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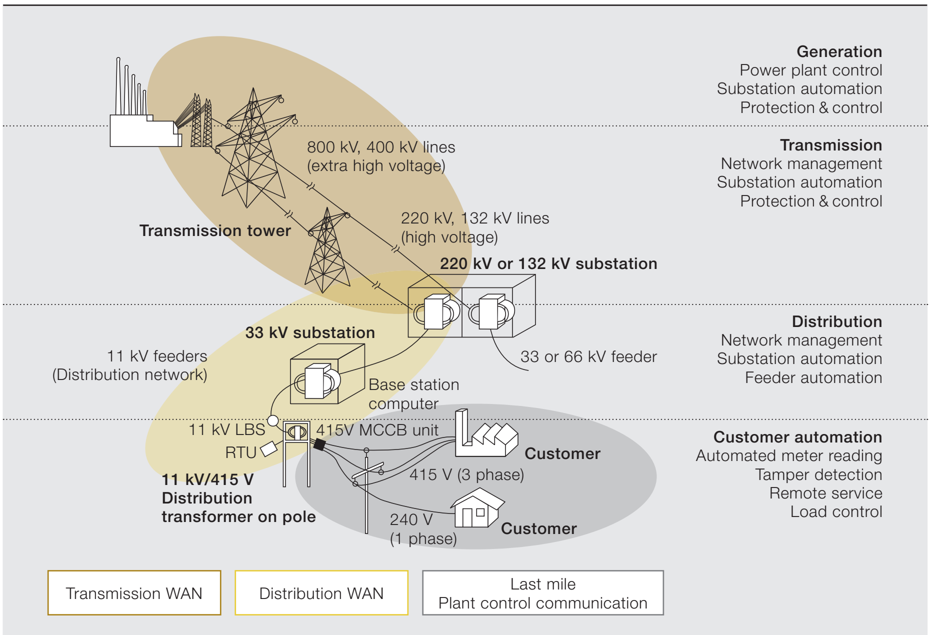
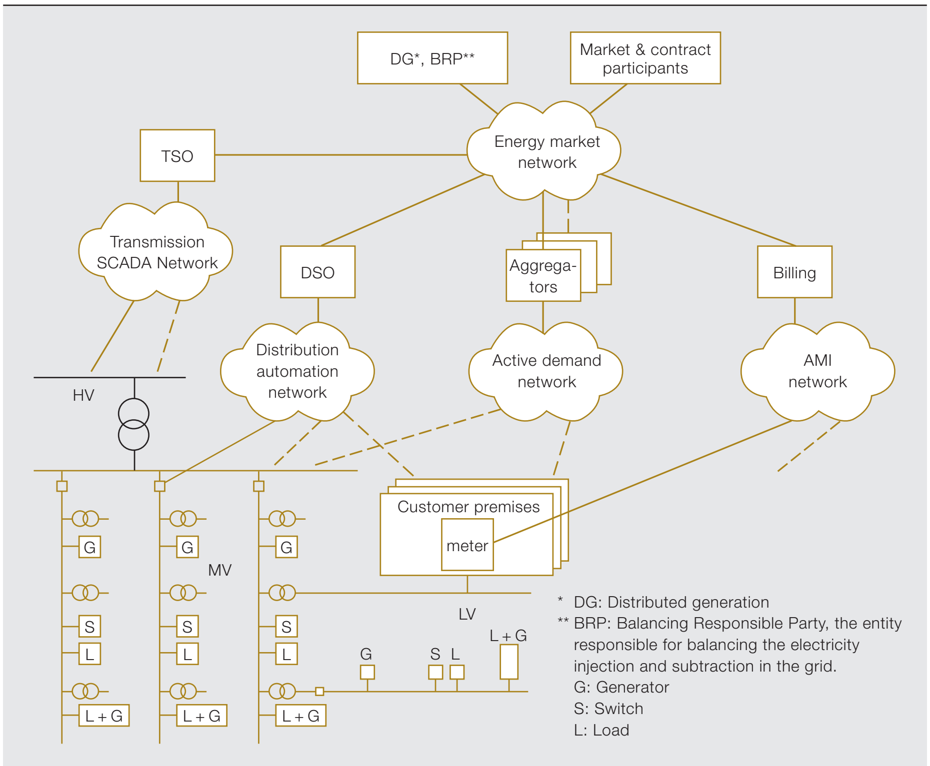
The nervous system of the smart grid

DACFEY DZUNG, THOMAS VON HOFF, JAMES STOUPIS, MATHIAS KRANICH – The evolution of smart grids, featuring more and more sophisticated control requirements, is leading to an increase in communication needs. Utility communications actually predate the launch of smart grids by many decades: In fact BBC (one of ABB's predecessor companies) commenced offering ripple control more than 60 years ago, permitting the remote operation of boilers, dryers, washing machines and other large loads during peak demand periods. As grids evolved, so did control needs and hence the demand for communication technologies. Today, power distribution networks are increasingly developing toward smart grids. Features of such grids include distributed generation, participation of the user in the liberalized market and an increased use of automation (including operational distribution automation, active demand management and automatic meter reading). The latter calls for a communication network to connect the protection and control devices used in the distribution grid. A key requirement is interoperability and reliability, ie, all control and protection devices must be able to communicate over a variety of channels.

