WHITE PAPER

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A smarter grid with the Internet of Things

Introduction

The Internet of Things (IoT) will deliver a smarter grid to enable more information and connectivity throughout the infrastructure and to homes. Through the IoT, consumers, manufacturers and utility providers will uncover new ways to manage devices and ultimately conserve resources and save money by using smart meters, home gateways, smart plugs and connected appliances.

This white paper discusses the different approaches being taken worldwide to connect the smart grid. Examples are provided on how TI is developing full system solutions by combining hardware (analog and digital) and software to address some of the challenges in building a smarter and more connected smart grid.

Making the grid infrastructure, meters, homes and buildings more connected

The Internet of Things (IoT) is expected to grow to 50 billion connected devices by 2020 (Cisco, 2011) providing valuable information to consumers, manufacturers and utility providers. Within the IoT, devices across a variety of industries will be interconnected through the Internet and peer-to-peer connections as well as closed networks like those used in the smart grid infrastructure.

With the global focus on energy and water management and conservation, the IoT will extend the connected benefits of the smart grid beyond the distribution, automation and monitoring being done by utility providers. Management systems for in-home and in-building use will help consumers monitor their own usage and adjust behaviors. These systems will eventually regulate automatically by operating during off-peak energy hours and connect to sensors to monitor occupancy, lighting conditions, and more. But it all starts with a smarter and more connected grid.

The grid needs to change to face today's challenges

In the simplest terms, building a smart grid means securing the future of energy supply for everyone in a rapidly growing population with a limited power production capacity. A smart grid reduces the losses, increases efficiency, optimizes the energy demand distribution and also makes large-scale renewable energy such as solar and wind deployments a reality. With an aging infrastructure, the grid is facing severe challenges including recurring black-outs in major industrialized cities around the globe, more than 30 percent electrical energy lost from production to homes in countries like India, and 35 percent drinkable water wasted in leakages in France and Australia.

The grid topology needs to adapt and shift from a centralized source to a distributed topology that can absorb different energy sources in a dynamic way. There is a need to track real-time energy consumption and demand to the energy supply: this goes with the deployment of more remote sensing equipment capable of measuring, monitoring and communicating energy data that can be used to implement a self-healing grid, increase the overall efficiency, and increase the level of self-monitoring and decision making. The connected smart grid provides a communication network that will connect all the different energy-related equipment of the future. From the transmission and distribution power infrastructure, electrical, water, gas, and heat meters, to home and building automation, Texas Instruments (TI) is addressing global smart grid challenges and building system solutions to connect grid devices.

The first key step towards a smart grid that makes the IoT real is the mass deployment of smart meters.

Millions of smart electrical meters are already connected

Around the world, electric meters are leading the way in smart meter deployments. For instance, the adoption rate of smart electrical meters (e-meters) in the United States is close to 50 percent with millions of electrical meters deployed today in the field, connected to the grid and regularly communicating data. Essentially,

