Executive Summary

Driven by new regulation, new market structures and new energy sources the smart grid is the response to profound changes in the way that electricity is generated, distributed, managed and consumed. What makes the challenge particularly acute, is the essential role that energy production plays in modern democracies. Keeping the lights on is a political, economic and social imperative.

Enabled by current and future developments in technology, smart grids will better enable electricity companies to meet rising demand, increase the reliability and quality of power supplies, improve energy efficiency, and integrate low-carbon energy sources into power networks.

This paper looks at the environment in which the smart grid is being developed, based on industry standards and how a newly intelligent, interconnected and interoperable grid can be seen as a leading example of the Internet of Things in action.

The changing landscape

The smart grid can be viewed as the response to a number of fundamental challenges within the energy market.

1. Rising wholesale prices. The European Commission (EC) estimates electricity prices will rise by 31 per cent between 2010 and 2020, while global energy demand is set to double by 2030. Combined with political and social pressure to minimize ‘energy poverty,’ and restrictions on building new plants to respond to jumps in peak demand, grid systems operators must find ways to do more with their existing – but aging – infrastructure.

2. Regulation. Adding further costs are a series of increasingly stringent regulations. Requirements such as ‘20 per cent by 2020’ commitment under the EU Directive on Energy Efficiency are adding compliance costs. Less directly, but equally significant, are the emissions trading schemes that expose utilities with little room for hedging to fluctuating carbon prices in the mid- to long-term.

3. Market structures. Regulation is also changing the structure of the markets themselves. More countries are making the move to deregulated...
energy markets and introducing a more competitive landscape. At the same time unbundling in both the energy and telecommunications markets is bringing new players into the utility business: telecoms providers, internet service providers and software companies. Increasing focus on establishing key performance indicators (KPIs) and defining the total cost of ownership of the grid reflect these changes.

The grid in transition

The analog grid is already evolving as the adoption of low-carbon technologies leads a shift away from a demand-driven to a more supply-dependent energy system.

1. Renewable impact. Solar energy, combined heat and power (CHP), onshore and offshore wind generation, hydro and biomass are increasing their share both of industrial-scale and smaller, distributed generation. The IEA suggests that solar alone could be the top source of electricity by 2050, with solar photovoltaic (PV) systems generating up to 16 per cent of the world’s electricity by 2050, and solar thermal electricity (STE) providing a further 11 per cent.3

This increase in unpredictable and intermittent supply is disrupting carefully calibrated supply and demand relationships and putting pressure on today’s load-shedding and demand-response capabilities. The increase in intermittency also means that some grid areas will absorb more renewable energy generation than their actual consumption at specific times in the day.4

2. The prosumer phenomenon. Grid system operators and utilities are losing their monopoly on energy generation. The prosumer – a traditional consumer, at either residential, commercial or industrial level, who also produces power – challenges the old one-way relationship from generator to consumer. Whether using PV panels to heat a single home, or commercial wind farms to power entire supermarkets, prosumers are creating a myriad of economically motivated entities that operate or own a power system that contains generation loads and even energy storage.

3. Fragmentation. As a result, the traditional monolithic grid is morphing into series of interconnected systems from ultra-high-voltage super-grids to ultra-low-voltage micro- and pico-grids. The edge of the grid is becoming more unpredictable and even mobile as electric and hybrid vehicles add new intermittent storage capacity.

4. Interconnectivity. This more federated and flexible grid structure is set to play a key role in the European vision of the future, in which a completely interconnected infrastructure facilitates a pan-continental energy market.

Smart grid: the Internet of Things in action

If market conditions have driven the development of the smart grid, technological development has enabled it. Fundamentally, the smart grid is an energy generation, transmission and distribution network enhanced by digital control, monitoring and telecommunications capabilities. In addition to providing real-time, two-way flow of electrical power, it also enables automated, bidirectional flow of information. Consequently, all stakeholders in the electricity chain – from generation plant to commercial, industrial, and residential users – gain...
insight into both electricity flow and the infrastructure transporting it.

To add intelligence to existing infrastructure, new digital equipment and devices are strategically deployed to complement existing equipment. This new layer of digital equipment connects all assets in what can be described as an ‘Internet of Watts’ – but which is in fact an example of the Internet of Things (IoT) in action.

The IoT is built by integrating Internet-connectivity into all kinds of plant, equipment and devices, connecting those devices in intelligent networks, and using data analytics to extract meaningful and actionable insights from them. In the context of the smart grid, this means distributing computing intelligence throughout the infrastructure. This includes everything from embedded sensors in wind turbine vanes that control its pitch, rotation and function in real-time response to changing wind conditions, to substation control systems that respond quickly to events and minimize production downtime associated with network disturbances – in both cases without human intervention.

