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White Paper

Networking the smart grid

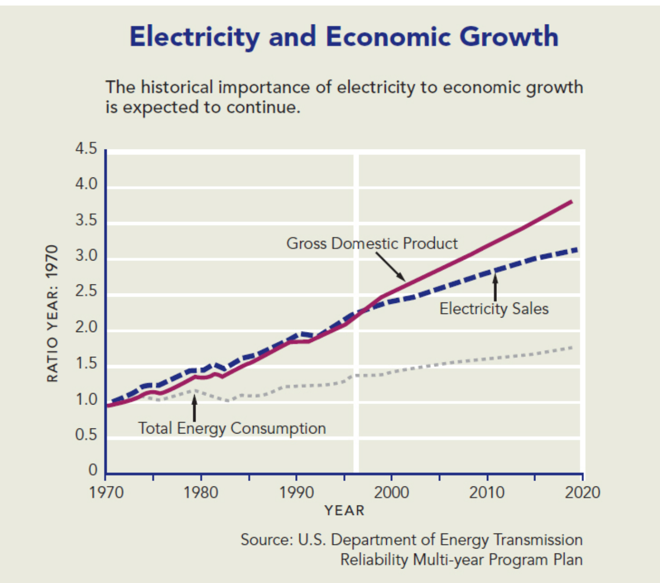
Hitachi Energy

The power grid is aging and congested and faces new challenges and stresses that put at risk its ability to reliably deliver power to an economy that is increasingly dependent on electricity. A growing recognition of the need to modernize the grid to meet tomorrow's challenges has found articulation in the vision of a smart grid. The essence of this vision is "a fully-automated power delivery network that can ensure a two-way flow of electricity and information between the power plants and appliances and all points in between". The three key technological components of the smart grid are distributed intelligence, broadband communications and automated control systems. Focusing in on the role of broadband communications in enabling the smart grid, this paper lays out the key communications system requirements and explains how the Tropos mesh network architecture, leveraging Tropos wireless broadband products and technology, enables the smart grid of the future.

The power grid today

The North American power grid has been described as the "supreme engineering achievement of the 20th century". It is a vast electricity delivery infrastructure comprising transmission and distribution networks spanning the continental United States, connecting electricity generation to the consumers of electric power. The grid contains over 200,000 miles of high-voltage (over 230 kV) transmission lines1 and more than 6 million miles of distribution lines that deliver power to over 100 million customers and 283 million people.

However, the power grid today is aging, congested and increasingly seen as incapable of meeting the future energy needs of an Information Economy. As businesses have become dependent on electronic devices for information exchange and commerce, the use of electricity as an energy source has grown relative to fuels, currently representing 40% of overall energy consumption in the US. The importance of electricity as a driver of economic growth can be gauged from the fact that electricity sales trend with the growth of the GDP more closely than other energy sources, as shown in the following graphic. Assembled over the last century, the power grid was not designed to support the extensive coordination of generation, transmission and distribution that is called for today and it faces stresses and challenges that are creating drivers for the modernization and restructuring of the grid to accommodate the needs and requirements of a 21st century economy.



Drivers for modernization of the power grid

New challenges and drivers: The grid faces new challenges and stresses that will put at risk its ability to reliably deliver power to an economy that is increasingly dependent on electricity:

- **Growth in demand:** Peak demand is forecasted to grow by 18% over the next 10 years, driven by economic growth and the evolution towards an Information Economy. Electricity's growing importance as a source of energy supply to the economy is reflected in the fact that over 40% of energy consumption in the US is used to produce electricity, up from 10% in 1940 and 25% in 1970.2
- **Constraints on capacity expansion:** Simultaneously, generation capacity is forecasted to hit critical reserve limits within the next 10 years for most of the US and new transmission and generation projects are not expected to be completed in time to avoid hitting capacity issues.
- **Shifts in generation sources:** The shift towards newer renewable and distributed energy generation sources such as wind and solar that can be variable and located far from demand present new challenges of control and coordination for the power grid. Co-generation from non-traditional sources will be mandated in some places requiring two-way control and monitoring at non-utility owned facilities.