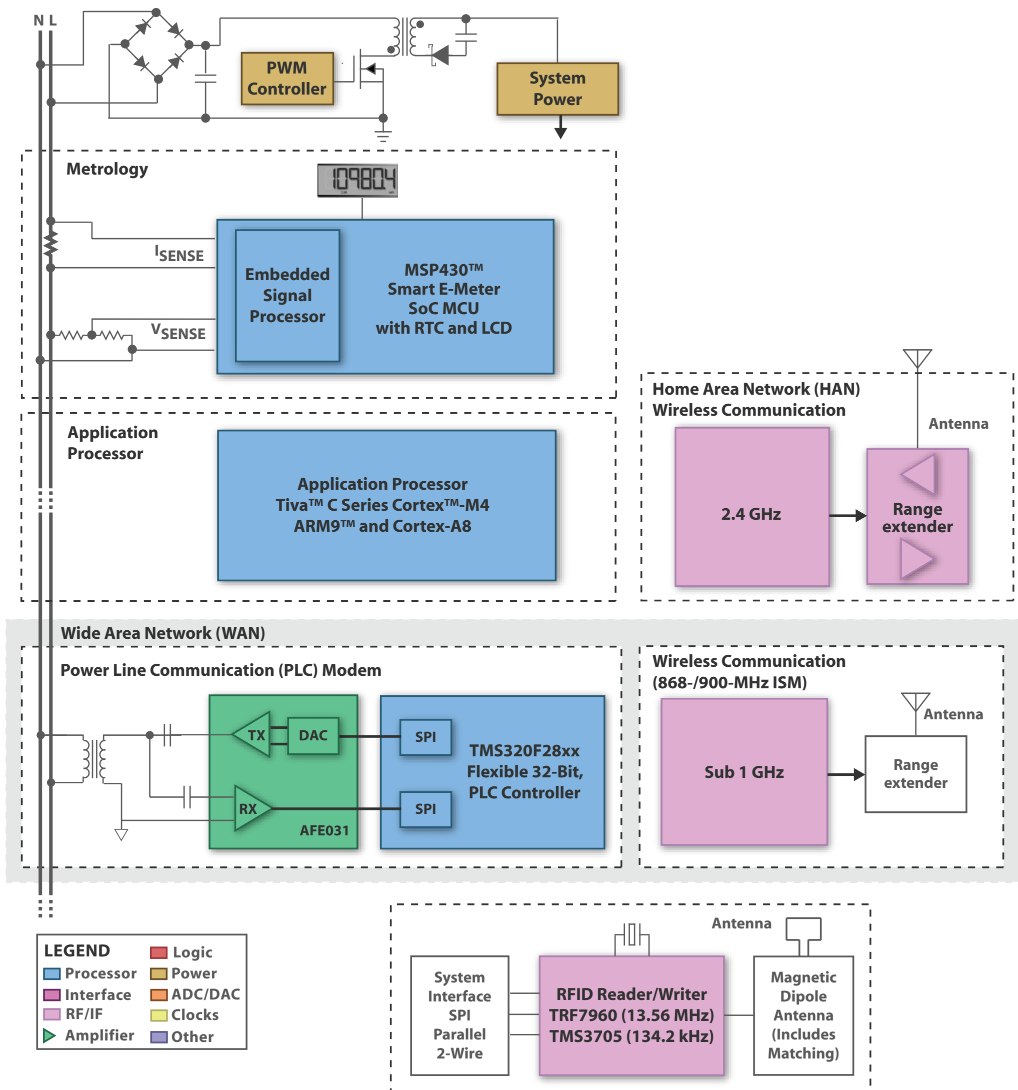

Figure 1. A TI-enabled smart electrical meter supporting multiple connectivity options

electrical meters are extending their functions from an energy measuring device to a two-way communication system as shown in Figure 1 on the previous page.

Modern e-meters must meet certain criteria to play such a critical role in the smart grid rollout. First, meters need to report energy consumption information from houses and buildings back to the utilities. In the U.S. the appropriate solution is low power RF (LPRF) communication using a Sub-1 GHz mesh network. However, depending of the country and the nature of the grid, a wireless solution might not be the best choice, for example in Spain or France where wired narrowband OFDM power line communication (PLC) technologies are used. There is no one connectivity solution that fits all deployments. Making the IoT real requires a larger portfolio that can go from wired to wireless and sometimes combined together.

Second, the meter needs to deliver useful power consumption information into the home through an in-home display or a gateway. This information allows consumers to adapt energy behavior and lower utility bills. In the U.S. the IEEE 802.15.4 2.4 GHz ZigBee® standard is being used in combination with Smart Energy application profile. Other countries such as the U.K. or Japan are evaluating Sub-1 GHz RF or PLC solutions for greater reach or a combination implementation with both hybrid RF and PLC. So in essence, electrical meters are becoming smart sensors that communicate both ways, inside and outside homes and buildings, connected to each other in a mesh network while reporting essential energy data to utilities.

For meter vendors, the move to the smart meter has a big impact on the meter topology as shown in Figure 1. On top of the metrology piece that measures energy consumption, several radios or PLC solutions are now integrated onto the meters. Sometimes, pre-payment and near field communication (NFC) functions are also implemented. The needs of host microcontrollers (MCUs) are changing, which require them to have greater memory size and more connectivity and security options to carry the communication protocol. Additionally, the MCU on a smart meter needs to support advanced functions like dynamic pricing/demand response, remote connect and disconnect, network security, over-the-air downloads and post-installation upgrades so utility providers don't have to send out technicians to each meter.

