ABB review

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The corporate technical journal

Energizing the digital grid

Power and productivity
for a better world™

ABB

The electrical grid is one of the great enablers of human activity and productivity. In fact artificial light is one of the most obvious signs of human activity when the Earth is seen from Space. The front cover shows Mumbai, India.

One of the challenges facing the grid of the future lies in integrating “new” renewable power sources. The present page shows wind turbines and power lines in Kent, United Kingdom.

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Energizing the digital grid

Claes Rytoft

Dear Reader,

Electricity is all around us. Whether we are at home or in the workplace, in a busy metropolis or in a remote outpost, electricity, whether directly or indirectly, enables almost everything we do. Electricity is in many respects an ideal means of transmitting and delivering energy, being controllable, safe, economic, efficient and relatively unobtrusive. Electrical transmission and distribution has been one of the main pillars of ABB's business since the early days and the company has always been at the forefront of pioneering and introducing new technologies.

Far from approaching an end point in terms of development, the entire electricity system is undergoing changes on a scale not seen since its inception. Traditionally, a small number of centralized power plants supplied the surrounding centers of consumption. Generation was dictated by demand levels and electricity flowed essentially in one direction. Today, we are seeing a rapid growth in renewables such as wind and solar, which are by nature subject to supply fluctuations. Furthermore this generation (as well as storage) is distributed over a myriad of locations and often integrated in consumer sites. A given site can thus arbitrarily change from being a net consumer to a net producer and the traditional model of one-way electricity flows is giving way to multi-directional flows. This is not only affecting the hardware of the transmission infrastructure but also the way it is operated. A balancing of generation and consumption can no longer rely purely on supply strictly following demand, but must be achieved by managing both supply and demand. This requires sophisticated monitoring, communication and control systems across generation, transmission, distribution, storage and consumption.

This issue of *ABB Review* is dedicated to these developments, following how they affect different levels and components of the electrical network, from the long-distance transmission lines to local level developments such as microgrids, as well as the control and communication systems that will make the collaboration possible.

I would like to use this opportunity to remind you that besides the print edition, *ABB Review* is also available electronically. Please visit http://www.abb.com/abbreview for more information.

I trust that this issue of *ABB Review* will provide you with a deeper understanding of the grid of the future, and of some of the exciting challenges and opportunities it is creating, as well as showcasing ABB's ability to address these challenges and become an integral part of your energy future.

Enjoy your reading!

Claes Rytoft
Chief Technology Officer and
Group Senior Vice President
ABB Group

Enabling digital substations

The smarter grid needs a smarter substation, and it has to be digital

STEFAN MEIER – The concept of a digital substation has long been an insubstantial thing – an ideal vision of all-knowing substations networked into an intelligent grid. But the concept is now a lot more practical so the specifics of what makes a substation "digital," and why that is such a desirable thing, can be discussed.

Digital signaling offers excellent reliability and capacity, and has been in use in power infrastructure for decades. Most existing electricity grids employ digital fiber-optic networks for the reliable and efficient transport of operation and supervision data from automation systems in substations – and even power line networks carry tele-protection signals these days. But only now are the advantages of standardized digital messaging starting to extend into the deeper substation environment.

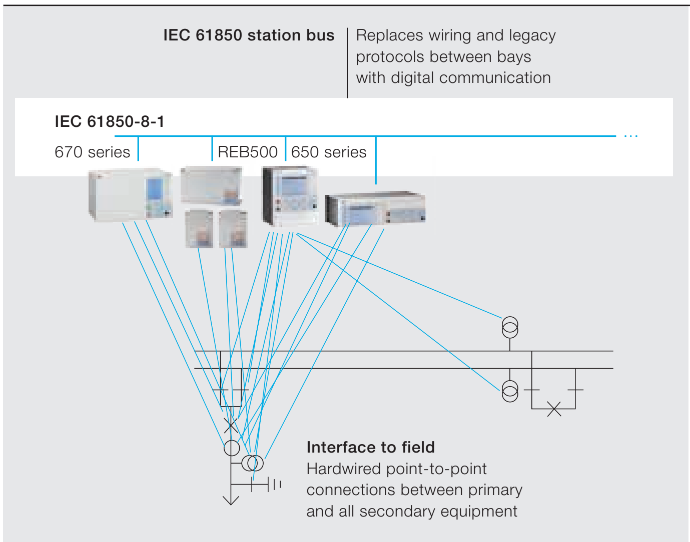
IEC 61850

Without standards, the adoption of digital messaging for intrasubstation communication was piecemeal and fragmented, with mutually incompatible signaling creating an assortment of messaging within vertical silos. ABB has long championed industry adoption of IEC 61850, a standard with which the company has been intimately involved since its inception. "Communication networks and systems for power utility automation," as the IEC document is properly known, is a comprehensive standard broken down into components that, for example, specify how the functionality of substation devices should be described – how they should communicate with each other, what they should communicate and how fast that communication should be. All of this is critical to realizing the benefits of a truly digital substation.

