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Hardware Design of a Smart Meter

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Abstract
Smart meters are electronic measurement devices used by utilities to communicate information for billing customers and operating their electric systems.
This paper presents the hardware design of a smart meter. Sensing and circuit protection circuits are included in the design of the smart meter in which resistors are naturally a fundamental part of the electronic design.
Smart meters provides a route for energy savings, real-time pricing, automated data collection and eliminating human errors due to manual readings which would ultimately reduce labour costs, diagnosis and instantaneous fault detection. This allows for predictive maintenance resulting in a more efficient and reliable distribution network.
Keywords: Advanced Metering Infrastructure (AMI), Automated Meter Reading system (AMR), Communication, Power line carrier (PLC) PLC, Smart grid, Smart meters.

I. Introduction

Smart meter systems are an integral part of the Smart Grid infrastructure in terms of data collection and communications (Clemente 2009, Ericsson 2010, Galli 2011).

The Smart Grid is not just a compilation of smart meters, wind, solar, or plug-in electric vehicles, but is essentially the modernization of the transmission and distribution aspects of the electrical grid. Functionally, it is an automated electric power system that monitors and controls grid activities, ensuring the efficient and reliable two-way flow of electricity and information between power plants and consumers—and all points in between from customer preferences to individual appliances/ equipment (Ping 2010, Judy 2009). A Smart Grid monitors electricity delivery and tracks power consumption with smart meters that transmit energy usage information to utilities via communication networks (Budka 2010, Farhangi2011, Hamilton andGulhar 2010). The two-way nature of Smart meter systems allows for sending commands to operate grid infrastructure devices, such as distribution switches and recloses to provide a more reliable energy delivery system known as Distribution Automation (DA) (Khurana 2010, Metke and Ekl 2010, Santacana 2010).

Smart meters are often promoted as a route for energy savings, real-time pricing, automated data collection, avoiding human errors due to manual readings which would ultimately reduce labour costs, diagnosis and instantaneous fault detection allowing for predictive maintenance resulting in a more efficient and reliable distribution network (Horowitz 2010, Joseph 2010, Massoud and Wollenberg 2005).
Basic Types Of Smart Meter Systems:
There are two basic categories of smart meter system technologies as defined by their local area network (LAN). They are radio frequency (RF) and power line carrier (PLC). Each of these technologies has its own advantages and disadvantages in application. The utility selects the best technology to meet its business needs. Factors that influence the selection of the technology includes evaluation of existing infrastructure, impact on legacy equipment, functionality, technical requirements as well as the economic impact to the utility's customers. The selection of the technology requires a thorough evaluation and analysis of existing needs and future requirements into a single comprehensive business case (Ping 2010, Yarali and Bwanga 2008).

Radio Frequency (R.F):

Smart meter measurements and other data are transmitted by wireless radio from the meter to a collection point. The data is then delivered by various methods to the utility data systems for processing at a central location. The utility billing, outage management and other systems use the data for operational purposes (Ericsson 2010, Horowitz 2010, Khurana 2010). RF technologies are usually two types: Mesh technology and Point to point technology.

Mesh Technology:

The smart meters talk to each other to form a LAN cloud to a collector. The collector transmits the data using v

The smart meters talk directly to a collector, usually a tower. The tower collector transmits the data using various methods to the utility central location for processing.

The advantages include little or no latency and direct communication with each endpoint and large bandwidth.

The disadvantages are licensing, terrain may prove challenging in rural areas, proprietary communications used for some technologies and less interface with distribution automation (DA) devices (Ba and Kirkman 2010, Budka 2010).

Power Line Carrier:

Smart meter requirements and other data can be transmitted across the utility power lines from the meter to a collection point, usually in the distribution substation feeding the meter. Some solutions have the collection point located on the secondary side of a distribution transformer. The data is then delivered to the utility data systems for processing at a central location. The utility billing, outage management and other systems use the data for operational purposes (Dickarman and Harrison 2010, Ericsson 2010).

Power line networking or power line carrier is a potentially attractive means of connecting the smart meter to the electrical devices in the homes, The latest versions of this technology use orthogonal frequency division multiplexing (OFDM) and claims speed of up to 200 M hps. Though, practical results are probably far lower in most instances, it would still be more than adequate for smart home communications(Ericsson, 2010). To incorporate this technology in the smart grid, the smart meter will need PLC technology built in the supplies so that the signals could be injected into the home wiring from the source. The smart appliances to be controlled in the home would also have embedded PLC devices that can also be supplied through an adaptor. In this application, the smart meter would act as the server and send control messages to the attached devices (Perrig 2012, Sautar 2011, Wallace 2010).