TI has increased the availability of its field-tested metrology evaluation kits and grown its portfolio of metrology ICs with more memory, security and accuracy. For example, as part of its extensive **MCU portfolio**, TI's new polyphase metering kit, based on the **MSP430F6679 SoC**, provides developers with best-in-class accuracy, more integrated memory and advanced anti-tampering protection. These SoCs can achieve electricity measurement accuracy that meets or exceeds global regulatory requirements for smart polyphase e-meters including IEC 62053-22 and ANSI C12.20 Class 0.2 standards. In addition, the large 512KB integrated Flash memory enables more sophisticated metering features like dynamic pricing tables, DLMS/COSEM or stacks for connectivity.

Addressing the need for diverse connectivity solutions TI offers the industry's broadest portfolio of Sub-1 GHz, 2.4 GHz, Wi-Fi®, ZigBee, NFC and PLC connectivity for the smart grid. In addition to being an active founding member of the major PLC alliances, TI has leveraged its extensive expertise and field trials to create the industry's first PLC device with PRIME, G3 and the drafted IEEE P1901.2 narrowband OFDM PLC support on the same chip. This device allows developers to easily create future-proof smart e-meters that can efficiently transmit data over existing power lines in any country. As demonstrated in the Smart Meter Board 3.0 **video**, TI provides unique system solutions that combine analog and digital hardware components with the associated software stack to support the various smart meter architectures options around the world.

Smart flow meters deployments are next

While connected meter deployments started initially with electricity, the adoption of smart meters within the flow meter market (gas, water, heat and heat-cost allocators) is also gaining momentum and millions of units are expected to be deployed in the near future. The global smart water meter installation base continues to grow, tripling from 10.3 million units in 2011 to 29.9 million units by 2017 (Pike Research, 2012). Specifically for gas meters, annual shipments will rise from 1.9 million units in 2010 to 7.8 million by 2016 (Pike Research, 2011). The 20 percent energy efficiency goal, part of the 20-20-20 initiative driven by the EU's Energy Efficiency Directive (EED) that attempts to address the long-term challenge around maintaining an affordable, secure and sustainable energy supply, is driving massive smart gas meter rollouts like in U.K. (largest deployment with 22 million units) followed by Italy (21 million) and France (11 million) (van Dyck, 2011 and Itron, 2010).

Again, moving from a simple meter to a smart flow meter involves communication and establishing a connection across devices.

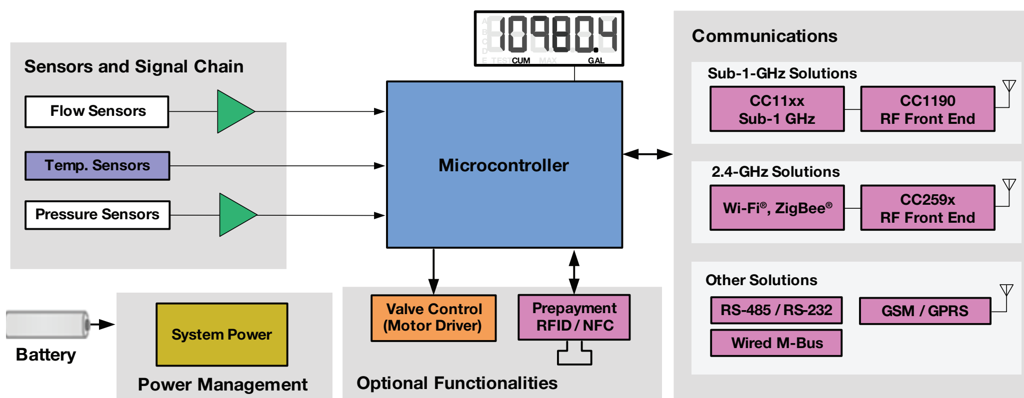

Figure 2. A TI-enabled smart flow meter solution featuring various connectivity options

Figure 2 highlights the different connectivity options for a generic flow meter topology. LPRF radios are typically used to communicate between the battery-powered gas or water meter and either another meter in a mesh network or a data collector on top of a legacy wired solution like wired MBUS. The meter can also receive tariff information, firmware upgrades or shut-off valve activation typically used in combination with prepayment, sometimes based on an NFC system. The battery life expectation ranges from 10 to 15+ years, creating a challenge for flow meter manufacturers. Power needs to be addressed at the system level by combining the right power supply design to sustain the required power output and radio performance without draining the battery. For instance, the combination of the **TPS62730 step-down converter** and

MSP430™ microcontroller together with TI's growing portfolio of Sub-1 GHz wM-Bus solutions, such as the **SimpleLink™ CC1120 RF transceiver**, is perfectly suited to deliver the industry's best selectivity and blocking performance. The system-level solution also delivers the lowest system power consumption to ensure the meter remains in the field for many years without needing a battery change.

