting and processing information from smart meters. AMI requires a database known as meter data management system (MDMS) to store and manage the data. Traditionally, AMI uses centralized MDMS architecture. Communication architecture of smart grid is also very complex. Smart grid has automated control through bidirectional connection of power flow as well as data flow. Addition of communication technology is a major part of the idea of smart meter. However, for a stable and well integrated communication architecture, proper infrastructure is a must.

C. Advanced Metering infrastructure (AMI)

AMI is the system to add the communication link to the smart grid network. AMI includes bidirectional data flow between end users and utilities. AMI provides intelligent management, better maintenance, easier and proper additions and replacement of utility assets which results in better power quality. AMI comprises three key elements[10]: Smart Meters, Meter Communication Infrastructure and Data Management. The combination of all three is vital to the development of a smart grid.

- Smart Meter provides two-way communication between customer and utility, enabling functions such as outage detection, real time pricing and power quality monitoring.
- Meter Communication Infrastructure describes the various methods of communication between meter and utility. These include power line communication (PLC), cellular (broadband or GPRS) and radio frequency (RF).
- Data Management broadly covers managing all the data created by the meter- this includes transfer, storage and protecting privacy.

III. NEED FOR SMART METER INSTALLATION AND EFFECTS

A.Drivers:

Despite its widespread benefits, deploying AMI presents three major challenges that include high upfront investments costs, integration with other grid systems, and standardization.

1. High Capital Costs: A full deployment of AMI requires expenditures on all hardware and software components, including meters, network infrastructure and network management software, along with cost associated with the installation and maintenance of meters and information technology systems.

2. Integration: AMI is a complex system of technologies that must be integrated with utilities conformation technology systems, including Customer Information Systems(CIS), Geographical Information Systems(GIS), Outage Management Systems(OMS), Work Management (WMS),Mobile Workforce Management(MWM), SCADDA/DMS, Distribution Automation System(DAS), etc.

3.Standardization: Interoperability standards need to be defined, which set uniform requirements for AMI technology, deployment and general operations and are the keys to successfully connecting and maintaining an AMI- based grid system.

B. Driving Force for Smart Meter Installation:

The goal of achieving increased energy efficiency is the main driving force for implementation of smart meter installation. Smart metering system is expected to provide more information to the consumers and utilities and better informed customers will use less energy[4]. In addition, a need for improved billing accuracy is also a driver for smart metering. The need to reduce losses due to fraud has been a strong driver for companies to introduce smart metering. The advancement of smart grids is also becoming a more important part of the implementation of smart metering. It is also expected that smart meters will play a key role to enable incorporation of renewable energies and distributed generation to the grid.

C. Benefits of Smart Meters:

Implementation of smart metering will provide a number of benefits to the consumer, the utility and to our society.

Benefits to the customer:

• Consumers get more information about their energy usage. This will provide energy efficiency gains for both the consumer and the industry.
• Increased knowledge of quality of delivery and more detailed feedback on energy use.
• Bills are based on actual consumption.
• Customer can adjust their habits to use more during off peak hours to lower electric bills.
• Power outages are reduced.
• Switching and moving are easily facilitated.
• The necessity of bill estimation is reduced.
• No need to provide access to utility people for taking reading of meters located indoors.

Benefits to the utilities:

• Demand peaks are reduced.
•Remote controlling enables better management of billing and other consumer related issues.
• Automated and remote meter reading.
• Electric systems are monitored more quickly.
• Enabling more efficient use of power resources
• Power outages are reduced.
• Enabling dynamic pricing.
• A voiding building of new power plants.
•Optimizing income with existing resources.
•Increased information on low voltage network.
•Important part in the development of Smart Grids.
•Freeing up experienced staff for other high priority areas to better serve the customers.
• Operational costs are reduced.

Benefits to the environment:

• Smart Meters communicate directly with the utility, eliminating the need to put utility trucks out on the street.
• Smart meters prevent the need for new power plants by contributing to the proper distribution of existing power usage, and as a result reduce pollution.
• Smart meters indirectly reduce the emission of greenhouse gas from existing power plants.