The advantages of PLC technology include leveraging the use of existing utility infrastructure of poles and wires, improved cost effectiveness for rural lines, more effective in challenging terrain and the capability to work over long distances (Yarali and Rahaman 2012).

PLC technology has the disadvantages of longer data transmit time, less bandwidth and limited interface with DA devices and higher cost in urban and suburban locations (Ipkchi and Albuyeh 2009, Anthony and Metke 2009).

II. Basic Architecture of Smart Meter System

The smart meters collect data locally and transmit via a local area network to a data collector. The collector retrieves the data and may or may not carry out any processing of the data. Data is transmitted via a wide area network (WAN) to the utility central collection point for processing and use by business applications. Since the communications path is two-way, signals or commands can be sent directly to the meters, customer premise or distribution device(Yarali and Bwanga, 2008).

The general block diagram-showing the main and auxiliary sections- of a smart meter design is shown in Figure 1. Depending on the application, energy, gas, or water metering, one or more sensors may be interfaced to front end electronics, an energy source with the associated power management circuitry, a communication node, and a microcontroller for system management.

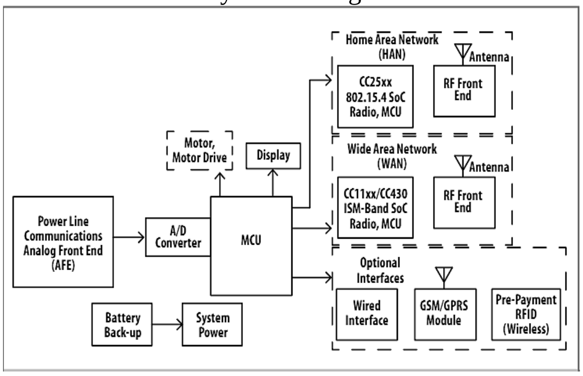

Figure 1: Block Diagram of a Smart Meter

There are three main areas of a smart meter design namely- the power system, microcontroller, and communications interface. The power system has a switched mode power supply and battery backup to ensure that the metering electronics remain powered even when the main line is disabled. A Microcontroller Unit (MCU) includes an Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC) to provide intelligence. A wired or wireless communication interface allows the meter to interact with the rest of the grid and in some cases the end user's network.

The advantages of this technology include acceptable latency, large bandwidth and typically operates at higher frequencies.

The disadvantages include terrain and distance challenges for rural areas, proprietary communications and multiple collection points(Khurana, 2010).

Point to point technology:

Smart meters are electronic measurement devices used by utilities to communicate information for billing customers, track and record customers' electric use and operating their electric systems. With smart meters, sending data to the electricity supplier automatically, there would not be the need to have the meter mounted outside the customer premises. Placing the meters inside a garage or other room would provide a much more protected location and aid in the security of the smart grid. This would require moving or extending the power line terminus from their normal location to the interior which would add considerable expense, and most likely be prohibitive for any extensive smart grid projects. As a matter of fact, for any new homes built in areas with existing smart meters infrastructure, this may be a useful option. Data can be sent wirelessly to an access point at the power pole or via communication over the low voltage power lines. Large amount of smart meter data can be collected at a substation and then sent back to the utility(Santacana, 2010).

Digital smart meters that automatically capture information about the consumption of electricity have replaced the old analogue meters that are read manually. The information captured about electricity consumption are transmitted back to the electricity companies for appropriate actions(Wallace, 2010).

III. Hardware Design

A smart meter is comprised of sensitive circuitry and may support numerous communications protocols. In addition, there are sensing and circuit protection circuits included in the design of the smart meter in which resistors are naturally a fundamental part of the electronic design. The metrology AFE revenue-grade measurements rely on the accuracy of series resistors for current sampling. A complete implementation include power line communication to the electricity meter and low power wireless communication from the electricity meter to other utility meters.