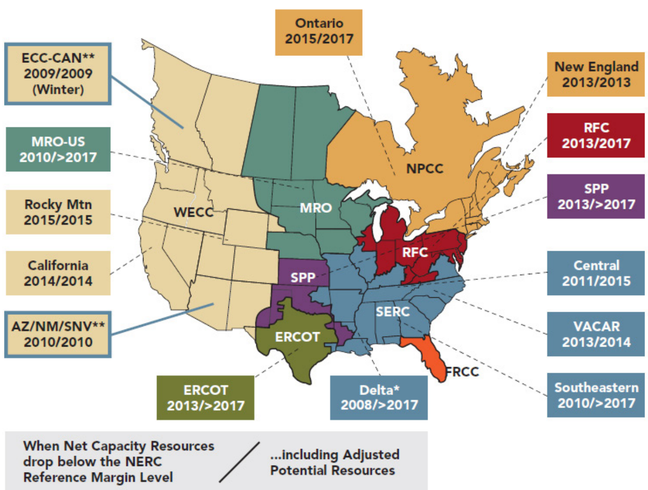
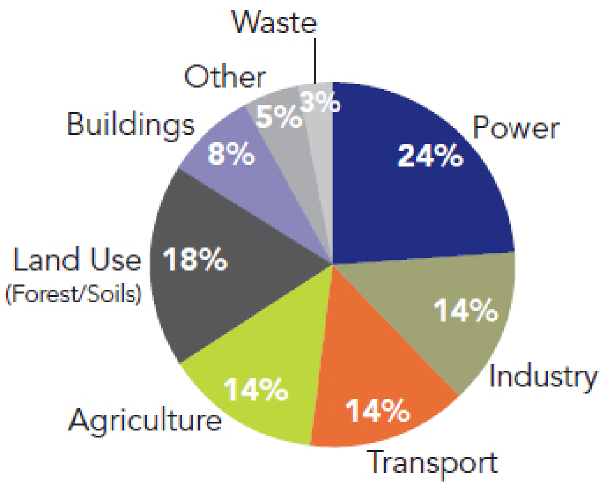


Figure 1: Net Capacity and Adjusted Potential Resources compared to NERC's Reference Margin Level[3]



The power sector accounts for 24% of CO_2 emissions, according to the 2006 Stern Review on the Economics of Climate Change. (Source: 'The Electricity Economy[4])

- **Transmission congestion:** Investments in the transmission infrastructure have not kept pace with the growth in demand, resulting in heavier utilization, frequent congestion, increased transmission losses and increased risk of catastrophic failures. Costs of building transmission lines and obtaining rights-of-way have increased dramatically and construction timelines will continue to increase.
- **Distribution:** Increased use of information technologies, computers and consumer electronics by customers has resulted in lowered tolerances to outages and power quality disturbances. A growing interest in distributed generation and electric storage devices at the edge is adding new requirements for interconnection and safe operation of electric distribution systems. Emerging trends such as plug-in hybrid electric vehicles (PHEVs) promise to put still more stress on the already-strained generation, transmission and distribution systems.
- **Demand management:** Utilities see an increasing need for demand management as a way to improve operating costs, enhance reliability and to potentially defer construction of generation and transmission capacity. The need to regulate and control the demand side through demand response and time-based rates — both of which require two-way communications capabilities down to the individual meter — adds another layer of complexity to the grid.
- **Regulatory policy:** Federal governments and many states are passing energy efficiency mandates and PUCs are enabling utilities to recover investments in upgrading the grid infrastructure and implementing measures such as demand response.
- **Environmental impact:** Electric power generation accounts for approximately 25% of the world's carbon dioxide emissions and new carbon regulations will have a major impact on the industry. Building new transmission lines will encounter stricter environmental impact requirements than ever before.

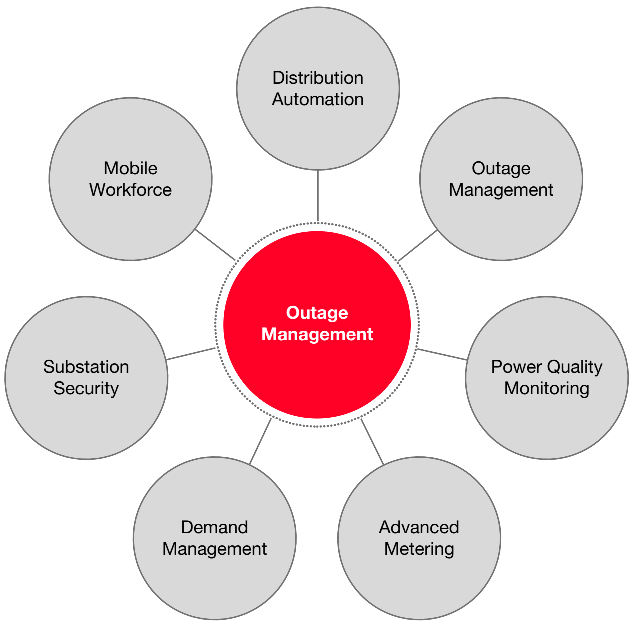
The vision of a smart grid

A growing recognition of the need to modernize the grid to meet tomorrow's challenges has found articulation in the vision of a smart grid5,6,7. Multiple industry and research groups have created architectural blueprints for the evolution of today's power grid into a smart grid that share several commonfeatures.