The ability to connect flow meters or by extension any battery operated end nodes such as wireless sensors requires a system-level approach combining analog and digital hardware with software expertise. For instance TI has demonstrated that using 802.15.4e MAC layer combined with TSCH and IPv6 with RPL routing protocol significantly increases longevity, reliability, coverage and scalability of sensor network applications (see **video**). The IoT requirement impacts the future connected device, but the device and application are dictating the feasibility of the IoT.

In addition, while the modular, more risk-averse approach tends to carry a higher price for bill of materials (BOM), design reuse creates potential cost savings for complex smart meter designs targeted for multiple markets. One example would be to use the same MCU platform based on the ultra-low-power MSP430F5435A MCU for both Sub-1 GHz and 2.4 GHz markets, or to use the same RF module based on TI's SimpleLink CC1200 Sub-1 GHz transceiver for both gas and water meter solutions. IC suppliers typically also offer pin-compatible MCU or RF derivatives with additional memory and/or better system performance (Stefanov, 2012). Having this flexibility can significantly reduce resources needed for subsequent design changes. For meter manufacturers, this translates to reduced manufacturing costs and, all else being equal, greater return-on-investment. For the smart grid, it also means a faster deployment of connected devices, granted regulations are in place and standards defined.

Regulations and standards are key for large volume connected devices deployments

Regulations affect smart meter adoption rates and also specifications that determine a meter's functionality. For instance, the U.S. Department of Defense appears to be taking the lead on targeting government infrastructure managed by the GSA (general services administration) as a means to get cost out of the federal budget. Like the U.S., China is taking a central role in incorporating energy savings through the Smart City programs launching in mainland China. Particularly noteworthy is the adoption of Sub-1 GHz frequency bands for better range and penetration in large apartment buildings.

Standards are ensuring interoperability between multiple vendors, enable massive volume deployments and make the smart grid real – today. For instance, today's narrowband OFDM power line communication standards enable full electrical meter roll-outs or significant pilot programs with the **PRIME Alliance** in Spain, Poland, or with the **G3-PLC Alliance** in, France, Netherlands, Japan and other countries. For flow meters, the **wireless MBus** 169 MHz communication standard is now established in Europe and is enabling massive gas meter deployments plans in France and Italy.

At the same time, standards are continuously evolving and having the right implementation (hardware and software) and keeping with the pace with change is key. For instance, in order to accelerate power line communication at a global scale and provide future-proof designs to smart grid developers, TI has leveraged its extensive expertise and field trials to create the industry's first PLC device with PRIME, G3 and the drafted IEEE P1901.2 narrowband OFDM PLC support on the same chip.

On the RF front, the Department of Energy and Climate Change (DECC) in the U.K. is now on its second version of the Smart Metering Equipment Technical Specifications (SMETS). Under the SMETS v2, both 2.4 GHz and 868 MHz frequencies, with ZigBee SEP v1.x as the proposed application layer for gas meters, have been recommended as viable RF communication choices for the U.K. While 2.4 GHz-based meters will continue to be developed and deployed in the market, the possibility of having to also support 868 MHz-based meters in the future adds complexity to designing future-proof smart meters.

For the success of a connected smart grid today, being compliant to the regulatory standards is mandatory and TI an active founding member of the major PLC alliances and is actively participating in various standards bodies including ZigBee, WISUN, IEEE 802.15.4g and more in order to deliver leading-edge hardware and software solutions. The various standards and regulations make software and communication stack availability crucial to the smart grid and the IoT.

Millions of meters are already connected today and the connected grid momentum is growing. However, to obtain its maximum potential, the first step for the smart grid is to transition from mechanical meters to smart electronic meters to establish two-way communication between the meter and utility providers. Evolving regulations and standards are driving this trend but also underline the importance of flexibility in hardware and software. The second step is the automation of the grid infrastructure to connect power transmission and distribution by building out the communication network between power substations.