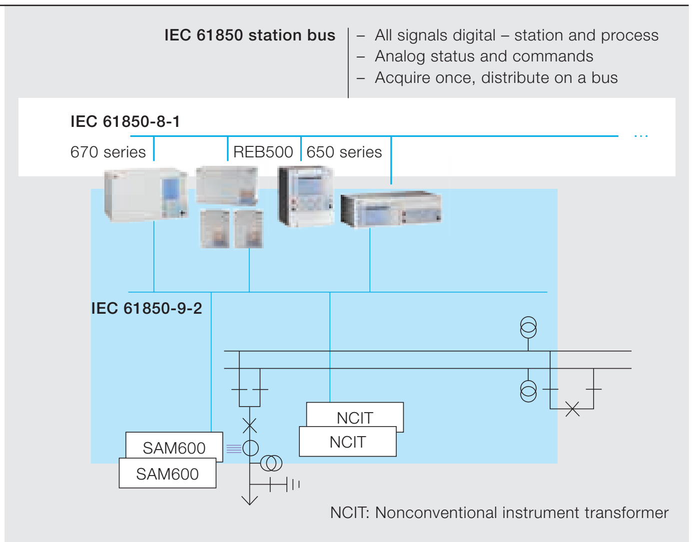
At the station level, things are generally digital, even in relatively old installations. SCADA (supervisory control and data acquisition) systems usually demand

Title picture
Technology is now available to allow substations to be completely digital – right down to the current transformers. The advantages of having a digital substation are manifold.

1 Digital substation and IEC 61850



1a Today



1b Tomorrow

Digital signaling offers excellent reliability and capacity, and has been in use in power infrastructure for decades.

digital information and ABB has been selling fiber-optic "backbones" for more than two decades.

Between the station level and the bays, fibers can carry digital data – conforming to IEC 61850 – but to become a true digital substation the standard has to extend even further.

Deep digital

The world beyond the bays is still predominately analog. The conventional primary equipment, like current and voltage transformers, is connected back to intelligent electronic devices (IEDs) using parallel copper wires carrying analog voltage signals ➔ 1a. The IEDs receiving that data perform first-level analysis and often provide the gateway into a digital world.

But there is little advantage in keeping the data in analog form for so long and to properly earn the title of "digital substation" the transition to digital must take place as soon as the data is gathered ➔ 1b.

Through permanent system supervision, digital equipment reduces the need for manual intervention and the adoption of the all-digital process bus allows sensitive equipment to be relocated into the bays. The digital equipment that has to be located out in the yard must be easy to fit, and every bit as robust and reliable as the analog equipment it is replacing or interfacing to ➔ 2.

FOCS

Robustness and reliability requirements apply to new technologies such as ABB's fiber-optic current sensor (FOCS) too. A FOCS [1] can directly monitor current running through a high-voltage line without having to involve a current transformer (CT) to step down the current to a measurable value. Eliminating the CT also eliminates the risk of open CT circuits, in which life-threatening voltages can occur, and so increases safety.

A FOCS exploits the phase shift in polarized light introduced by an electromagnetic field (the Faraday effect). The shift is in direct proportion to the current flowing in the high-voltage line, around which the fiber carrying the light is wrapped. The measurement is digitized right at the source and transmitted as a digital signal, via the process bus, to the protection and control IEDs, as well as the revenue meters.

Such an optical CT takes up a lot less space than its analog equivalent. It can even be integrated into a disconnecting circuit breaker (as ABB did in 2013) to combine the functions of circuit breaker, current transformer and disconnector in one device – halving the size of a new substation.

The FOCS is one of a range of nonconventional instrument transformers (NCITs) that can make things entirely digital. NCITs have to be every bit as reliable as the equipment being replaced – and they

2 New equipment destined for use out in the yard is exposed to the elements so has to be very robust.

A FOCS can directly monitor current running through a high-voltage line without having to involve a current transformer to step down the current to a measurable value.

are: Over the past decade ABB has supplied more than 300 NCITs (combined current and voltage sensors fitted into gas-insulated switchgear) for use in Queensland, Australia, and the utility has yet to see a single failure in the primary sensor. Extensive use of NCITs makes a substation simpler, cheaper, smaller and more efficient.

Not everything can be digital – analog data will continue to arrive from conventional current and voltage transformers, for example. But there is no reason for wholesale replacement when a standalone merging unit can perform the transition to digital right beside the existing instrument transformer. Fiber optics can then replace the copper cables connecting the primary equipment to the protection and control IEDs.

ABB has long championed industry adoption of IEC 61850, a standard with which the company has been intimately involved since its inception.

Process bus

As a conductor, every bit of copper in a substation is a potential risk. For example, where current is incorrectly disconnected, such as with an open secondary current transformer, arcing may occur as dangerously high voltages build and a copper line can suddenly carry high voltage, putting workers and equipment at risk. Less copper brings greater safety.

The digital substation dispenses with copper by using the digital process bus, which might use fiber optics or a wireless network, such as ABB's Tropos technology. Just the removal of copper can, in some circumstances, justify the switch to digital. Going digital can cut the quantity of copper in a substation by 80 percent – a substantial cost saving and, more importantly, a significant safety enhancement.

The process bus also adds flexibility: Digital devices can speak directly to each other →3. For this, IEC 61850 defines the GOOSE (generic object-orientated substation events) protocol for fast transmission of binary data. Part 9-2 of the standard describes the transmission of sampled values over Ethernet. These principles ensure the timely delivery of high-priority data via otherwise unpredictable Ethernet links. ABB's ASF range of Ethernet switches fully supports this critical aspect of substation messaging.

3 IEC 61850 makes the fully digital substation a reality.

An optical CT takes up a lot less space than its analog equivalent and can even be integrated into a disconnecting circuit breaker to combine the functions of circuit breaker, current transformer and disconnector in one device – halving the size of a new substation.

Installations

ABB has been heavily involved in IEC 61850 since its inception. The standard is essential to ensure that utilities can mix and match equipment from different suppliers, but, through compliance testing, it also provides a benchmark against which manufacturers can be measured.