The smart grid, as it is conceived today, will offer several benefits to utilities and consumers:

- It will provide utilities the ability to monitor and manage their power delivery down to the home or business in real time
- Utilities can offer multiple rate structures to manage demand peaks and offer demand management services to encourage efficiency
- It will allow utilities to manage outages more effectively by reducing their occurrence through better monitoring and control of the grid and by reducing the impact of outages through more efficient and early problem isolation, using techniques such as automatic load-shedding and islanding as well as faster recovery procedures. Power outages are estimated to impose an economic cost of upwards of $100 billion every year and, in an increasingly interconnected Information Economy, it is imperative to reduce the frequency and the impacts of outages as well as of disturbances in power quality.
- It will allow utilities to delay the construction of new plants and transmission lines and better manage their carbon output through implementing measures such as demand response and time-based rates to more actively manage load.8
- It will allow utilities to provide real-time information to their customers and to utility workers in the field, resulting in operational efficiencies and more reliable service.
- It will allow utilities to more proactively manage the integration of clean energy technologies into the grid to maximize their environmental benefits and operational value.

The smart grid is envisioned to offer these benefits by enabling and enhancing a broad range of utility applications, including Advanced Metering Infrastructure (AMI), outage management, demand management, distribution automation, substation security and mobile workforce connectivity.



Smart grid is about more than just Advanced Metering.

From a technological perspective, the essence of the smart grid vision is "the digital control of the power delivery network and two-way communication with customers and market participants" through the realization of "a fully-automated power delivery network that can ensure a two-way flow of electricity and information between the power plants and appliances and all points in between."9 The central idea behind the smart grid vision is that information technology can revolutionize the generation and delivery of electricity just as it has transformed other aspects of business. It is an ambitious but attainable vision that comprises distributed intelligence, broadband communications and automated control systems – building on commercially-proven technologies that exist today.

- **Distributed intelligence:** This builds on advanced sensors with processing and communications capabilities built into every element of the grid (switches, transformers, substations, distribution lines, etc.) as well as advanced metering endpoints and smart appliances in the home. The distributed intelligence will enable real-time monitoring, coordination and control. For example, advanced meters with wide-area wireless communications capabilities can report back interval data to a meter data management system several times a day, allowing for real-time demand response coordination. Advanced sensors can be used to monitor the health of the grid in real-time and respond (perhaps autonomously, without central coordination) to avert system-wide failures and outages.
- **Broadband communications:** A broadband communications infrastructure is key to enabling comprehensive system-wide monitoring and coordination to enable applications as diverse as distribution automation, demand response, outage management and power quality monitoring. These applications include requirements for low latency, high bandwidth and QoS prioritization that require a broadband network. The communications infrastructure would tie together the meter end-points, the utility mobile workforce, advanced sensors and control centers into a single integrated network. SCADA systems employed today do not sense or control nearly enough of the components of the grid and there is a need for reliable, up-to-date information to feed state estimation, contingency analysis and other procedures. Furthermore, the communications links in use today are proprietary (non-standard) and slow (high latency, low capacity). However, standards-based technologies exist today to enable multiple low-latency high-data-rate, two-way communications links among all the nodes in the network, extending from the control centers down to the substations and all the way down to individual meters.
- **Automated control systems:** The third major element consists of centralized software tools and algorithms for self-reconfiguring and adapting the grid, executing protocols for demand response and automatic load-shedding, and promoting better coordination within and between utilities.

Role of communications in the smart grid

Grid communications architecture today: The architecture of monitoring, control, coordination and communications of the grid as it exists today predates the huge advances made in the last 30 years in the fields of computing, networking and telecommunications. These last 30 years have seen the development of the Internet and networked communications and the large-scale deployment of wide-area broadband wireless networking technology.

