Modernizing the Grid to Make it More Connected, Reliable and Secure

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Communities and their electric grid systems increase demand for real-time communication, sustainability measures and decentralization efforts to meet a variety of energy needs, while engineers and designers define connectivity standards and approaches.

At a glance

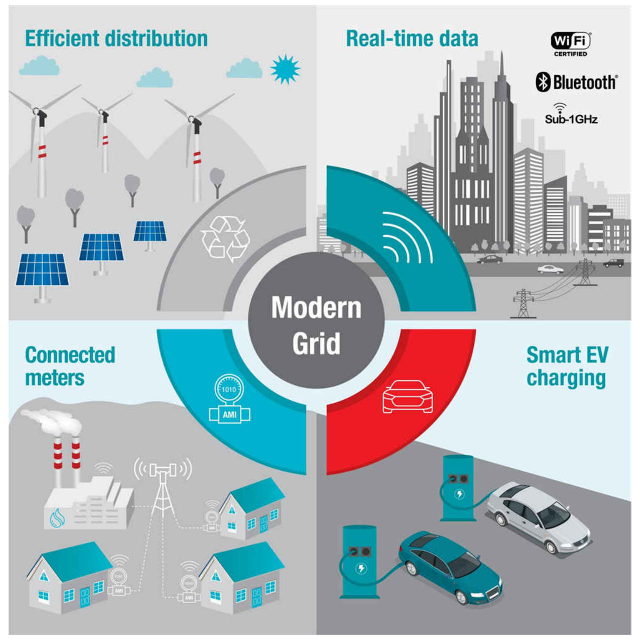
This white paper summarizes developments in four key elements of grid modernization:

1. **Distributed energy resources as an integral part of the grid**
   More regions are seeing the decentralization of renewable energy sources as a means to strengthen their infrastructure.

2. **Bidirectional EV charging to help balance the grid**
   Electric vehicles (EVs) play a significant part of the smart grid, from forecasting charging needs to conserving power or adding excess energy back to the grid.

3. **Real-time data, monitoring and control of the grid**
   Wired and wireless technologies enable the transfer of real-time data for the grid, as well as automation, distribution and control.

4. **Connected battery-powered gas and water meters**
   The connected grid is about more than electricity; gas and water utilities can adopt a variety of simple, low-cost solutions for connectivity, sensing and control.



The distribution network that connects generating plants to homes, buildings, factories, vehicles, cities and other sectors continues to require upgrades for reliability and resiliency. By employing advanced, connected sensors in generation, transmission and distribution, grid operators can monitor health and safety needs, optimize old and costly assets, detect faults and increases in demand, and restore power more quickly during an outage.

Data from grid assets gives operators greater insight into infrastructure performance, including different generation mixes, environmental conditions or security risks. Smart grid sensors enable the remote monitoring of equipment such as transformers and power lines, and facilitate demand-side resource management. Smart grid sensors can also monitor weather events and power-line temperatures in order to calculate a line's carrying capacity. A variety of wired and wireless protocols such as industrial Ethernet, RS-485, Controller Area Network and Wireless Smart Utility Network (Wi-SUN) can communicate the information gathered by the sensors.

On the load side, smart meters help consumers ease the migration toward more renewable energy solutions in their homes as well as for charging their EVs. Smart meters can also help consumers make better choices based on energy needs and sources. And in other cases, such meters can help monitor for bidirectional charging, such as when homes or cars return energy to the grid.

What was once a network of electromechanical systems with minimal feedback and passive loads has become highly automated and driven by intelligent devices and modernization strategies. The result is a more interconnected power delivery network – from generation to transmission and from distribution to end use – integrating distributed energy resources and ensuring greater grid reliability and resiliency.

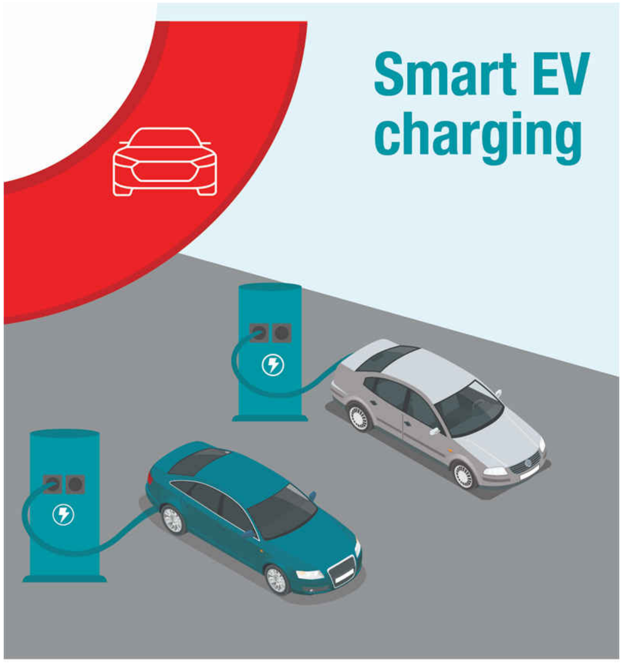
Distributed energy resources as an integral part of the grid