IV. SMART METER WORKING PRINCIPLES

Smart meters include a combination of hardware, software, and calibration systems. Metrology, security, and communication are the core elements of smart meters. Figure 1 presents a block diagram of a smart meter showing the building blocks for a complete smart metering solution[9]. A smart meter system may include: Accurate real-time clock (RTC), Data communication module, Metering system-on-chip (SoC), Security module, Power management system, Supervisory module, Tamper detection, Transformer driver and Voltage reference (VREF). The center of a smart meter hardware is based on system-on-chip (SOC) processor including the architecture to support the measurements. The analog front-end of a meter consists of analog to digital converters (ADCs) supporting differential inputs. An integrated gain stage provides gains for low-output sensors. A hardware (HW) multiplier on the SOC chip can be used to further accelerate math intensive operations during energy computation. RMS current and voltage, active and reactive power, power factor and frequency are the main parameters calculated during the energy measurements.

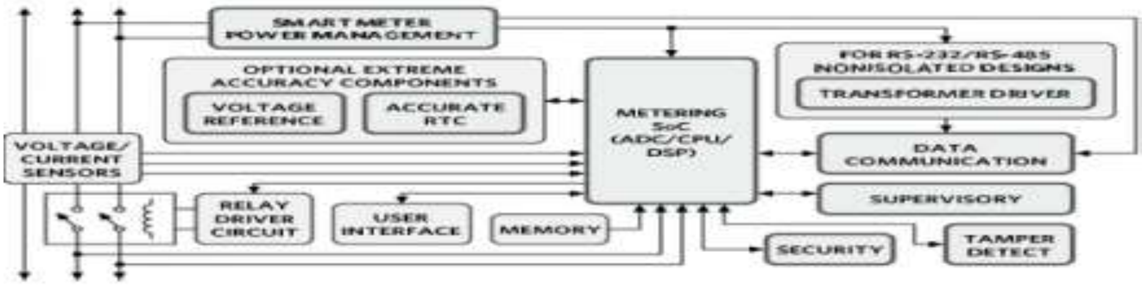

Fig1. Block Diagram of a Smart Meter

A. Analog Front of a Smart Meter Power supply: The power supply of a meter allows the operation of the energy meter powered directly from the mains or through step-down transformer.
Anti-aliasing filter: The analog front-end for voltage consists of spike protection resistors followed by a voltage divider and a RC low-pass filter that acts like an anti-alias filter. The anti-alias resistors on the positive and negative sides are different, because the input impedance to the positive terminal is much higher and therefore a lower value resistor is used to avoid large phase shift.
Battery charger: A backup battery is kept and is charged through stepped-down voltage.
Real time clock (RTC): RTC clock is used to indicate current date and time of measurement.
Voltage and current measurement: A resistor is used and voltage is measured as drop across that resistor and a current transformer or current sensor is used for current measurement.
Anti-tampering circuitry: Anti tampering circuit is present in the analog part of smart meter. The most common process is using two current sensors for tamper detection .
Harmonics analysis: Harmonics analysis is performed to reduce transmission loss[5]. Three processes of harmonics elimination from the analog signals are: using band limiting filter, using Fourier based methods (FFT), and using adaptive real-time monitoring (ARTM).
B. Digital Part of a Smart Meter: The digital section of a smart meter includes microcontroller unit (with register and RAM). The microcontroller is the heart of the energy meter, and it does all the calculations, stores the values, transmits data according to ANSI C 12.22 standards with the data format of ANSI C12.19 as per the request sent by MDMS or at pre-scheduled time.

V. FUNCTIONALITIES OF SMART METERS AND SMART METERING

A. Utilities Requirements of Smart Meter Functionalities: The utilities should aim for the highest level of Smart Metering functionality and make sure that the regulations take full advantage of the existing level of technology in order that the investments do not become obsolete too soon. The following main functionalities can be considered for Smart Meters:

- Remote meter reading
- Load profile data
- Option of variable time-of-use tariffs
- Remote meter management
- Remote demand reduction
- Remote connection/disconnection
- Quality of supply
- Price signal to customer
- Dynamic pricing and Demand-response
- Tamper and theft detection and correction
- Power outage detection
- Detection of power use over specific demand

B. Dynamic Pricing: Dynamic pricing is a way to flat peak demand. The consumers are encouraged to lower their energy consumption during peak period. This lowers wholesale market price in short run, and customers can reduce their electricity bill by shifting their use to off peak hour. There are three types of dynamic pricing scheme: 1. Time-of-use pricing (TOU), 2. Critical peak pricing (CPP), and 3. Real-time pricing (RTP). Time of use rates means different energy rate during different period of the day or different days of a week or different seasons of a year depending on the peak demand during that period. For example, electricity price changes (rise and fall) throughout the day, and tends to drop overnight and on weekends, based on available supply and consumers demand. Smart meters record total electricity consumption along with the time of consumption. As a result, different prices can be applied to calculate the bill. Consumers can be able to manage their electricity consumption habit according to the time-of-use rates and hence manage their bills. With this pricing, electricity prices will vary based on the time when it is used which affect the total bill.