ABB deployed the first commercial IEC 61850-9-2 installation in 2011 at the Loganlea substation, for Powerlink Queensland. The use of ABB's IEC 61850-9-2-compliant merging units and IEDs, not to mention NCITs, makes the deployment a landmark in the evolution of substation design.

That project was part of an upgrade of an existing station, an upgrade that saw it move into an IEC 61850 future, adopting digital standards for effective future-proofing. ABB created a retrofit solution based on specifications from Powerlink that can be applied to another five Powerlink substations when they are ready for refitting.

Two of those stations, Millmerran and Bulli Creek, were already upgraded in 2013 and 2014, respectively. The refurbished substations have a MicroSCADA Pro SYS600 system and RTU560 gateway that manage Relion 670 protection and control IEDs, with REB500 busbar protection. These all communicate over IEC 61850-9-2 to the merging units and over IEC 61850 to the station-level devices.

A fully digital substation is smaller, more reliable, has a reduced life-cycle cost and is simpler to maintain and extend than an analog one. It offers increased safety and is more efficient than its analog equivalent.

Not every substation needs to be catapulted into a wholesale digital world – it depends on the substation size and type, and whether it is a new station or a retrofit of the secondary system. Different approaches and solutions are required. ABB's extensive IEC 61850 experience and portfolio of NCITs, merging units, protection and control IEDs as well as station automation solutions eases utilities into the digital world. Flexible solutions allow utilities to set their own pace on their way toward the digital substation.

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Reference

[1] S. Light measures current – A fiber-optic current sensor integrated into a high-voltage circuit breaker. Available: http://www05.abb.com/global/scot/scot271.nsf/veritydisplay/0d948cedb40451cec1257ca900532dd0/$file/12-17%201m411_EN_72dpi.pdf

Forward-looking information

Operating the grid closer to its limits by preempting problems

TORBEN CEDERBERG, RICK NICHOLSON – Modern electricity transmission and distribution networks are undergoing dramatic changes. They have to cope with more distributed and renewable energy resources, more data from smart power equipment and meters, and more pressure to run efficiently. This all results in more work and stress for network operators. Help is at hand in the form of SCADA energy management systems, advanced distribution management systems, demand-response management systems and advanced business analytics. These systems, when integrated and operated in concert, enable utilities to move from reactive to proactive operation of the grid, enabling it to operate closer to its limits. The well-established Ventyx solution, Network Manager advanced distribution management system, together with the company's demand-response management system and FocalPoint analytics, deliver the new distribution system optimization applications required to manage evolving grid operating conditions.

Society's quest for sustainable energy is driving a redesign of transmission and distribution networks, from both operational and asset performance perspectives, so that clean, renewable energy resources can be accommodated. Many of these resources are distributed, eg, rooftop-mounted solar panels or onshore wind generators. Battery storage banks, large and small, also play a role.

> A new solution called distribution system optimization recently introduced by ABB will help foresee and forestall events that lead to alarm conditions.

The new power landscape is a mix of grid-scale and distributed power resources, with an increasing share of small, distributed units – a constellation for which distribution networks were never designed.

The typical distribution network is changing from one that connects producers and consumers in a one-way power flow to one that carries flow in both directions in a complex, dynamic way.

New challenges in the control room

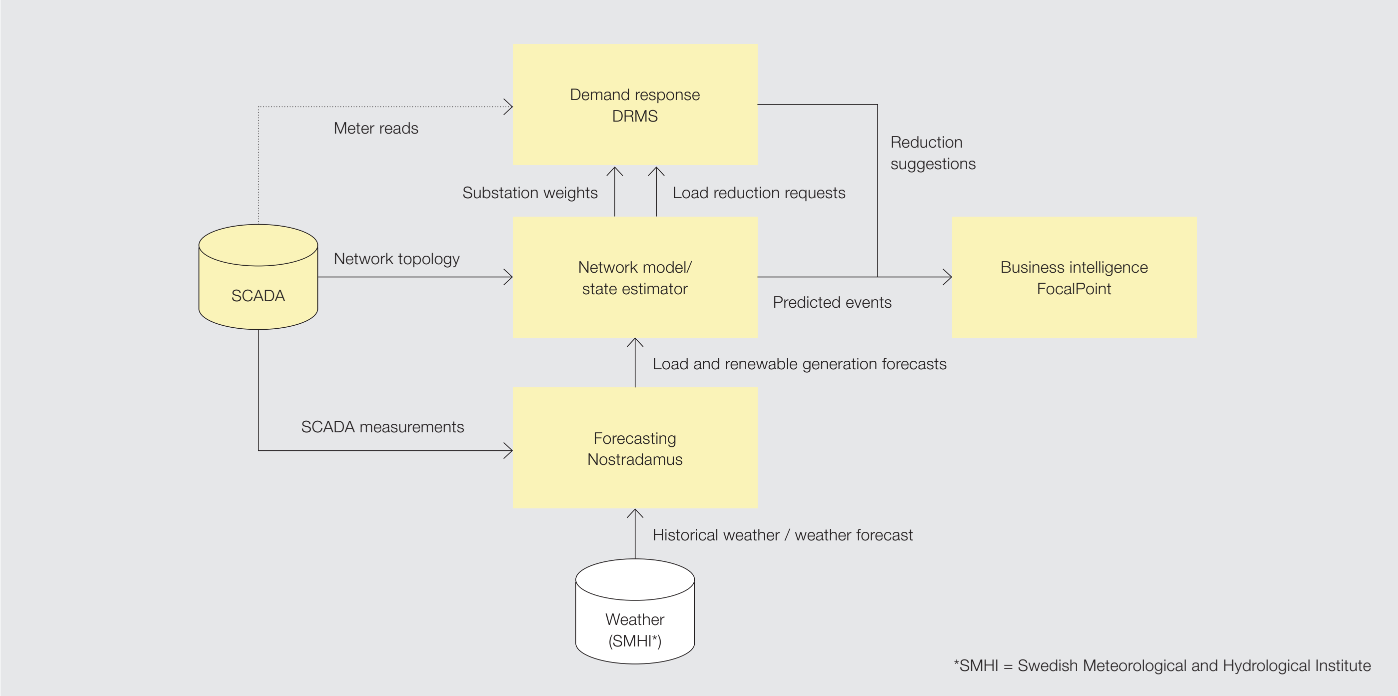
Renewable energy production is dependent on weather and is therefore considered to be intermittent. The energy a wind generator or a solar panel can produce over a longer period, such as a year, can be forecast with a high degree of precision using long-term weather studies. However, daily and hourly production varies considerably and can be accurately predicted only two to three hours ahead. This results in two problems for network operators: The network strength (power available) varies over the day and unexpected power surges and sags can cause rises and drops in voltage, leading to network instability.