1 Overview of utility communications



2 Communication requirements in a smart grid



A single regional area network may support all Smart Grid functions of Distribution Automation, Active Demand control, and Automatic Meter Reading.

Smart operation of the electric distribution grids began more than 60 years ago, when BBC and other companies began implementing ripple-control systems in several European countries. These permitted load peaks to be managed through the selective connection or disconnection of groups of electrical loads [1]. This ripple-control system uses the distribution line itself as a reliable communication medium. The utility sends electrical signals at audio frequency, which are able to pass through medium and low-voltage transformers and are detected by ripple-control receivers connected to low-voltage (LV) lines on the customer premises. These commands remotely switch large loads or groups of loads such as washing machines, hot water boilers, electrical heating and street lighting. The availability of a reliable communication channel between the control center and the end user's equipment thus permits utilities to better control load peaks.

ABB provides electric utilities with turnkey solutions for wide-area communication networks → 1. For SCADA (supervisory control and data acquisition) applications in the HV power transmission grid, wide-area communications links are based on broadband optical-fiber links, digital point-to-point microwave radio, and point-to-point communication using the HV power lines themselves [2]. A number of standardized protocols are in use for such applications [3].

A changing market

As discussed elsewhere in this issue of *ABB Review* [1], the economic and regulatory framework for the power grid and its operation have changed in the last decade. Power markets have been deregulated and the share of distributed power generation has increased. In a liberalized power market, consumers can be active market participants: Due to the increase in distributed power sources, power distribution no longer occurs in the traditional tree-like manner with one-way flows from large generating plants to consumers. Local production, storage, and consumption units are distributed geographically, and as a result, the direction of power flow in the distribution grid may change rapidly, requiring a higher degree of protection and control. At the same time, dependency and expectations of customers on the availability of power has risen. This is also mirrored by recently introduced or upcoming regulations that penalize utilities for outages. The objective is to maintain and increase power quality and reliability: A measure for this reliability is the System Average Interruption Frequency Index (SAIFI), which is taken as a base for compensation payments. To fulfill the rising requirements, the distribution grid requires a higher degree of smart automation – and a smart automation system requires an advanced communication infrastructure.

Communication requirements for the smart grid

Much of the emphasis of smart grids is on regional-area medium- and low-voltage distribution infrastructure. From the perspective of communications, smart grid functions can be categorized into three classes according to their communication requirements ➔ 2:

Distribution automation (DA)

DA concerns the operational control of the grid, ie, monitoring currents and voltages in the distribution grid and issuing commands to remote units such as switches and transformers. When a fault occurs on an MV segment, protection switches should isolate it. The paths of power flow should then be rapidly reconfigured using MV switches to restore the power supply to the largest possible

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area. Remote reconfiguration performed by the MV distribution system operator (DSO) or substation computer is a main function of DA. Typically, several tens or hundreds of remote units must be addressable. The communication latencies for such applications are in the hundreds of milliseconds to several seconds. It is important to note that distance protection functions requiring fast communications with latencies of milliseconds are not typically supported.

Active demand control (AD)

AD functions perform active control and scheduling of energy demand, storage, and distributed generation, and are based on volume and price signals. The objective is to increase grid efficiency and avoid overloads through a combination of optimized scheduling/forecasting and load shedding. This functionality is less time critical as the distribution automation and the latency requirements are in the range of several minutes.

Advanced meter reading (AMR)

AMR records the actual realized power flows and calculates the appropriate billing information, taking into account any time- and contract-dependent prices. The corresponding AMR infrastructure (AMI) connects thousands to millions of meters to the billing center, some in difficult-to-reach locations. Actual cumulated energy data or load profiles for billing need be transmitted only daily or monthly.

Smart homes may be connected to the smart grid [4], and further (local-area) communication requirements may hence exist within buildings [5]. The present article, however, addresses only the regional-area communications needs of smart grids. [2]

The above analysis shows that the technical requirements on communications for the smart grid are moderate, in particular regarding data rate and latencies (protection functions being excluded). Where some communication delays are acceptable, high communication reliability can be assured by error detection and automatic retransmission. The main selection criteria are thus the costs of procuring and installing equipment and the operation life-cycle costs.