However, the real value of IoT is that it creates opportunities to realize the potential of data that resides in existing, unconnected infrastructures and, using data analysis, to extract insight and intelligence from them. After gathering data about every aspect of the electricity supply chain, system operators can use powerful analytics, simulation models and what-if scenarios to create more precise predictions about a wide variety of factors from grid status to weather conditions.

The possibilities associated with predictive analytics and the transition from reactive to proactive operations is one of the defining and most important features of a smart grid. It enables electricity companies and grid system operators to:

- **Reduce capital expenditure.** With a smart grid, a more precise match of supply and demand across the grid is possible. Utilities can meet peak demand without unnecessary generation capacity and can ensure the most efficient distribution paths, which minimizes transmission costs and ensures optimal asset operation.

- **Manage demand.** Granular insight into consumption patterns combined with greater predictive ability allows more energy conservation initiatives to be implemented, including demand-response, time-of-day usage fees and dynamic pricing. This helps balance demand with supply and minimizes waste caused by overprovisioning base or peak load.

- **Increase renewable capacity.** More onshore and offshore renewable generation can be incorporated into the energy mix. Utilities can respond more effectively to intermittency from industrial-scale renewable plant as well as smaller distributed generation while still ensuring security of supply.

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Daikin Applied*, the world’s largest air conditioning, heating, ventilating and refrigeration company, is harnessing the power of the Internet of Things using a pre-validated and flexible open-compute Intel Gateway solution to create a complete end-to-end system for commercial HVAC equipment. By deploying the integrated intelligent gateway, Daikin Applied can focus on rapidly implementing differentiated value-added services to its customers, such as real-time unit performance, remote diagnostics, monitoring and control, advanced energy management and third-party content integration.
• **Lower maintenance costs.** Insight into the activity of various generation, transmission and distribution assets enables remote fault diagnosis, minimizes site visits, and enables more predictive maintenance for more efficient technical support that focuses engineering teams on areas of greatest need.

• **Comply with regulations.** By enabling greater use of renewable generation, supporting more efficient generation, transmission and distribution, and aiding more efficient consumption, digital technologies help electricity and utility companies meet regulatory obligations to reduce carbon emissions. In the EU, this includes the commitment to reduce emissions to 20 percent below 1990 levels by 2020, to 54-68 percent below 1990 levels by 2030, and to nearly 100 percent below 2020 levels by 2050.

• **Enhance customer engagement.** Increasingly required to compete within deregulated markets and meet energy savings targets in certain regulated markets, electricity companies can use insight to develop an accurate picture of customers’ usage patterns on which to base more tailored and competitive product and service offerings.

### Technology imperatives

As the electrical grid moves from analog to digital, nearly every device and piece of equipment will need built-in, secure, interconnected intelligence. A supporting cloud and network infrastructure will also need to be enhanced in order to protect data, manage devices and perform data analytics.

To achieve the promise of the smart grid four broad technology criteria must be fulfilled.

1. **Security.** Security is key: without it, the smart grid, like any data network, cannot function. Electricity grids are valuable and critical targets that need to be protected from cyber threats. As a large system of distributed and interconnected systems, the smart grid offers an exceptionally large attack surface. Any successful attack on a critical element can jeopardize grid security and cascade into a whole system blackout.

   End-to-end security is therefore one of the major starting conditions for an effective digital energy infrastructure. Each smart grid subsystem, its associated assets and the data derived from those assets require specific security functions and solutions. The solution to secure a substation is not the same as the solution to secure demand response or protect personal data or operational intelligence.

   Cyber security technologies and best practices necessary to protect the smart grid include: anti-virus, firewalls, intrusion prevention systems, network security design, defense-in-depth and system hardening.

   In addition, countering more sophisticated advanced persistent threats (APTs) requires advanced cyber security technologies including security information and event management (SIEM) systems, application whitelisting, and security features embedded at the processor level, among others.

   Intel® provides a combination of technologies from Intel, Wind River® and McAfee® that incorporate the security layer in the hardware, embedded operating system and security software to ensure end-to-end security in a smart grid. Intel® Trusted Execution Technology (Intel® TXT) integrates new security capabilities into the processor, chipset and other platform components. These hardware-based security features, unalterable by rogue software, run mission-critical applications in a safe partition, protect crucial platform data and keep malware from launching. In addition, the McAfee data exchange layer (DXL) provides real-time context sharing and orchestration, as well as collective threat intelligence and adaptive threat prevention techniques suitable for massively scalable networks such as a smart electricity grid.
2. Communications. The ultimate success of a smart grid, as with any other data network, depends on the ability of individual devices and systems to interconnect and share information with each other in a secure and reliable manner.