The first problem has, so far, been managed by controlling the network strength by adding spinning reserves – conventional and hydropower plants that can be brought online very quickly, exploiting the inertia in the generator rotating mass. The growing number and spread of renewable energy resources on the grid makes this solution less tenable.

Utilities have traditionally countered the second problem, fluctuating power surges and sags, by regulating the reactive power with reactors and capacitor banks. By switching these devices on or off, power flux and voltage change can be minimized. Most modern SCADA energy management systems (EMSs) and advanced distribution management systems (ADMSs) have functionality built in for controlling these units, but they are often manually operated – meaning it is the operators in the control rooms who are responsible for monitoring the SCADA system and taking appropriate action. This was suitable in the traditional network when (usually seasonal) changes occurred only a few times a year, but is much less so now when the networks may need to be reconfigured several times per day, or even per hour.

Title picture
The integration of renewable generation sources poses significant challenges for power networks. ABB's grid optimization applications can predict grid issues and assist with solving them before they happen.

1 Block diagram of DSO application components



New solutions to manage the networks

The primary task of a SCADA EMS or ADMS is to manage the network remotely, by gathering data from it, and provide a snapshot at any given time. This includes monitoring analog values such as voltage, current, active power and reactive power as well as the digital state of switching devices. The system will issue an alarm if it detects an abnormal state or if a preset limit is exceeded.

A traditional SCADA EMS or ADMS needs additional functionality to be effective in the modern power network. Here, the key is the integration of information technology (IT) and operational technology (OT) systems. ABB is taking this type of integration a step further by designing and testing integrated functionality during the development of the individual components that make up the final solution. This is made possible by a set of tools that can be combined for full functionality from the start, with less subsequent integration work and low maintenance. At the same time, it is also possible to start with only some of the components and integrate these with legacy systems or systems from other vendors using a more conventional approach.

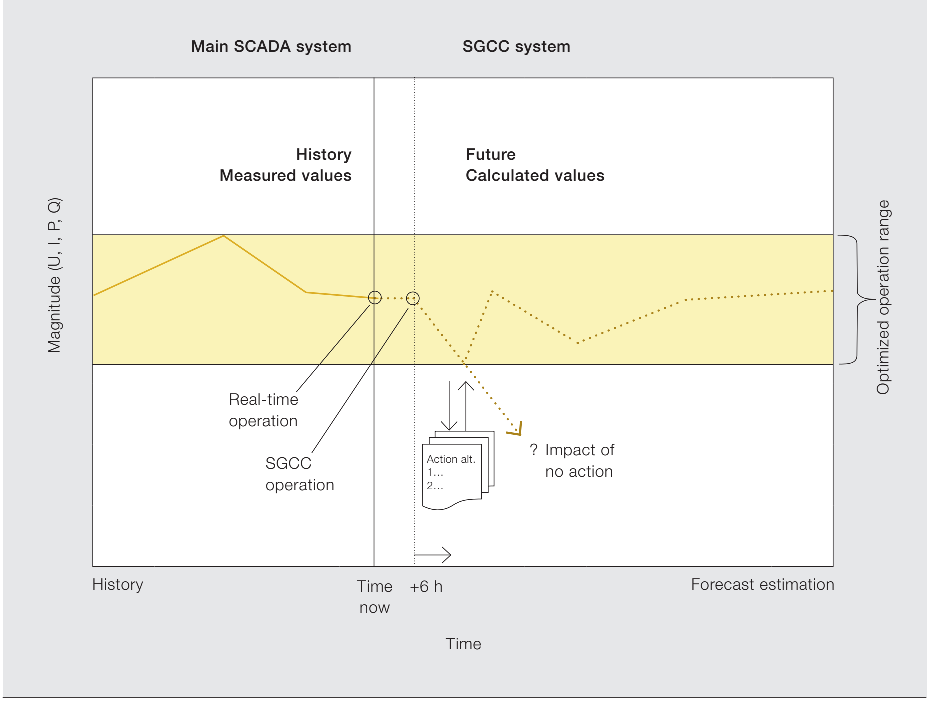
> Society's quest for sustainable energy is driving a redesign of transmission and distribution networks from both operational and asset performance perspectives.

Grid optimization

Traditionally, the operational mode in the control room can be said to be in one of two states: normal or abnormal running condition. Now there is a third mode, "suboptimal," in which the network is not suffering from major disturbances comma but some power equipment could be run more efficiently and a number of alarms and warnings are present. The alarms keep the operators busy, leaving less time for switching the network into a more optimized and efficient mode or performing planned maintenance activities. In some control rooms, operators are stressed beyond acceptable levels, increasing the likelihood of mistakes. The utilities must, therefore, seek better support when implementing new SCADA EMS and DMS solutions.