Traditionally, the power grid has been a "one-way street," with power flowing from utility-owned centralized generation, transmission and distribution lines toward consumers. As solar and wind energy start to make up a greater share of the electric grid, dynamic management will become more prevalent. Utilities have come to view the electric grid as more of an interconnected web, with a small but growing number of consumers generating electricity with small-scale, distributed systems. In other words, homes and vehicles may alternate between acting as energy consumption and generation units.

Solar and wind energy have zero carbon emissions, and unlike fossil fuels, are not affected by price volatility. More and more regions (especially those with abundant sunlight or wind and a high cost of electricity) have reached grid parity – the point at which renewable energy is equal to or cheaper than the cost of fossil fuel.

Solar microinverters are an integral segment of the solar power industry. Texas Instruments (TI) has a comprehensive selection of isolated and non-isolated gate drivers, digital isolators, Ethernet and RS-485 transceivers, current-sensing and voltage monitoring devices, and microcontrollers (MCUs) that can handle digital control loops targeted at all sizes of inverters, both grid-tied and off-grid, to maximize system efficiency and extend product life spans. All of these products must operate in the harshest environments, especially in extreme temperatures.

Bidirectional EV charging to help balance the grid



And while the electric distribution system was originally designed and built to serve peak demand and passively deliver power through a radial infrastructure, a smart grid not only facilitates more customer choice but can be managed locally, remotely or automatically. The smart grid enables utilities to keep up with changes in consumer behavior (for example, most EV battery charging at home will likely take place at night during off-peak hours).

The highest-performing EVs feature onboard chargers in the 22-kW range. The idea of bidirectional chargers brings along with it the possibility of using an EV as a battery storage element. Say that the EV in the garage can go 400 miles on one charge. But through communications, cloud computing and the modernized grid, the car "knows" that the owner is not going to drive more than 50 miles tomorrow. The battery does not technically have to be full at 7 a.m., so energy could be pulled out of the car overnight for local consumption or put back into the grid during peak hours. Similar approaches exist in the public charging infrastructure, while also achieving load balance between stations.

Additionally, improving grid power quality and reducing the drawn harmonic currents requires power factor correction, as many of the forward loads are DC. For example, in an offboard fast EV charger operating at 350 kW, the input is a three-phase AC connection from the grid, and the output to the battery is DC.

Many topologies exist for active three-phase power factor correction. The **10-kW, Bidirectional Three-Phase Three-Level (T-Type) Inverter and PFC Reference Design** is capable of bidirectional power correction and uses silicon carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs) with higher switching frequencies to improve efficiency and shrink the size of magnetics, thus reducing overall system size. This topology is scalable to higher-power smart grid applications such as EV charging and solar inverters. SiC MOSFETs with lower switching losses ensure higher DC bus voltages (up to 800 V) and a peak efficiency >97%.

As part of TI's continued investment in the future of the grid, TI is advancing the components required to enable EV charging, both on the charger connected to the grid as well as the battery-management system within EVs. With the potential for high voltage from the grid and from EV batteries, isolated devices are essential for any EV charging or battery-management system design. These devices include communication and protection circuitry such as isolated and non-isolated amplifiers, isolated and non-isolated interface integrated circuits, and power for signal isolators.

Real-time data, monitoring and control of the grid

Electric utilities face important challenges in key aspects of their business as a result of the ongoing and rapid transformation of the grid.

Conventionally, grid networks in cities relied on above-ground distribution with wires. This system will yield to power conduits dug down into the ground, because there is not space for more overhead lines in big cities, and because people do not like to see power lines over or in front of their homes.

In the past, utilities had fairly simple ways to find faults above ground: They sent out a maintenance truck to drive along the power line to discover a fallen power line, a tree hanging on a line or too much snow on a line. In all of these instances, the cause of the power outage was pretty obvious. But grid modernization allows for real-time communication, measurement and surveillance – and quick response and repair –when it is not possible to see underground failures.