Moving to smart substations: Connectivity is the key to automation

The grid topology is changing, moving to a radial centralized topology to a mesh network approach with various distributed sources of energy.

From production to consumption, the substation is they key piece of grid equipment that establishes the link between utilities and homes and building premises. A substation transforms voltage, drives the flow of

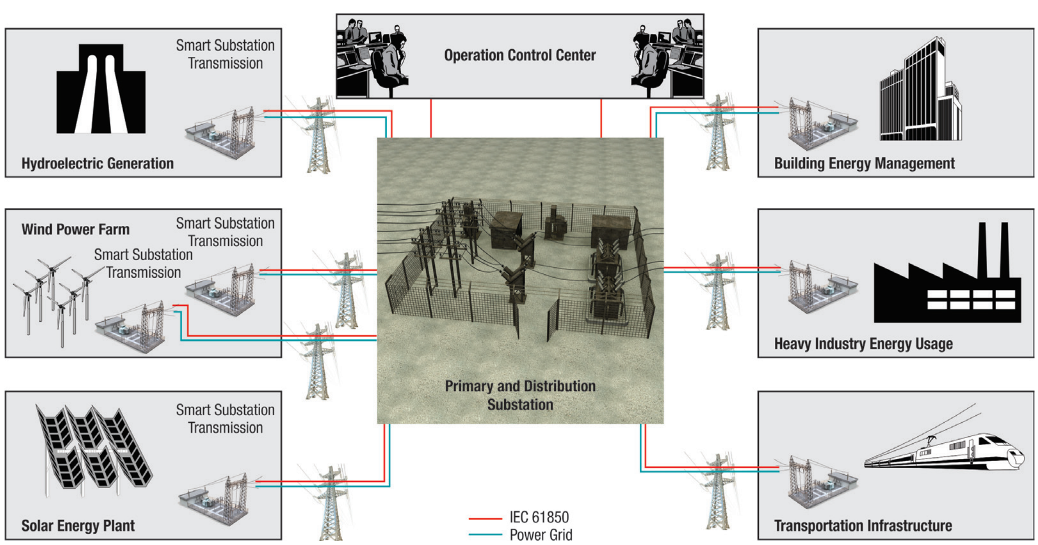

Figure 3. The power grid and the substation automation communication network

power, isolates and reroutes the power path as needed, manages and coordinates distributed energy source from solar to wind and deals with power outages and recovery (see Figure 3 on the previous page).

The ability to dynamically locate, map, monitor and control the substation at the city-, state-, or country-level is one of the key goals of an automated distribution to ensure better grid operation. Here again, using connected substations to build a network of power-related information is the answer. First, substation systems are evolving, moving from multi-copper and wire proprietary buses to Ethernet-based communication. This communication function is enabled by intelligent equipment devices (IEDs) installed inside the substations, as a part of new installations or retrofitting existing equipment. Second, similar to the meters, there is a need for interoperability across equipment vendors inside substations and with the collected data to enable volume deployment. The IEC 61850 industry standard implemented in the IED resolves this challenge. With IEC 61850, equipment in substations like breakers, transformers, and generators create a time-sensitive network, collecting all the substation information in a centralized operation center, which also establishes a two-way communication. With connected smart meters and substations we are moving to a fully connected grid (Figure 3).

As part of the substation equipment, communicating data concentrators are currently being installed at the substation- and transformer-level at the same deployment pace as smart meters. Figure 4 shows the block diagram of TI's recently announced Smart Data Concentrator. It provides the ultimate level of flexibility and