DSO effectively combines readily available forecast data, such as load and weather data, and inputs this into a software tool that calculates and builds production and load profiles for the near future.

2 Network optimization using calculated values based on a six-hour forecast



"Grid optimization" is the new terminology that describes what needs to be done to manage this situation. Constantly reconfiguring the network by switching capacitor and reactor banks on and off is one example of how voltage levels can be controlled and kept within the limits set out by the regulator. This is referred to as Volt/var optimization (VVO) in transmission networks. Symmetrical loading of transformers, temporarily overloading lines and dynamic line rating (DLR), are other examples of grid optimization techniques that lead to better use of network assets.

But how can operators identify the best time to reconfigure?

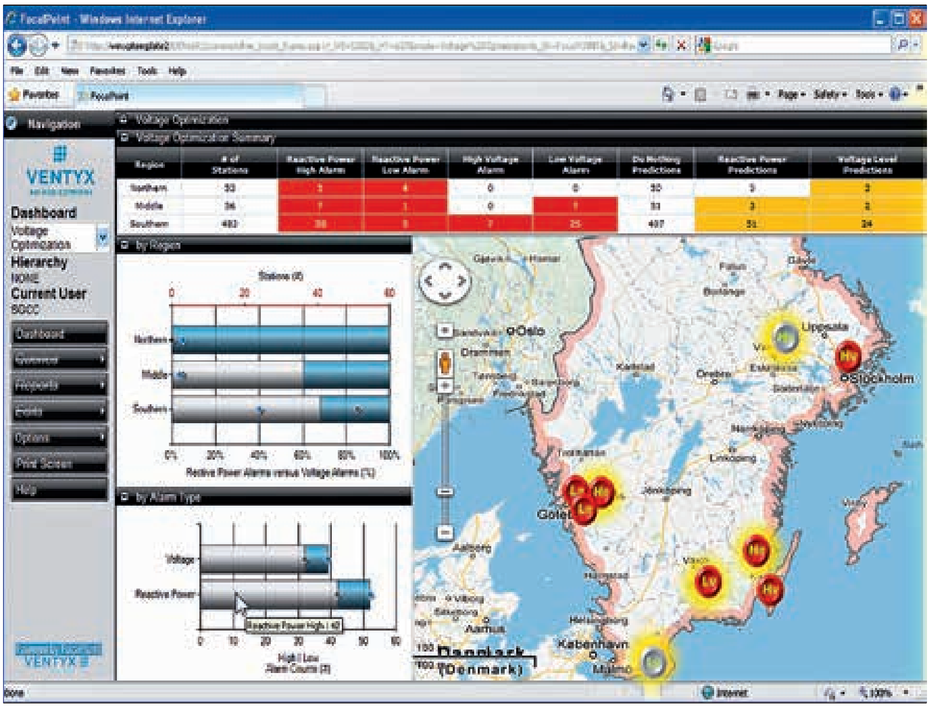
Proactive control using forecast data

Calculating the optimal state of the network fast enough to allow preventive switching has always been difficult. The ideal situation would be to foresee and forestall events that lead to alarm conditions. If a network can adapt faster to changing conditions caused by power flux, it can also be operated in a more efficient way – resulting in better utilization and reduced losses. New applications, such as the distribution system optimization (DSO) recently introduced by ABB will help to do this → 1.

A demand-response management system is a new tool used by utilities to control the balance between power available and power needed.

A DSO effectively combines readily available forecast data, such as load and weather data, for input into a software tool that calculates and builds production and load profiles for the near future. Adding this information to the network software function that mimics the network, often in an EMS referred to as the state estimator (SE), results in a simulated network. The network switching states are copied from the real-time SCADA system. The output of these calculations is a simulated network that mimics the real network, but with electrical values estimated a number of hours into the future – the same timeframe as in the forecasts. Typically, this timeframe is six to 12 hours ahead of the current time, which is a good

3 Example dashboard using the DSO business intelligence tool



The output is a simulated network that mimics the real network, but with electrical values estimated a number of hours into the future – the same time-frame as in the forecasts.

balance between acceptable accuracy and the time needed to reconfigure the network → 2. It also allows time for a signal to be sent to participating units in a customer demand-response program.

For the first time ever, the network operator is able to foresee alarms and warnings expected in the near future and make informed, proactive decisions. The result is improved network efficiency, more stable operation and fewer outages.

Demand response

A demand-response management system (DRMS) is a relatively new tool used by utilities to control the balance between the power available and the power needed. The basic idea is to model and aggregate controllable loads into a virtual load that has a lower peak curve. By signaling this load, the utility can control the load profile and better match production at any given hour. It is important to note that, for domestic loads, this solution differs from the older load management systems (LMSs), which controlled loads without the participation or consent of the end users for every switching command that was sent out. The DRMS tool often requires customers to actively sign up to the demand-response (DR) program.

Typically, signals are sent from a central system to selected program participants, who are able to set up response profiles that, upon receipt of the signal, automatically execute the selected program curtailment option. Suitable loads to control include electric water heaters and temperature-controlling devices such as heat pumps and air conditioners – a small change in room temperature is hardly noticeable to consumers. Less suitable loads include lamps, electric stoves, televisions and computers – for obvious reasons. In return for their flexibility, customers are often rewarded in some way, which varies by utility. Such incentives are seen as a way to change consumption habits in the long term, which is considered by many experts to be the most important behavioral change of all.

