Renewable and Sustainable Energy Reviews 49 (2015) 720–735

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Performance analysis of smart metering for smart grid: An overview

Konark Sharma*, Lalit Mohan Saini

Department of Electrical Engineering, National Institute of Technology, Kurukshetra, Haryana, India

ARTICLE INFO

Article history:
Received 13 November 2014
Received in revised form
16 April 2015
Accepted 27 April 2015
Available online 18 May 2015

Keywords:
Cyber security
Energy measurement
Renewable energy
Smart grid
Smart meter

ABSTRACT

Smart metering systems generally referred to as the next-generation power measurement system, is considered as a revolutionary and evolutionary regime of existing power grids. More importantly, with integration of advanced computing and communication technologies, the smart meter (SM) is expected to greatly enhance efficiency and reliability of future power systems with renewable energy resources, as well as distributed intelligence and demand response. Different electrical energy metering standards are point of concern for power/energy measurements. As measurement standards are formed, systems built around them can become interoperable from a standards point of view but still have incompatible configurations or different maturity levels, or include non-standardized functions. Even in areas that are standardized, there are sometimes implementation decisions that can result in different measurement and security behavior. With this paper we make three contributions: firstly, we identify various 1-channel and 3-channel metrology integrated circuits (ICs), which are mandatory for the standard measurement of distributed and renewable electricity generation. Secondly, we describe harmonics effect on metrology, which impacts on reliability of widespread smart metering infrastructure. Finally, we develop and describe a comprehensive set of security issues for SMs. Specifically, we focus on reviewing and discussing smart metrology meter (SMM) applications (i.e. metrological functions and real-time monitoring functions), security requirements, network vulnerabilities, attack countermeasures, secure communication protocols required in smart grid (SG) architectures. This review will enable the researchers, public policy makers and stakeholders to open the mind to explore possible in an evolving energy domain as well as beyond this area.

Contents

Abbreviations: ADC, Analog to digital converter; ADVISE, Adversary view security evaluation; AES, Advanced encryption standard; AGC, auto gain control; AIM, Artificial intelligent met; AMI, Automatic metering infrastructure; AVISPA, Automated validation of internet security protocols; BAN, Building area network; CPS, Cyber-physical system; DSP, Digital signal processing; DOS, Denial-of-services; DSSS, Direct-sequence-spread-spectrum modulation; ENOB, Equivalent number of bits; FPGA, Field programmable gate array; FTP, File transfer protocol; GPRS, General packet radio service; GSM, Global system for mobile communications; GT, Green technology; HSDC, High speed data capture; HTTP, Hypertext transfer protocol; HV, High voltage; HVQFN, Heat-sink very-thin quad flat-pack no-leads; IC, Integrated circuit; IGBT, Insulated gate bipolar transistor; I^2C, Inter-integrated circuit; IPH, Index of phasor harmonics; IPSEC, Internet protocol security; JTAG, Joint text action group; KB, Kilo bytes; LCD, Liquid crystal display; LED, Light emitting diode; LFCSP, Lead frame chip scale package; LFLO, Logic function logic output; LV, Low voltage; LQFP, Low profile quad flat package; MR, Magneto-resistive; MDMS, Meter data management system; MOA, Massive online analysis; MGS, Modified gradient search; MID, European directive on measuring instruments; MITM, Man-in-the-middle; MOSFET, Metal oxide field effect transistors; MPU, Microprocessor unit; MTTF, mean-time-to-failure; MV, Medium voltage; NAN, Neighbor-hood area network; OMPA, Optimal meter placement algorithm; PLC, Power line communication; PMU, Phase measurement unit; PSTN, Public switched telephone network; PUF, Physically un-clonable function; PV, Photovoltaic; QFN, Quad-flat no-leads; QFP, Quad-flat package; RF, Radio frequency; RFID, Radio frequency identification; RISC, Reduced instruction set computing; RMS, Root mean square; RTC, Real-time clock; SCADA, Supervisory control and data acquisition; SG, Smart grid; SM, Smart meter; SMM, Smart metrology meter; SNR, Signal-to-noise ratio; SOC, System on chip; SOIC, Small outline integrated circuit; SPI, Serial peripheral interface; SSH, Secure shell; SSI, synchronous serial interface; SSL, Secure socket layer; SSOP, Shrink small outline package; SSP, Secure signal processing; SUN, smart utility network; TCP/IP, Transmission control protocol /internet protocol; THD, Total harmonic distortion; THD_F, Total harmonic distortion of fundamental; TLS, Transport layer security; TOD, Time-of-day; TOE, target of evaluation; TOU, Time-of-use; TQFN, Thin quad flat no-lead; TQFP, Thinner quad flat package; TSSOP, Thin-shrink small outline package; TSV, Tunable signing and verification; TTL, Transistor-transistor logic; UART, Universal asynchronous receiver transmitter; USB, Universal serial bus; VFQFPN, Very thin fine pitch quad flat pack no lead package; V2G, Vehicle-to-grid; WAMS, Wide area management system; WAN, Wide area network; WELMEC, European cooperation in legal metrology

* Corresponding author.
E-mail address: konark123@gmail.com (K. Sharma).