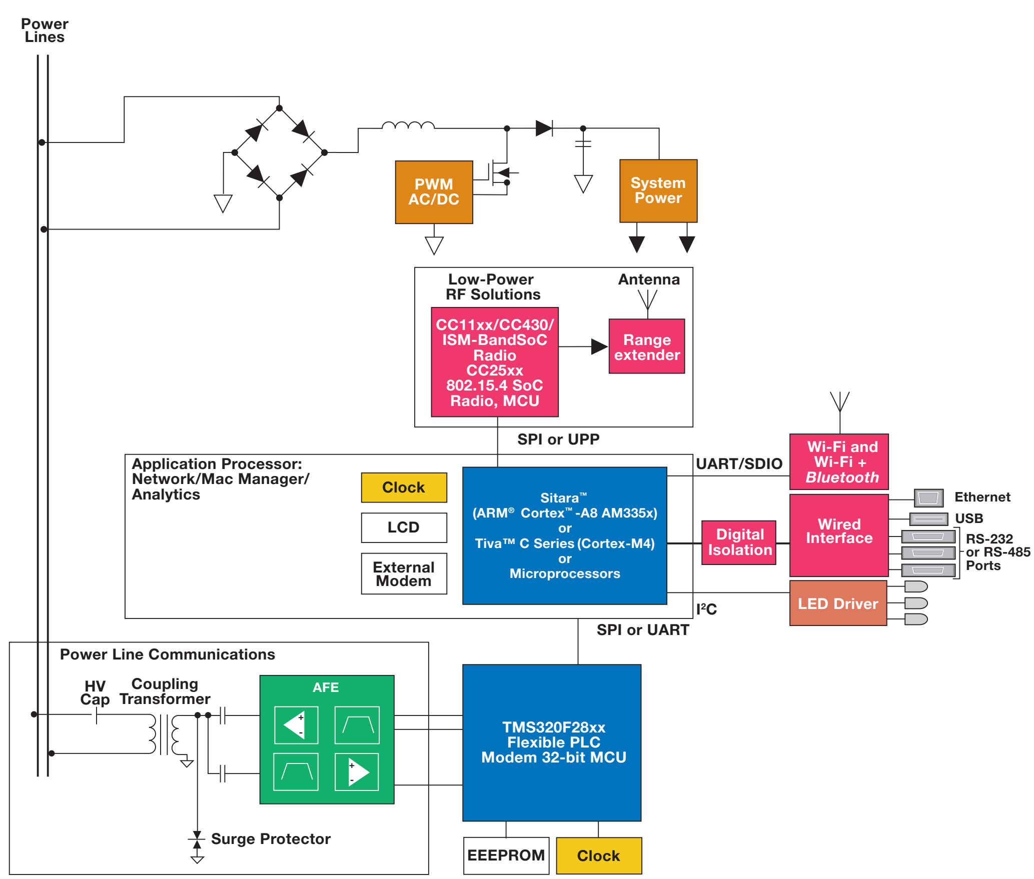

Figure 4. A TI-connected data concentrator block diagram

scalability with numerous performance, cost and connectivity options so developers can design data concentrators that adapt to any worldwide smart grid standard. The Smart Data Concentrator enables advanced metering infrastructure (AMI), and sensor network automation applications and allows utilities to simultaneously connect and manage more than 2,000 e-meters. The Smart Data Concentrator contains TI's highly scalable Sitara™ AM3359 processor with flexible peripherals that enable multiple wired and wireless connectivity options including Sub-1 GHz , 2.4 GHz ZigBee, Wi-Fi, NFC and multiple PLC standards (G3, PRIME, IEEE P1901.2, PLC-Lite™). The accompanying PLC system-on-module, paired with TI's PLC software stacks allows smart grid developers to easily set up a data concentrator demo with PLC connectivity in 10 minutes.

Again, with complete system-level solutions that incorporate hardware and software, TI's smart grid solutions reduce complexity, speed time to market and facilitate IoT deployment. From measurement and management to the communication of the energy information, TI delivers complementary software to provide a complete solution for smart grid and IoT developers.

Energy saving, comfort and security: Smart grid and the IoT for consumers

Electric meter deployments in the U.S. received early stimulus funding allowing regional utilities in 10 states to start pilot deployments in markets where educating customers was seen as a means to encourage adoption, and more importantly, real energy savings. One of the side benefits of the smart grid was to proactively allow repair teams to pinpoint outages by using the communication system in neighborhoods. By driving inquiries to the home and office, critical infrastructure could be restored sooner than the traditional method of self-reporting outages. A critical piece of the demand response system was connecting smart appliances to the energy-monitoring portal to give customers the flexibility to defer energy usage to non-peak times.