Virtual power plants

An aggregation of distributed generation resources managed in a way similar to demand-response loads is called a virtual power plant (VPP). The capability of a VPP would, typically, be comparable to that of a grid-scale renewable power plant. Studies are currently being conducted by research institutes in countries with plentiful wind and solar resources to find economical and technical methods for using VPP units as spinning reserves. Large-scale battery storage, with its ability to smooth power peaks and troughs, is one leading candidate here. The con-

The DSO solution features a business intelligence tool that collects information from the network model and uses a map to guide the operator to areas where there are predicted alarms and warnings in the simulated six hours ahead.

trol room engineer needs to take these changes into account when planning network operations.

Dashboard

The DSO application features a business analytics software platform that collects information from the simulated network and uses a map to guide the operator to areas where there are alarms and warnings → 3. Business analytics solutions have been used for some time to support decision making, primarily in financial matters, but are now finding their way into control rooms to aid technical decision making. An important function of the business analytics solution is to verify that incoming data is both correct and complete. It can then turn a massive amount of data into actionable information.

E.ON smart grid control center

A new generation of system support is being designed to help utilities manage their increasingly larger and more complex networks. The DSO makes it easier for the operators to follow and foresee changing network conditions. It allows the operators to better manage the increasing quantity of data being made available to them. In a pilot installation at E.ON Sweden, this application will be used in parallel with the SCADA system in the dispatch center to guide the operators, who control a distribution network that provides service to over one million customers. This application will be the first of its kind in the 50 to 130 kV subtransmission network that connects the transmission network with the distribution network. The new system study has been named the E.ON smart grid control center (SGCC).

The pilot installation will run in its own environment with a closed link to the real-time SCADA system and will only suggest actions to be executed. When there is more field experience, a tighter integration will be explored to allow optimization to be carried out directly in the real-time SCADA system. Finally closing the loop will be a major step toward the next generation of advanced distribution system management and optimization. It will allow the control room operators to stay in full control and proactively manage their networks.

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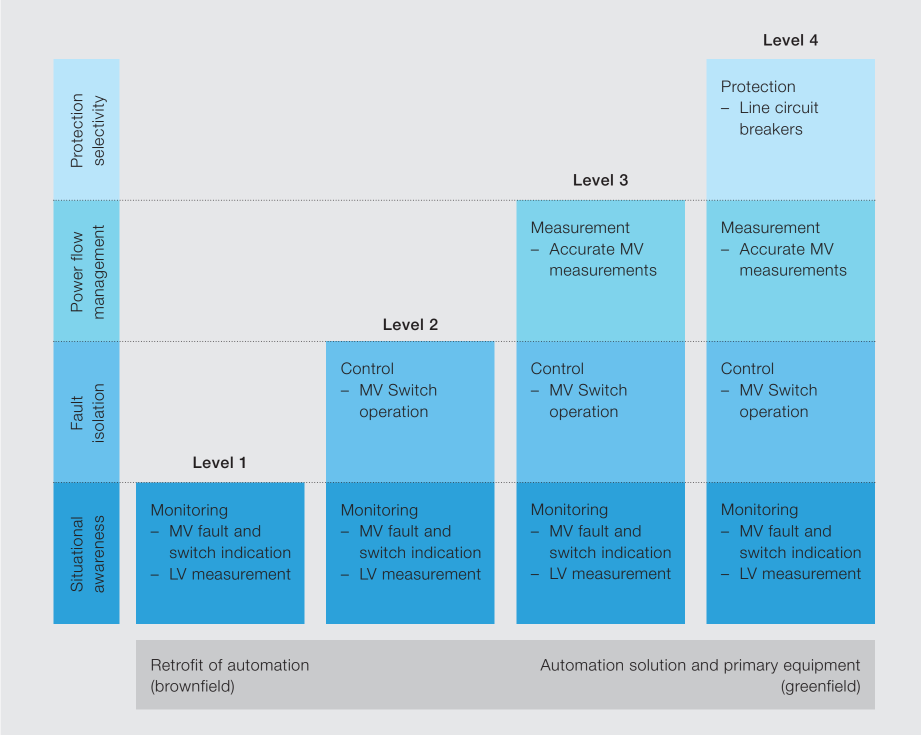
Break free

Outages can be reduced by handling faults in an intelligent way

VINCENZO BALZANO – The permeation of intelligence into the medium-voltage network is continuing apace, bringing the reality of the smart grid ever closer. One target of the smart grid is to improve service continuity by recognizing, locating and isolating faults as quickly as possible. At the same time, the amount of equipment taken out of service should be minimized in order to keep energy provision to the consumer at a maximum. Although faults and outages have always occurred in the power network, their frequency has increased with the growth of renewable energy sources connecting to the grid. To mitigate the effects of faults and outages, improve continuity and quality of electrical service, and increase the network energy efficiency while minimizing losses, it becomes necessary for network monitoring equipment to work in real time and intelligently.

If a fault occurs at any point in an electrical distribution circuit, it is essential that it is recognized, located and isolated in the shortest possible time.

1 Automation equipment can be classed in four logical levels



If a fault occurs at any point in an electrical distribution circuit, it is essential that the fault is recognized, located and isolated in the shortest possible time. Circuit breakers (CBs) are used to isolate the faulty section and the extent of this has to be minimized in order to reduce disruption to consumers. In parallel, power should be quickly restored to the maximum number of consumers possible by rerouting the power flow through unaffected areas.