Two communication scenarios are prominent here in the first scenario, the Advanced Metering Infrastructure (AMI) utility-network transceiver (the physical element that connects the meter to the communication channels back to the utility) would be located in the utility domain whereas the home area network (HAN) transceiver (the physical element that connects the meter to the communication channels in the home) would be in the customer domain. The second scenario allows direct utility access to customer-owned devices

Power Source Considerations:

A switched-mode power supply provides power to the electronics in the meter, converting from the main line alternating current (AC) voltage to the direct current (DC) voltages required. A switch will turn on the battery backup AC/DC only when there is no power from the main line. The battery remains isolated from the power system during normal operation.

For the electricity meter, power for the electronics can be derived from the single 3-phase power lines. For other utilities, the meter would either need to be attached to a power source or leverage an internal battery. In some regions, it may also be possible to use rechargeable batteries and small solar cells to recharge them during the day. In order to do this effectively, high efficiency power and battery management devices are necessary.

Microcontroller UnitSelection:

The microcontroller is of central importance in the design of smart meters. There are several possible levels of integration with the other functional blocks in the system. A two-chip architecture for a smart meter illustrates three possible architectures for a smart meter that includes Analog Front End (AFE) metrology, ADC and Digital Signal Processor (DSP). The first is a two-chip solution that provides flexibility for system upgrades. Second is a single-chip solution with tight hardware and software integration, making it less flexible for upgrades or modification.

Given the need for very low power consumption, microcontrollers like the MSP430 are ideal for any metering application. An advanced electronic meter requires a micro controller unit (MCU) that offers precise measurements over a wide dynamic range, programmable flash, non-volatile storage, real-time clock function, flexible display and AMR-enabled communications features. The MSP430 family offers up to four 16-bit independent sigma-delta converters and programmable gain amplifiers along with specific integrated e-metering modules such as the ESP engine or 32x32 hardware multiplier allowing for easy, high performance metering calculations and utility metering.

As utilities requirements increase, pushing more and more smart functions like load demand response, tariff management, communication and others, may require the metrology organisation to be qualified and isolated from the rest of the functions. The application layer for the smart electricity meter may require an additional functional unit to the primary. The MCU will typically require large amount of on-chip flash and connectivity. This can be MSP430 with devices going up to 256kB flash.

TI's F28x controller platform provides a cost-effective means to implement PLC technology. Along with advanced DSP cores, the controllers integrate robust peripherals such as analog-to-digital converters (ADCs), timers and pulse-width-modulation (PWM). F28x controllers offer a unique combination of 150 MIPS of 32-bit control-optimized performance and system integration. This high level of system integration simplifies design and keeps control systems compact and cost-efficient.

GSM/GPRS Module Selection:

Transceiver communication can be achieved using a variety of technologies and standards as shown in the schematic block diagram shown above in figure 2...The communication between the utilities company and the customer would be carried out through a GSM/GPRS network with the help of a GSM/GPRS module.

Using the Telit GE865-QUAD which happens to be one of the smallest GSM/GPRS Ball-Grid-Array (BGA) modules, two-way communication can be established.

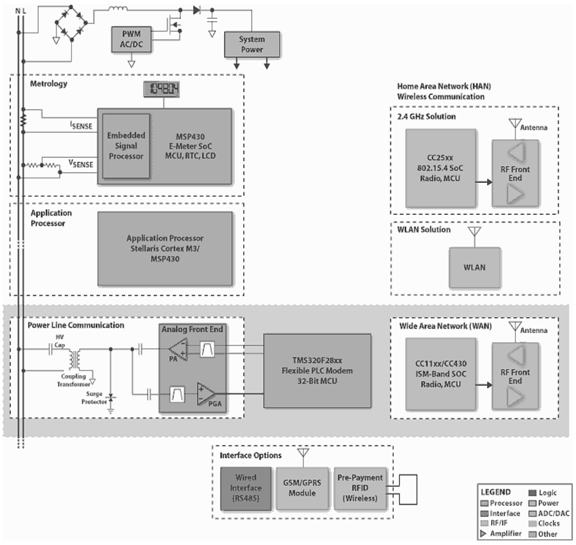

Figure 2: Complete Circuit Diagram of aSmart Meter

IV. Conclusion

The hardware design and architecture of a smart meter, a wireless sensor and actuator node which can monitor current consumptions of attached appliances and control their mains connection. Based on the low-cost reprogrammable components, smart-meter has been designed as a versatile experimental platform. Specific sensing or actuation behavior can be easily integrated through the reprogrammable character of the used microcontroller to raise user awareness for their energy consumption.

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