The introduction of electric smart plugs, in-home displays, smart thermostats (Figure 5) has given consumers a choice on which household devices they want to monitor. Simply plug the appliance into the smart plug and add it to the home network. Through ZigBee or Wi-Fi the user can then connect to the Internet to

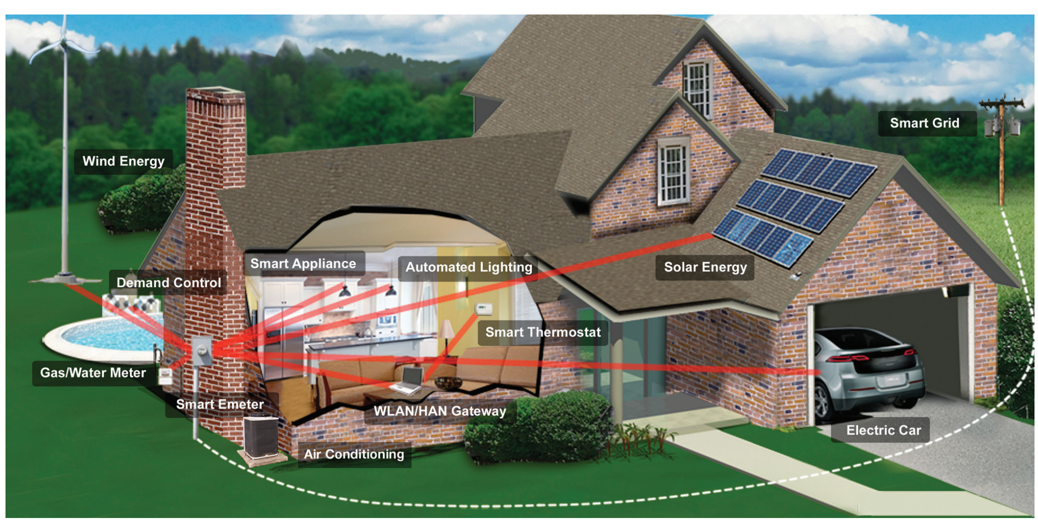

Figure 5. Smart grid connectivity enabling smart home services

get information through a home gateway or allow direct connection via cloud connectivity with a smartphone or tablet. Consumers are adopting smart plugs more quickly than high-end appliances with smart technology since they are lower cost and allow retrofitting of existing appliances. TI is making sub-meters less complex by packaging its complementary metrology, connectivity and processors in an easy-to-use, low-power solution. As an example, TI's **SimpleLink CC3000** Wi-Fi module and MSP430 microcontroller enable a simple design for sub-metering applications making Wi-Fi implementation easier than ever for embedded applications and stimulates many innovations in the industry (see **(see video example of connecting TI CC3000 Wi-Fi to the cloud with Exosite using the MSP430 MCU)**.

Connecting devices together in building and homes is one of the next steps to reach the full benefits of the smart grid and many innovative solutions and convenient applications are already offered to the consumers. The introduction of dedicated home energy gateway, smart-hub or energy management system in mandated deployments like in the U.K. or Japan will greatly accelerate connected grid and IoT benefits for consumers.

Conclusion

Regulations and standards continue to drive the adoption of connected devices all across the smart grid industry from grid infrastructure to smart meters down to homes and buildings. While migrating to smart meters adds a new layer of complexity, the return on investment, such as improved customer experience and energy efficiency, is becoming more apparent. The grid itself is also changing and moving towards a fully automated substation network with connected data concentrators already being deployed.

The connectivity and accessibility that the IoT brings further enhance the customer experience and efficiencies allowing greater interaction and control for consumers. Additionally the IoT delivers more data for manufacturers and utility providers to reduce costs through diagnostics and neighborhood-wide meter reading capabilities. Ultimately, the IoT will be instrumental in building a more connected, cost-effective and smarter smart grid.

TI and the IoT

With the industry's broadest IoT-ready portfolio of wired and wireless connectivity technologies, microcontrollers, processors, sensors and analog signal chain and power solutions, TI offers cloud-ready system solutions designed for IoT accessibility. From high-performance home, industrial and automotive applications to battery-powered wearable and portable electronics or energy-harvested wireless sensor nodes, TI makes developing applications easier with hardware, software, tools and support to get anything connected within the IoT. Learn more at **www.ti.com/iot**.

TI's smart grid solutions

With millions of energy meter ICs shipped over the past decade, TI is the global systems provider for innovative, secure, economical and future-proof solutions for the worldwide smart grid. TI offers the industry's broadest smart grid portfolio of metrology expertise, application processors, communication systems, wireless connectivity and analog components in readily available silicon, with advanced software, tools and support for compliant solutions in grid infrastructure, utility metering and home or building automation. Learn more at **www.ti.com/smartgrid**.

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