The use of real-time data management has become more important than ever when it comes to connecting the utility grid system. The goal is to place data in the hands of those who can make the best use of it. Modern mobile devices are a readily available platform for data delivery and control of both smart grids as well as the multiple energy sources incorporating the solar photovoltaic panels that make up a microgrid. Wi-Fi® and *Bluetooth®* are obvious methods for wireless grid connectivity; if necessary, an intermediate gateway can be another option. TI's Grid IoT Reference Design: Connecting Circuit Breakers and Sensors to Other Equipment Using Wi-Fi is designed for real-time asset monitoring in the smart grid. The main benefits of the reference design include:

- Real-time asset health monitoring (monitoring current, voltage and temperature levels through Wi-Fi® communications).
- Adding redundant, variable data-rate transfer capability for critical applications.
- Backup for wired communications within the substation.
- Improving response times for detecting faults.
- Reducing power downtime.

The reference design shows how integrating Wi-Fi is a viable solution for substation equipment and residential breakers that require high data rates and large bandwidth. Sub-1 GHz connectivity is another applicable wireless technology when transmitting data over a long range with low power consumption for substation and distribution automation, useful when multiple nodes (such as fault indicators) need to transmit data to one data collector for the formation of a star network. Both technologies are available through the SimpleLink™ family of wireless MCUs based on the foundational SimpleLink software development kit, promoting 100% code reuse and seamless transition between multiple wireless connectivity technologies.

The Grid IoT Reference Design: Connecting Fault Indicators, Data Collector, Mini-RTU Using Sub-1 GHz RF employs wireless Sub-1 GHz communication in a star network between multiple sensor nodes (in this case, fault passage indicators [FPIs]) and a collector using the TI 15.4 stack. This design is optimized for low-power consumption for short ranges (<50 m) using overhead

FPIs and a data collector in distribution automation as an application scenario.

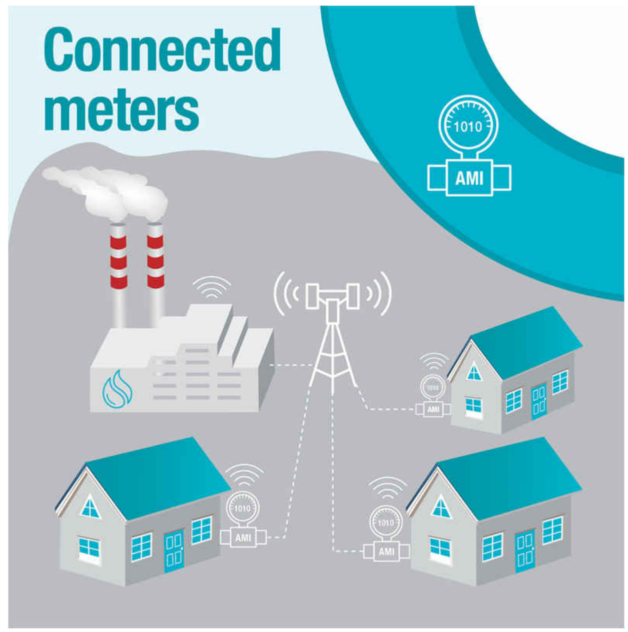
It also employs the **CC1310** from TI's SimpleLink family, which incorporates a Sub-1 GHz radio-frequency (RF) transceiver and an Arm® Cortex®-M3 MCU. The TI 15.4 stack configures beacon-mode communication over the U.S., European Telecommunications Standards Institute and China frequency bands. Current consumption data is available for a single-packet data transfer of 1 to 300 bytes at a 50-Kbps data rate by optimizing transmit power levels (0 to +10 dBm) and beacon intervals (0.3 s to 5 s).

As electric networks connect to renewable power sources with multiple feed-in points from wind turbines and solar panels, distribution becomes more complex. Increased automation is a defining feature with remote measurement, services and repairs, and requires real-time monitoring and control as well as high reliability. Network redundancy is of fundamental importance in these complex smart grids. This duplication of important components or functions enables systems to continue functioning in failure scenarios, decreasing network downtimes that might lead to property damage or even loss of life. Network redundancy can also enable workers to perform maintenance on a subset of the network without interrupting power delivery.

Ethernet is popular and readily available, based on the International Electrotechnical Commission (IEC) 61850 Ethernet standard for grid management. Redundancy protocols are a building block to add reliability and enable Ethernet as a management network for smart grids. IEC 62439-3 defines two architectures, parallel redundancy protocol (PRP) and high-availability seamless redundancy (HSR), for implementing zero-loss redundancy on wired Ethernet. Arm-based processors and MCUs integrate support for these protocols and the associated cut-through switching. With PRP, each node connects to two separate parallel local area networks (LANs).