In the context of the smart grid, communications fall into two broad categories: the protocols needed to transmit data within a relatively closed environment such as a home area network or industrial area network; and the protocols required to transmit data externally back to a central location. This will involve a broad range of protocols, including 2G, 3G, LTE, LTN, WANs, and the involvement of specialist telecommunication service providers, hardware and software companies.

This requires common frameworks, based on open industry standards, so that grid system operators can ensure interoperable connectivity without tying their grid ecosystem to one company’s solution. A report from the joint working group of SGAM and The Internet of Things offers a tremendous opportunity for businesses to truly transform themselves by realizing the potential of data in existing, unconnected infrastructures. However, open interoperability standards and common architectures are essential for connecting legacy devices to data centers and the cloud and for the end-to-end analytics that help realize its benefits. AT&T*, Cisco*, GE*, IBM* and Intel have formed the Industrial Internet Consortium (IIC), a not-for-profit group with an open membership that will take the lead in establishing interoperability across various industrial environments for a more connected world.

ETSI has already outlined numerous standards to be used in specific circumstances within the SGAM-identified domains.5

3. Analytics. There are a range of insights that can be gathered throughout the grid: from real-time visibility and analysis of operations that support more efficient maintenance planning, to predictive analytics that enable more precise generation planning and load balancing. Analytics are needed to develop actionable intelligence from these millions of data points.

In energy generation, computationally intensive simulation models can be used by renewable energy plants to better predict energy demand, factor in weather conditions and optimize capacity. Analysis of wind patterns, for example, can give an indication of the kilowatts likely to be generated – and also indicate when high wind speeds could cut generation completely. This information can be used to address intermittency issues and reduce spinning reserve. Similarly analytics can enable distribution service operators (DSO), transmission service operators (TSO) and vertically integrated utilities to optimize service voltage and phase of substations in real-time, thereby improving energy efficiency.

As the grid grows in complexity, utility operators will need intelligent agents dispersed throughout the electrical network to make real-time decisions that directly affect operational efficiency. This distributed intelligence, and the machine-to-machine communication that it enables, is essential for increasing the capabilities of the future smart grid.

The Intel® Xeon™ E7 v2 product family delivers the most advanced in-memory analytics capabilities for gathering real-time insights and making data more valuable. Using analytics to unlock hidden insights in a matter of seconds enables energy companies to make quick decisions and better adapt supply to demand. To help businesses maximize the value of their big data investment, Intel also offers the Intel® Data Platform, a software suite based on open source technologies that is designed to make it easier for organizations to move from big data to big discoveries and faster decision-making.

4. Manageability. With smart grid infrastructure stretching over many thousands of kilometers, equipment ranging from vast turbines to smart meters at the end-users’ premises, and technology covering a variety of software and hardware types,
manageability of equipment and communications is the fourth critical element in the successful smart grid. Manageability covers three broad areas: equipment, software and security – and can extend all the way to managing upgrades and repairs to field-force worker’s mobile PCs and tablets.

Remote diagnostic, control and repair capabilities can dramatically increase equipment availability and drive efficiencies in maintenance and operations, particularly when assets are geographically dispersed or are otherwise hard to access: underground, underwater, or in customer premises, for example.

Data models also have to reflect the challenges of the complex technical and operational challenges. Virtualized execution environments can allow developers to isolate different workloads, run multiple operating systems and prevent them from interfering with one another – which safeguards millions of lines of computing code and improves control-system reliability.

Finally, using hardware-based security features built into computing systems creates a trusted execution environment, in which only validated software can be added to prevent hackers executing malicious software on the control network.

The smart grid in action

The SGAM standard models identify five key domain areas in the smart grid. Some of the more immediate benefits in each domain are identified below.

Generation
Maintaining assets for optimal operation is a constant challenge. Sending technicians for speculative repairs is costly and inefficient, while dispatching maintenance teams after a fault has been identified – but not necessarily located – reduces output for unnecessary periods of time. The problem is compounded when a generator is more remote or not easily accessible, as is the case with offshore generation.

Adding intelligence at the point of generation, and combining it with an understanding of demand nearby and nationwide, enables the electricity supplier to plan optimal electricity generation. Sensors within the machine can monitor both the status of the equipment and the health of engineers performing dangerous tasks. They can send real-time alerts on faults, accidents or anomalies to technicians, while remote control management systems allow certain faults to be fixed without dispatching a technician.

If a technician is required on site, location-based services can use information supplied by several sensors to identify the precise location of the fault within the machine. The constant monitoring of the equipment enables a shift from scheduled to predictive maintenance. This offers significant cost benefits, as well as enhancing asset management programs and prolonging the life of the asset.