http://dx.doi.org/10.1016/j.rser.2015.04.170
1364-0321/

1. Introduction

The smart meters (SMs) requirements are rapidly evolving in response to competitive market forces and various governmental regulations mandating smart grid (SG) deployments in most areas of the world. Now days it has made the scenario guaranteeing higher bit rates, robust and flexibility. Soon they will roll out utility consumers by the hundreds of millions smart meters by replacing century-old analog electro-mechanical (Ferrari's) energy meters [1]. A snapshot of analog electro-mechanical meter is shown in Fig. 1(a). Ferrari's energy meter were introduced in the late 1880s and operate by counting the revolutions of an aluminum disc which is made to rotate at a speed proportional to the power disc speed may fast or slow, during non linear loads (i.e. fluorescent light, energy storage systems) monitoring results error in readings. They could measure only active energy [2]. During 1990s, advanced electronics solutions such as microprocessor units (MPUs) and fast analog-to-digital converters (ADCs) allowed the manufacturers to start introducing meters that were mostly electronic and the only moving parts were the electro-mechanical counters used to record energy [3,4]. A snapshot of an electronic meter is shown in Fig. 1(b). A third generation power metering circuit could measure not only active power but also various important parameters such as reactive power, apparent power, voltage and current root mean square (RMS) values, power factor and harmonic distortion using configurable digital signal processing (DSP) core [5]. Early 2000s saw further advances in electronics, instrumentation, communication and data handling. They allowed manufacturers to produce meters that were all electronic without rotating parts [6]. These meters could measure following parameters such as.

- Instantaneous parameters: voltage, current, power, power factor, etc.
- Billing parameters: kilowatt-hour (kWh), reactive power (kVArh), maximum demand and load profile etc.

These meters with existing communication technologies such as radio frequency (RF), global system for mobile communications (GSM), general packet radio service (GPRS), public switched telephone network (PSTN) and power line communication (PLC), allowed consumers value-added services[7,8].

As compare to legacy electronic meter, present electronic meter is smart, and can provide a range of intelligent functions such as dynamic pricing, demand response, remotely power connect/disconnect; outage management, network security, and reduction of non-technical losses. It offer higher accuracy and require less power at a considerably lower cost. It is fully envisioned to integrate high-speed two-way communication into millions of power equipments to establish a dynamic and interactive infrastructure with energy management facility capabilities [9]. There are eight basic metrology computation blocks, which are the backbone of latest SM.

- Microcontroller unit (MCU): The integrated MCU core with inbuilt flash memory provides a flexible means of configuration, post-processing, data formatting, and interfacing to any host processor through suitable interface type or any data in/out pins. Records power consumption details can be sent to energy suppliers or prosumers on request.
- Analog-to-digital converter (ADC): It digitizes the voltage and current inputs and provides an instantaneous snapshot of power factor and energy consumption. It can also measure magnitude of phase currents and voltages over the cycle [4]. At present metrology IC with 64 bit ADC are available in market [10].
- Analog-front end (AFE): It is comprised of an input multiplexer, ADC converter and voltage reference It is a link between the real world and the processing world, which collects and calculates single phase and poly-phase voltage, current, power, energy, and power-quality disturbances such as harmonics. This computed results can be retrieved with the help of an external master unit through on-chip host interface [9,11].
- Interface unit: It supports various types of interfaces such as serial peripheral interface (SPI), universal asynchronous receiver transmitter (UART), high speed data capture (HSDC) and Inter-integrated circuit (I^2C), which are useful to connect external devices for special applications. An isolated RS-485 communications interface is also provided with the EM773, for any serial communications needs [12].
- Liquid crystal display (LCD) driver: It helps to display the calculated energy in LCD display for billing purpose. The MSP430F676 consist of integrated LCD driver with contrast control up to 25-MHz system clock for up to 320 Segments in 8 multiplexer modes [13].
- Real-time clock (RTC): The typical metrology IC always inbuilt with RTC for tariff information. This involves dividing the day, month and year into tariff slots (Time of Day). Usually higher rates are applied at peak load periods and lower tariff rates at off-peak load periods. Therefore RTC for metrological application must be very accurate to avoid dispute between consumer and utility applications regarding measurement of fundamental reactive energy even in non-sinusoidal conditions [14].
- Security scheme: It supports highest levels of available security schemes, which helps to protect ones physical tampering events (i.e. mechanical and electrical anti-tampering), consumer data and ensures privacy [15].
- Communication protocol stack (wireless/wire-line): With the help of communication processor, it supports all latest communication technologies (i.e. both RF and PLC solutions), which is useful for gateway concentrators and AMI applications [16].

Considering all necessary requirements SMM solutions can be classified into three categories:

1. Metrology AFE: Fig. 1(c) illustrates block diagram for metrology AFE. AS per latest metrological standards, the metrology IC integrator must be able to translate the class/range specification to the AFE fundamental requirements (i.e. signal-to-noise ratio (SNR), input referred noise voltage or equivalent number of bits (ENOB). At present latest metrology IC have high SNR with ADC built-in auto gain control (AGC) mechanism, which can perform wide range current measurement with accuracy better than class 0.5 [17]. The 71M6515HA with high-speed