Communication technologies for the smart grid

A wide range of communication technologies are currently available to support smart grid applications. These range from wired products to wireless devices and include hybrid systems incorporating both wired and wireless technologies. It is unlikely that one technology alone will ever provide a complete solution for all smart grid communications. Interoperability of different technologies will thus be a key requirement: Devices on different networks using different communication media must be able to communicate with each other. Interoperability also refers to equipment from different manufacturers and subsuppliers, hence technical standards play a key role.

In order to select a communication system for smart grid applications, many issues must be considered, some of which are listed in ➔ 3.

The technologies that will be deployed for smart grid applications will depend on these criteria and the requirements of each utility company. The main technical criteria are communication performance, security and interoperability. The bandwidth supplied by the communication infrastructure must be scalable and capable of supporting the thousands to millions of data points that exist in a utility system. Due to regulatory and operational requirements regarding cyber security of critical infrastructures, security is also increasingly becoming a major factor.

Interoperability and standardization are thus central attributes of future technology. They will reduce the utility's engineering time, with "plug and play" type applications becoming more prevalent. Only

3 Criteria to be considered when selecting communication media

- Availability of communication media, such as existing copper- or fiber-optic connections
- Availability of wire ducts, or sites for radio transmission towers
- Communication performance, such as data rate (bandwidth) and transmission latency for a given number of communication nodes
- Communication reliability and availability
- Security requirements, ie, confidentiality, integrity, authentication
- Interoperability and application of standards
- Upfront investment
- Recurring costs, eg, operational costs such as monthly data transmission fees
- Future-proof technology with respect to changes in technology

Footnote

1 See for example "The next level of evolution" on pages 10–15 of this edition of *ABB Review*.

systems fully satisfying these criteria will be capable of supporting the DA, AD, and AMR/AMI applications of a smart grid.

The major communication technologies that are currently available in the market to support smart grid applications are the following → 7:

Wired utility communication networks
A utility may build ducts to its power-distribution nodes to carry communication wires alongside the power cables. These wires may be copper wires, carrying low-rate telephone modem signals or broadband digital subscribe line (DSL) signals. Newer systems will be optical-fiber based, and carry, eg, Ethernet signals to establish large broadband metropolitan area networks (MANs) with user data rates of many Mb/s.

Utility-operated radio systems
Such networks → 4 are erected and operated by the utility. Radios typically offer narrowband communications with user data rates of only several kb/s, but have a long range (up to 30 km). Radio frequencies are either in the free unlicensed bands ("Ethernet radios" using spread-spectrum transmission at 900 MHz in North America), or in bands requiring license fees (narrowband radio modems at VHF 150 MHz or UHF 400 MHz in Europe [6]). For automatic meter reading, specialized radio systems with low-power transmitters and drive-by readers have been deployed. For high data rates, utility point-to-multipoint microwave systems are available.

Public cellular data systems
Established and ubiquitous examples of this type of network are CDMA [2], and GSM/GPRS [3] → 4. New fourth-generation systems being introduced are WiMax and the Long-Term Evolution (LTE) of UMTS. Such systems are optimized for public consumer usage in terms of coverage and traffic load, so it must be assured that performance is sufficient in terms of range for mission-critical grid control. In addition, adopting these technologies means utilities must enter into service agreements with third-party cellular service providers, implying recurring operating costs.

Satellite communications
Both low- and high-data rate systems are available, the latter typically requiring more costly parabolic antennas. Satellite communication systems are also third-party operated. In regards to bandwidth allocation satellite providers offer shared as well as dedicated services. For DA as well as AD applications dedicated services are normally used whereas for AMR shared services are sufficient.

4 Wireless communications: technologies and applications

Technology	Standards	Operator / owner	Frequency band	Data rate	Applications
VHF/UHF radio	Proprietary, PMR	Utility	150 MHz / 400 MHz	Narrowband	Voice; DA, SCADA
2.4 GHz wireless	WLAN, ZigBee	Customer, utility	2.4 GHz	Broadband	(Short range) AMR, Home Automation
Point-to-multipoint	Proprietary, WiMAX	Utility or 3rd party	5–60 GHz	Broadband	High speed data; DA, SCADA
Public cellular data services	GSM/GPRS UMTS CDMA	3rd party	900/1800 MHz (EU) 800/1900 MHz (US)	Narrowband / broadband	Voice, data; DA, AMR
Satellite communication	Proprietary	3rd party	6 GHz, 12 GHz	Narrowband	AMR

5 Power line and distribution line communications: classification and applications

	Narrowband powerline communication	Broadband powerline communication
High-Voltage power transmission lines	Long-distance SCADA communications [6]	–
Medium-Voltage power distribution lines	Distribution Automation Active Demand	Backbone communication network
Low-Voltage utility power distribution lines	Distribution Automation, Active Demand, Automatic Meter Reading	Public last-mile Internet access
Low-Voltage in-house power distribution lines	Home and Building Automation [7]	In-house local area network