Source nodes send two copies of each packet, one over each interface. The destination node receives a frame, accepts the first copy and drops the second frame. The destination node will always receive at least one packet with zero downtime, as long as either of the two networks is able to operate. The HSR ring provides the same level of redundancy as PRP, using a ring topology instead of two LANs.

Connected battery-powered gas and water meters



Although connected meter deployments initially started with electricity, the adoption of automatic meter reading (AMR) and smart meters within the flow meter market (gas, water, heat) is also gaining momentum.

To reduce mechanical failures, improve accuracy and add intelligence, gas and water meters benefit from:

- Ultrasonic flow measurement with high accuracy and low energy consumption.
- Wired isolated and non-isolated communication for real-time monitoring and communication of data and faults.
- Wireless communications, with long ranges to ensure connectivity or the ability to connect to an existing network infrastructure.

- Intelligent power management to maximize efficiency and provide at least 10 years of battery life.

Powering **electric meters** is obvious; because measurements are taken from a power line, there is power where the electric meter sits. But battery-powered technology is the norm in gas and water metrology, which makes it a lot more challenging because the power budget is much lower. There is also a commercial challenge: In many regions, entities smaller than electric providers handle gas and water. In the same area, you might have one organization owning the electric meter network, but multiple companies supplying water to residents.

Furthermore, water or gas utility providers that wish to add AMR capability face the choice of replacing all of their existing meters or installing an electronic add-on module to accurately measure the flow rate and wirelessly transmit the results. Such add-on modules offer an inexpensive solution to provide AMR features to consumers, as shown in the **Low-Power Water Flow Measurement with Inductive Sensing Reference Design**, which is enabled by the CC1350 SimpleLink wireless MCU.

In a gas or water meter network, the smart meter is the sensor responsible for collecting usage data and reporting it to upstream control nodes. Accurate ultrasonic measurement helps reduce mechanical failures and leads to greater system reliability. Ultrasonic measurement eliminates mechanical wear and tear by using a solid-state sensor architecture with no mechanical components. The introduction of ultrasonic flow-measurement systems-on-a-chip (SoCs) has greatly reduced the cost of transitioning to this technology.

TI's industry-leading integrated circuits and reference designs for smart gas, water and electricity meters help original equipment manufacturers (OEMs) meet design challenges to improve measurement accuracy and extend battery lifetimes through a large selection of ultra-low-power wired and wireless interface devices.

The **Ultrasonic Sensing Water Meter Front-End Reference Design** helps engineers develop an ultrasonic water-metering subsystem using an integrated, ultrasonic sensing analog front end (AFE), which provides high-performance metrology with low power consumption and maximum integration. The design is based on the **MSP430FR6047** ultrasonic sensing SoC. This SoC offers an integrated ultrasonic sensing subsystem AFE, which provides high accuracy for a wide range of flow rates through a waveform capture-based approach. Additionally, the device helps achieve ultra-low-power metering combined with lower system costs through maximum integration, requiring very few external components.

Similarly, the **Battery and System Health Monitoring of Battery-Powered Smart Flow Meters Reference Design** enables highly accurate power measurement and state-of-health projections, which forecast battery lifetimes. The monitoring subsystem also protects against overcurrent conditions, which can dramatically reduce battery life.

Conclusion

Across the country, states and utilities are busy building the grid of the future, transforming the transitional passive, electrical and electromechanical grid into an active electronic grid with dynamic control. The technology drivers for grid modernization include:

- Bringing electronic technologies and semiconductor devices to meters at the edge of the grid.
- Integrating distributed renewable generation resources.
- Adapting to electrical transportation systems and their charging infrastructure.
- Making improvements in grid monitoring, protection and control.

Modernizing **the grid** and the controls that communicate and work together to deliver electricity more reliably and efficiently greatly reduces the frequency and duration of power outages, diminishes the impact of storms, and restores service faster when outages occur. Updating an aging system is not easy, and it will not be accomplished quickly, but it ultimately proves beneficial to society and the economy for decades to come.

Additional Resources

- Learn more about **Connected Technologies for Grid Infrastructures**.
- Check out the technical articles **"How Wi-SUN FAN Improves Connected Infrastructures"** and **"Top 3 Design Considerations for EV Charging"**.
- Download ***The RS-485 Design Guide***.