The communications infrastructure for monitoring and control of the power grid today is a patchwork of protocols and systems, often proprietary and mutually-incompatible, including leased lines, fixed RF networks, microwave links and fiber. Furthermore, the legacy paradigm employs a purpose-built communications network for each application system – for example, it is typical today for a utility to use separate communications networks for SCADA, advanced metering and mobile workforce access.

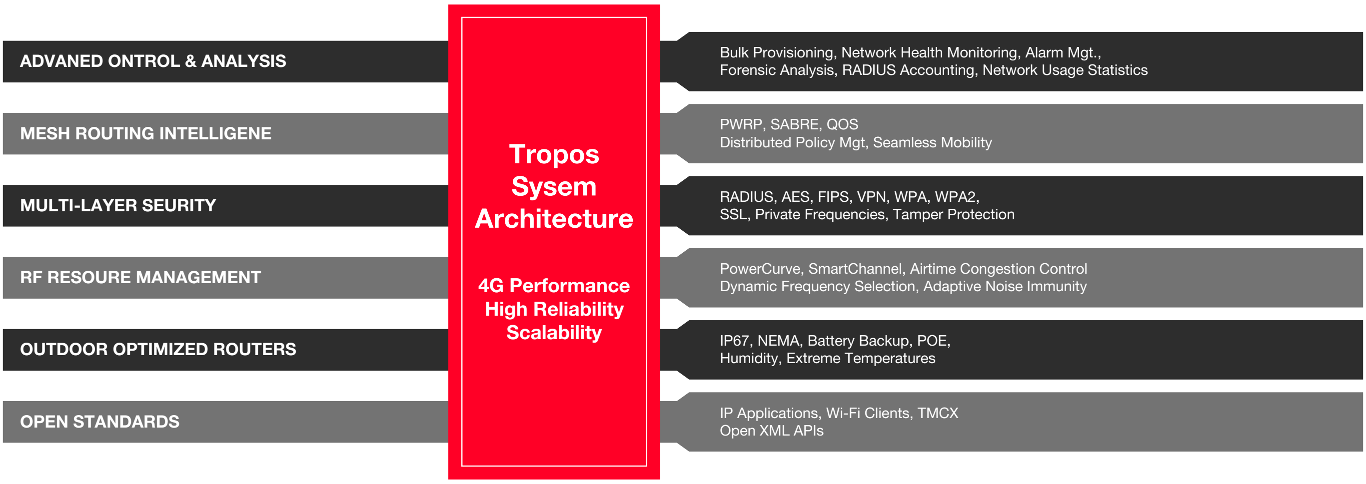
Automated meter reading systems for collecting meter data are still predominantly based on one-way low-bandwidth communications technologies, whether based on fixed RF networks or drive-by reading. These one-way communications technologies need to be updated to support the low-latency bidirectional traffic flows needed to enable applications such as demand response. While utilities frequently have fiber to the substations from the control center, it is often not consistently leveraged across applications. The poor communications infrastructure underlying the monitoring of the grid leads to inadequate situational awareness for utility operators who are often blind to disturbances in neighboring control areas and often within their own control areas, a fact highlighted in the post-mortem study on the August 2003 blackout10. There is no unified broadband communications infrastructure in place today that can simultaneously serve the needs of distribution automation, mobile workforce automation, advanced metering, SCADA and other applications.

Broadband communications underpins the smart grid: Many of the newer capabilities, such as demand response and remote disconnects, require real-time two-way communications capabilities down to the meter end-points.

Distribution automation applications require as close to sub-cycle latencies as possible. Advanced sensors that generate larger volumes of data require real-time high-speed communications links back to control centers. Utility field workforces employing bandwidth-intensive productivity applications such as mobile GIS need a communications network that is high capacity and supports seamless mobility for standards-based wireless devices.

Requirements for a communications infrastructure for the smart grid

- **Standards-based:** The communications infrastructure needs to be based on standards to ensure support for the diverse set of utility applications and to provide investment protection. Applicable standards pertain to radio communication protocols, networking interfaces (TCP/IP) and industry standard security specifications.
- **IP network:** A network that is based on IP provides the broadest possible platform for the delivery of a wide range of applications.
- **Real-time:** The network needs to provide the real-time low latency communications capabilities that are needed by such applications as distribution automation and outage detection.
- **Scalable:** The network and its network management system need to be capable of scaling to the large deployment footprints typical of many large IOUs.
- **Resilient and high availability:** To meet the reliability requirements imposed on utilities, the network architecture must be resilient and capable of continuing to operate even in the presence of localized faults. The network must have an uptime and system availability of 5 9's (99.999%)
- **Secure:** Since the grid and its components comprise critical infrastructure, the communications infrastructure for the Smart Grid needs to provide a secure foundation for information flow and conform to industry-standard security specifications including NERC CIP and FIPS 140-2.