Power and distribution line communication (PLC, DLC)
An obvious communication medium for electric utilities is the power distribution network itself → 5. On the HV grid, HV-PLC is a well established technology [6]. On the LV network, many attempts have been made to provide broadband over power line (BPL) service to consumers as an Internet-access technology. Aggregate data rates of up to tens of Mb/s are possible under good network conditions, but communication distance and availability may be insufficient for smart grid applications due to range and reliability being more critical than high data rates. Technologies and standards for narrow-band DLC on the MV and LV grids are currently being developed.

Typically, a given smart grid operated by a utility will use combinations of these technologies and systems.

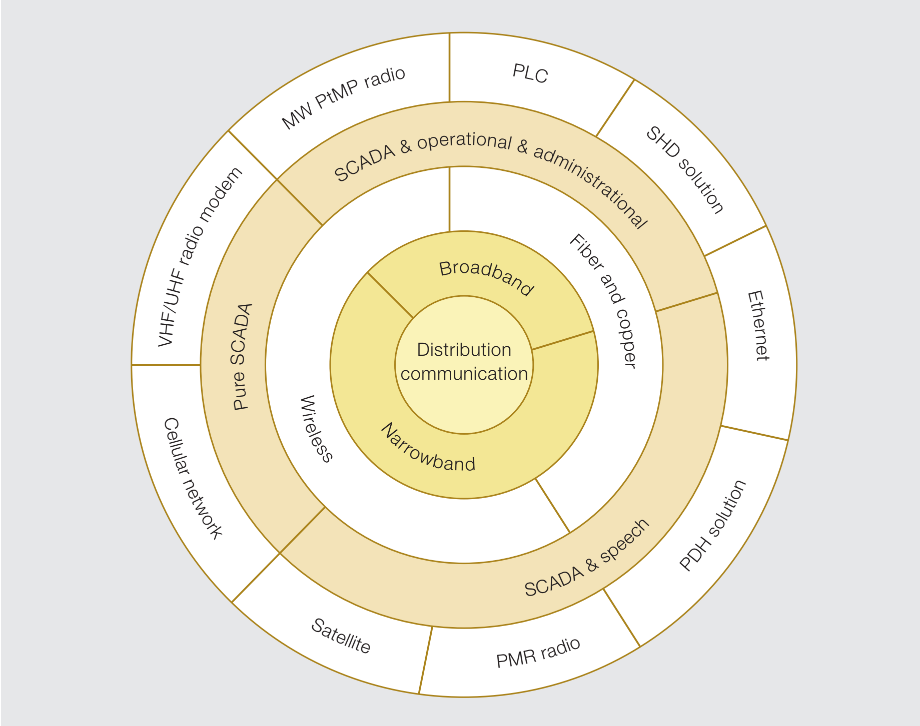
Mapping technologies to requirements
Depending on the smart grid functions, different technologies may be applicable. As described, bandwidth requirements are generally moderate, but availability must be high. Therefore utilities tend to prefer their own utility-operated infrastructures to those of third-party service providers. → 4 lists wireless systems for both of these options. In practice, utility-operated radio modems are often more suitable. As the bandwidth demand is low, radio modems are the solution with the best cost-benefit ratio. On the other hand, relying on public cellular networks allows simple and cost-efficient implementation of communications.

Deployment of new communication networks for electric utilities is easiest either using wireless, or using communication

Footnotes
2 In the United States
3 In most of the world (including the United States)

6 ABB UHF radio AR400

7 Communication options for distributed communication for the smart grid



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on the electrical power distribution grid itself. The latter, distribution line carrier (DLC) technology, has already been adopted for ripple control systems; extensive digital systems, mainly for automatic meter reading, are also in operation Factbox ➔ 3. More reliable and flexible DLC systems providing the option to incrementally add further services are required for operating smart grids. The challenge lies in meeting higher communication reliability and range requirements as well as allowing easy deployment.

What does ABB offer?

Communication networks for smart grids are complex and may involve many different systems and technologies. ABB has the experience to support utilities in their evaluation of communication technologies. With its understanding of the utility requirements and constraints, ABB can offer long-term solutions, which will be able to satisfy future requirements. Examples for new solutions are the new ABB radio AR ➔ 6, integration of communication modules into application devices (eg, Ethernet boards in to RTU560 family), and partnership with service providers (eg, satellite solutions). Integrated network management and routing over a variety of communication media will be supported.

Given its total offering of SCADA network management systems, RTU solutions, distribution and feeder automation products, and communication systems, ABB is an ideal partner and supplier for smart grids.

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Further reading

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