C. Bi-Directional Communication: The energy data is read and stored by smart meters at a regular interval (basically hourly for residential, every 15 minutes for commercial & industrial systems). These data are sent to the MDMS of utility via concentrator when requested.

D. Remote Service: The Smart meter is a digital technology device which enables remote control by the utility company for several power related functions, such as :

- Remote disconnect/connect of power to the consumer
- Tamper/ theft detection and correction
- Sent back time of use bill to the consumer
- Send back signals to the consumer
- Power outage detection
- Detection of power use over specified demand and sending warning to consumer

E. Outage (Fault) Detection: Smart meter can help the utilities identify where and when outage occurred as well as notify the utility when the power has been restored. For fault detection capability of the AMI, the smart meters should have the following features

- Last gasp capability
- Capability of differentiate between momentary and sustained events
- Power status check or verification capability
- Positive restoration notification sending options

F. Home Area Network (HAN) Functionality: HAN capability allows utilities to support customers and achieve operational efficiencies through the deployment of networks of interconnected devices. These devices include submetering devices, in-home displays for communicating price signals to ratepayers, load control devices, and programmable communicating thermostats[8].

G. Peak period demand reductions: Smart meters can provide consumers information about the timing of energy consumption and dynamic pricing. As a result consumers will be tempted to change their energy consumption habit toward off peak period for lower billing. This can reduce that peak demand. By managing the peak demand prevent power outage from occurring on the grid during high stress. The utilities will be able to manage better the electricity flows during peak periods and navigate effectively through system emergencies by using coordinated and networked smart meters[6].

H. Assessing Distribution Automation Performance Smart meters can be used to assess the performance of distribution automation equipment (reclosures, switches and FCl's) during emergencies, e.g., storm and outages. Smart meters can provide a way to automate the validation of proper operation of these devices.

I. Firmware Upgrade Capability Preference would be given to meters capable of local or remote upgrading of meter firmware without affecting metrological functions previously approved by the proper authority. Reprogramming of the meter firmware will allow addition of new features and correction of bugs in earlier software version. This will prevent early obsolescence of smart meters.

J. Reclosure: Smart meters must be immune to a distribution system reclosure. A reclosure is occurred when there is a power outage of 0.1 to 2 second caused by tripping of a protective device between the meter and the supply station. Up to four separate reclosings may occur in sequence over a 10 to 30 second period during any single power system event.

K. Functionalities of Advanced Metering Infrastructure: There are eighteen high-level requirements defined by Utility AMI pertinent to smart metering and are : standard comms board interface, standard data model, security, two-way communications, remote download, time-of-use metering, bidirectional and net metering, long-term data storage, remote disconnect, network management, self-healing network, selfhealing network, home area network gateway, multiple clients, power quality measurement, tamper and theft detection, outage detection, and self-locating. The detailed description for each of these items are beyond the scope of this article.

VI. CONCLUSIONS

In this paper, we have reviewed and discussed the smart meters and smart metering, functions and functional requirements of smart meters those are commercially deployed by various utilities, the working principles of smart meter, advanced metering infrastructure and meter data management system, standards for data structure and data communication. The interoperability among the utilities require that meters are designed to collect data and communicate following certain standards. Review of various meter data management solutions and billing solutions indicated that most of the solutions are versatile with much common functionality; however, implementation of those features depends on the utility requirements. Among the various functionalities, Time-of-use (TOU) and Bi-directional communication have been found to be the two top most functionalities, which benefit both the consumers and the utilities. Implementation of these functionalities and others can help reducing the power supply demand gap, efficient management of the power supply systems. With implementation of advanced functionalities of the smart meters and advanced metering systems, there is a significant potential to shift the paradigm of electric power supply.

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