Transmission
For the transmission domain, where visibility into electricity flow is already high, the transition to a smart grid is about minimizing operational losses. With thousands of kilometers of cables to monitor, the ability of smart sensors to identify anomalies, faults and causes of outages in real time is a significant advantage. Transmitting that information to a central location enables operators to respond swiftly – essential in the transmission domain. Sensors can even be used to steer unmanned drones for fully automated maintenance monitoring. This is a significant step up from the expensive helicopters currently being deployed.
In addition, real-time visibility minimizes losses from HVDC lines, helping operators to spot the impact of weather on cabling, for example, which prevents sag and any resulting loss of capacity.

**Distribution**

In contrast to the transmission domain, visibility at the medium-voltage level is relatively clear within the distribution domain thanks to the effective use of SCADA systems to secure energy supply. But transparency drops to near zero at the low-voltage level. Remote maintenance and monitoring is still relatively rare, creating a lack of insight into the real-time health of assets and activity on the last mile of distribution. Asset deterioration is also accelerated thanks to more intermittent electricity flows, while an aging workforce is depleting the pool of available operational expertise.

With a smart grid, remote monitoring and management of secondary substations is possible, as is greater interconnection with primary substations for a more stable distribution grid. For DSOs, the attraction of the smart grid is that it also supports smart field workers. Operations and maintenance personnel can evolve into highly connected asset intelligence teams and bridge the gap between centrally located experts and on-the-ground staff handling a series of critical or unfamiliar tasks. Remote contractors can use ruggedized laptop PCs and tablets to gain real-time access to central ERP, GIS and Asset Management systems, technical manuals and even instruction videos enhanced by augmented reality.

**Distributed Energy Resources (DER)**

In addition to the challenge of load balancing, volatile supply from diverse distributed generation sources creates sub-optimal conditions for existing transmission and distribution assets. It also extends the distribution network, creates greater complexity in the last mile and increases the likelihood of lost capacity.

An intelligent and interoperable grid supports the establishment of virtual power plants (VPPs) from clusters of distributed generation installations, and enables them to be run from a central control facility. With predictive analytics, secure communications and effective controls in place, VPPs can complement existing conventional generation by delivering peak-load electricity or load-aware power generation at short notice. By load shifting they can also provide steady base-load that is more carbon-efficient than conventional generation.

**Customer premises**

The final domain in the SGAM/ETSI model is customer premises. Here two dominant themes emerge. The first is encouraging users to reduce energy consumption and make savings in their costs, as well as carbon emissions, through highly granular insight into consumption patterns and costs.

Both depend on greater understanding of customer behaviors and requirements and the ability to forecast consumption. For example, using regional demand-response systems (DRS), utilities can develop dynamic pricing models that encourage manufacturers to adopt beneficial consumption patterns that help balance load, flatten peak consumption and stabilize the grid – while reducing their own costs in return.

Dynamic pricing and demand response are central tenets in a newly revitalized relationship between the electricity company and its traditional customers and the growing number of prosumers.

Intel is working with Westfalen Weser Energie* to build a smart monitoring system for its electrical substations. Two of 100 secondary substations are fully equipped with sensors, edge analytics, cyber security and communication. Two substations have been instrumented to measure low and medium voltage, current, environmental data and medium-voltage short-circuit indicators and to transmit that data in real-time intervals. The data is locally analyzed by industrial PCs powered by Intel® Core® i5 processors. Headline statistics are sent to the control center, which enables Westfalen Weser Energie to react to changes in demand for power generation.

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Conclusion: Intel Inside the smart grid

Electricity generation is in transition. No longer purely an engineering concern it is increasingly a question of infrastructure built around and incorporating information and communications technology. To facilitate this transformation, equipment manufacturers are deploying Intel® technologies that satisfy the computing requirements across many aspects of energy infrastructure, including energy generation, distribution and consumption monitoring systems. By leveraging Intel's technology leadership, commitment to quality and volume manufacturing capabilities, the energy industry can develop secure smart grid infrastructures in the fastest and most cost-effective manner.

Intel offers utilities, grid systems operators and OEMs the necessary computing horsepower as well as the essential ability to reuse software on multiple platforms as systems develop and evolve. Because Intel Architecture is compatible with a diverse array of software and hardware providers, and because specified standards are at the heart of smart grid development, a network running on Intel Architecture is not locked into specific vendors. The choice still remains, as it should, in the hands of the grid operator.

For more information about Intel® and the Smart Grid, visit http://www.intel.com/content/www/us/en/energy/energy-overview.html