Tropos mesh network architecture

- **Supports traffic prioritization:** The communications network must be capable of prioritized delivery of latency-sensitive mission critical applications such as distribution automation, over latency-insensitive traffic types such as metering data.
- **Mobile:** The network must support mobility to enable mobile workforce connectivity applications.
- **Future-proof:** In view of the long network lifetimes, the underlying network architecture and network elements must be selected so as to provide broad investment protection.
- **Cost competitive:** The communications infrastructure must be cost-competitive (CAPEX as well as OPEX) with wide area network alternatives including 3G and LTE.
- **Broad coverage:** The communications network should be capable of delivering broad coverage over thousands of square miles.

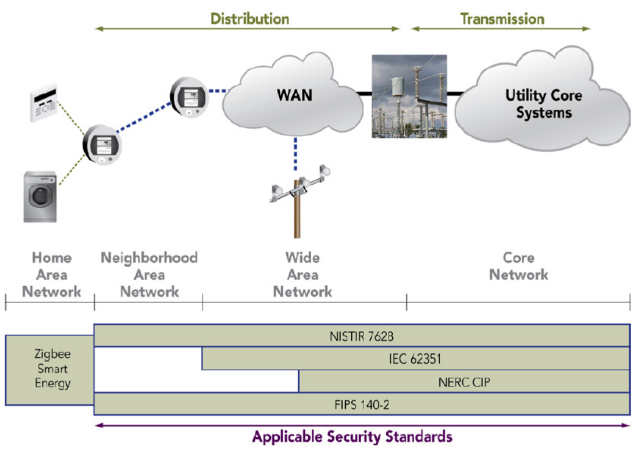
Tropos Wireless Communication Systems: networking the smart grid Tropos wireless broadband routers were initially designed to create a public safety communications infrastructure for use by mobile police officers. As such, the router hardware is highly ruggedized and weatherproof and the overall architecture supports mobility and is highly resilient and secure. Each router is built to withstand extreme temperatures and severe environmental conditions. The underlying mesh protocols and routing intelligence create a distributed self-healing network that is highly reliable and fault-tolerant, with no single point of failure, that can adapt quickly and optimally to changes in the RF environment. The advanced RF resource management algorithms allow the network to make the most efficient use of the available spectrum resources, utilizing multiple frequency bands including 2.4 GHz and 5 GHz. Tropos' multi-layered security approach builds on industry-standard security specifications such as IEEE 802.11i and FIPS 140-2 to create a secure communications infrastructure that can be used for mission critical applications.

As Tropos expanded into carrier markets, we added the ability to scale the network to cover very large geographic areas, multi-use capabilities, and a robust and scalable carrier-grade network management system. Tropos' routing and control protocols have been proven to scale to installations covering very large geographic areas. The multi-use networking feature-set enables a single infrastructure to support multiple applications, each with their own Quality of Service (QoS) and security needs. The advanced control and analysis tools allow for the secure provisioning and management of large-scale networks while providing deep visibility into network and application performance.

Underlying all of these elements of the Tropos mesh network architecture is a commitment to implementing and advancing open standards, from the radio layer (e.g., IEEE 802.11) to networking (e.g., IP and BGP) to industry-standard security (e.g., FIPS 140-2).

The Tropos mesh network architecture is a field area network architecture for smart grid communications that utilizes open-standard radios and IP communications. Realizing the vision of a smart grid requires a broadband network that can create a solid foundation upon which multiple demanding smart grid applications such as distribution automation can be deployed. The foundation for the Tropos mesh network architecture is field-proven technology that includes outdoor optimized Tropos routers; the patented Tropos Mesh OS built from the ground-up for large scale, mission critical outdoor network deployments; and a carrier-class centralized management and control system (Tropos Control). Tropos networks are highly resilient, scalable, high performance, and secure networks that seamlessly extend utilities' existing enterprise network and systems.

Taken together, these architectural elements combine to deliver the large-scale, resilient wireless IP network that utilities need to build out their smart grid communications infrastructure. Tropos' standards-based approach focuses on the wide-area wireless transport network that can carry data from multiple applications and allows the utilities to select best-of-breed vendors for the different sub-systems and applications.



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