Apart from consumer inconvenience, these failures give rise to significant costs and negatively impact resource planning, efficiency and profitability for utilities. In addition, utilities now come under intense scrutiny from overseeing bodies, like public ombudsmen, who have the power to administer penalties and levy fines. Therefore, utilities are highly motivated to avoid outages.

Logic selectivity is used when it is necessary to drastically reduce the number of outages, and their duration.

Metrics that matter

Utility performance is measured using a number of metrics. Two primary measurements are SAIDI (system average interruption duration index) and SAIFI (system average interruption frequency index). Government agencies and public utility commissions (PUCs) use these metrics to help them make various decisions – eg, whether or not to levy fines, or how high these should be.

The calculations for SAIDI and SAIFI are similar, and both metrics are related to unplanned outages. Short-term outages, called momentary disruptions, do not affect these indices, but the permissible disruption length is set by the local agencies and may vary from place to place.

SAIDI deals with the duration of the outage, that is, how long the customer is without power. Once a customer calls the utility to report an outage and the outage exceeds a set maximum time, the clock starts ticking on this metric. SAIDI is the annual outage duration per customer.

Title picture
To keep power flowing to as many customers as possible during fault conditions, it is necessary to minimize the section taken out of service. What products and strategies are available to do this?

2 The REC615 is a dedicated grid automation IED designed for remote control and monitoring, protection, fault indication, power quality analysis and automation.

Apart from consumer inconvenience, power failures cause a significant expense and negatively impact resource planning, efficiency and profitability for utilities.

SAIFI is concerned with the frequency of unplanned outages. In this case, each new outage that exceeds a set time affects this metric regardless of how long the customer is eventually without power. SAIFI is the annual number of interruptions per customer.

CAIDI (customer average interruption duration index) is a reliability index arrived at by dividing SAIDI by SAIFI.

To put these metrics in perspective: They are the basis of the decisions by some major utilities to budget several million dollars a year for fines arising from non-compliance.

Proper management of faults and outages provides a way to improve these metrics and reduce the risk of incurring large fines.

FDIR and logic selectivity

In general, there are two approaches to tackling faults and outages to improve service continuity:

– Fault detection isolation and restoration (FDIR)
– Logic selectivity

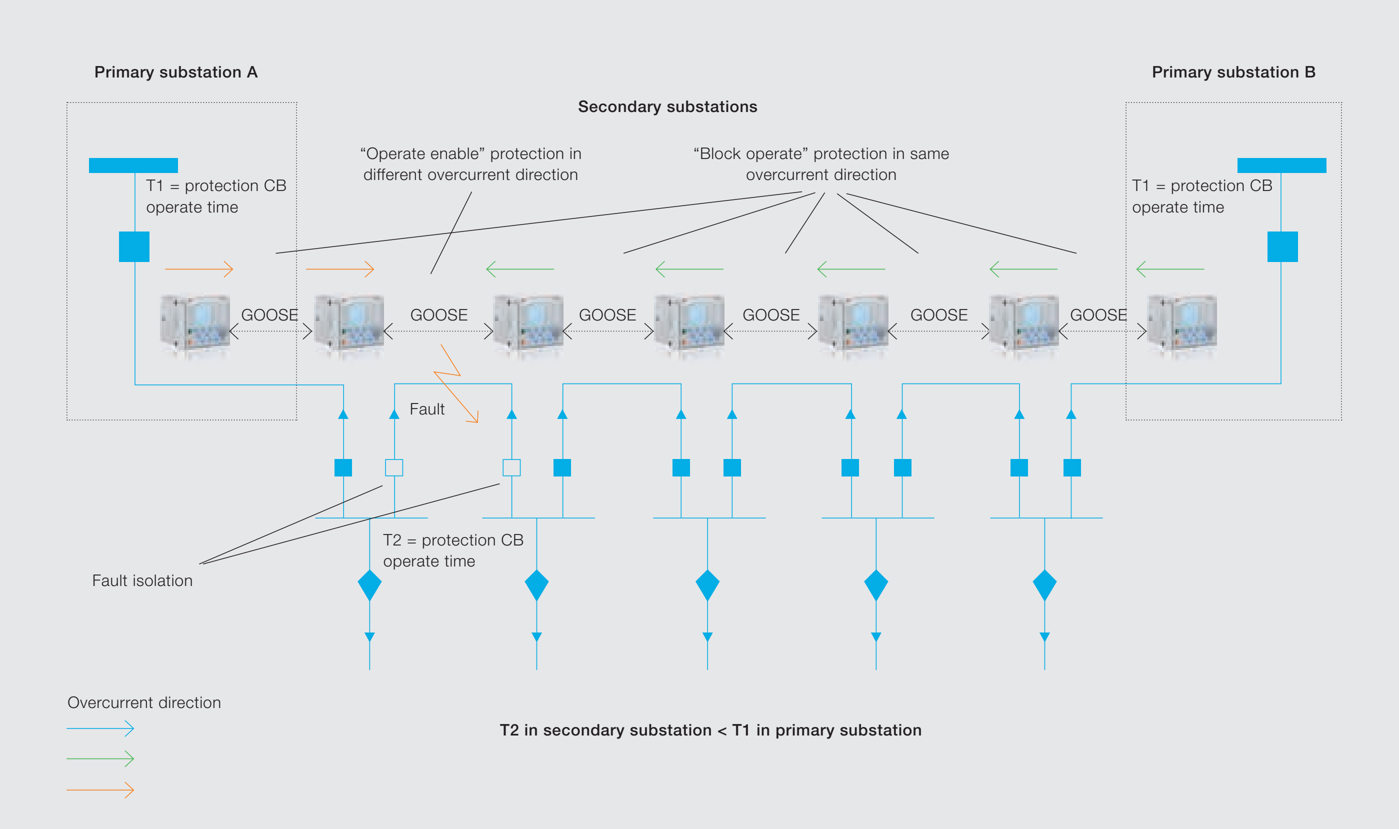
FDIR allows utilities to increase grid reliability mainly by decreasing the duration of outages for customers affected by unplanned incidents. Benefits of FDIR include improved customer service and increased revenues. FDIR reduces the cost of restoration as well as the risk of fines and lawsuits.

Logic selectivity is used when it is necessary to drastically reduce the number of outages, and their duration. The logic selectivity system allows rapid fault isolation. The system has the great benefit of isolating the fault without users other than those directly affected seeing any effect. Investment in primary equipment and communication network infrastructure might be required to accommodate the logic selectivity system – eg, circuit breakers and IEC 61850-protocol-enabled protection in secondary substations, or pole-mounted reclosers, in combination with a high-performance communication network that can provide the low latency necessary.

Remedial strategies for both FDIR and logic selectivity can occur on a number of levels:

– Peer-to-peer, where a group of switchgear or outdoor equipment operates in unison to restore power in the most optimal manner, and at substation level, where a coordinated control between switchgear or outdoor equipment is performed

3 Isolating the fault in an intelligent manner minimizes disruption.



Metrics like CAIDI are the basis of the decisions by some major utilities to budget several million dollars a year for the fines arising from noncompliance.

within a substation or with adjacent substations.

– Centralized level, where coordinated control extends across the distribution grid.

These strategies bring further advantages, such as reduced revenue loss and improvement of the utility's reputation in the eyes of customers, stockholders and regulators.

Grid automation

To successfully monitor and rectify grid outages, intelligent grid automation equipment is necessary. ABB has a wide variety of intelligent grid automation products, such as UniGear Digital for primary substations; SafeRing/SafePlus gas-insulated ring main units and UniSec air-insulated switchgear for secondary substations; Sectos and OVR reclosers for outdoor apparatus; UniPack-G for compact substations; RER/REC 601, 603, 615 and RIO600 for intelligent electronic devices (IEDs); and GAO and GAI intelligent low-voltage cabinets for outdoor and indoor retrofits.

Numerous investigations have shown that, as far as grid automation products are concerned, a "one size fits all" approach does not work – so ABB has defined four levels that correspond to the different functional levels of automation → 1.

Level 1 is the basic solution, which includes monitoring of the entire secondary substation, and current, voltage and energy measurement on the low-voltage side.

Numerous investigations have shown that, as far as grid automation products are concerned, a "one size fits all" approach does not work.

Level 2 adds control of medium-voltage and low-voltage primary apparatus to level 1. FDIR is enabled on this level by devices such as the ABB REC603 wireless controller – a device for the remote control and monitoring of secondary substations, such as ring main units with switch disconnectors in distribution networks.

Level 3 adds to level 2 accurate current, voltage and energy measurement on the medium-voltage side: Power flows can be managed with proper instrumentation and IEDs, which is important when distributed generation is connected to the distribution grid.

When a failure occurs, only the breakers in the substations immediately upstream and downstream of the fault are opened.

Level 4 is the most technically complete solution. Here, the circuit breaker and protection relay are essential in order to manage the logic selectivity and increase performance in topologies ranging from a simple radial topology up to a complex meshed solution. Level 4 adds to level 3 protection functions utilizing breakers on incoming and/or outgoing feeders.

This level features products such as the REC615 → 2. With the REC615, grid reliability can be enhanced as it can provide functionality ranging from basic, nondirectional overload protection all the way up to extended protection functionality with power quality analysis. Thus, it supports the protection of overhead line and cable feeders in isolated neutral, resistance-earthed, compensated and solidly earthed networks. In addition to the essential protection functionality, it can also handle applications where multiple objects are controlled, based on either traditional or sensor technology. REC615 is freely programmable with horizontal GOOSE (generic object-oriented substation events) communication, thus enabling sophisticated interlocking functions. It supports also specific protocol communication such as IEC 60870-5-101 and IEC 60870-5-104.

Logic selectivity

At level 4, the logic selectivity approach can reduce the number of outages without isolating users that are not directly affected by the fault. It can also accurately isolate the fault branch by quickly opening the adjacent circuit breaker(s) and reduce the fault time to hundreds of milliseconds, as opposed to the minutes associated with the FDIR approach.

The high performance of logic selectivity requires high-speed communication – usually using a protocol based on IEC 61850, which can perform peer-to-peer multicast. Generic substation events (GSE) is a control model defined by IEC 61850 that provides a fast and reliable way to transfer data over the substation network. GSE ensures the same event message is received by multiple devices. GOOSE is a subdivision of GSE. For good performance, it must be guaranteed that communication between two nodes of the network be accomplished inside tens of milliseconds.

In fact, the selectivity algorithm normally assumes that this high speed of communication does exist between the substations on the medium-voltage line involved and the relevant protection relays. When a failure occurs, the protection relays related to the area concerned communicate with each other and then only the substations immediately upstream and downstream of the fault are signaled to open the appropriate breakers. The selection algorithm must terminate and extinguish the fault conditions within the delay times set in the primary substation, ie, within the time after which the circuit breaker opens in the primary substation → 3.

The use of circuit breakers, devices based on IEC 61850 and the widespread introduction of a communication network with low latency enable the implementation of massive selectivity logic on the secondary distribution network. This results in early detection and quick restoration – meaning a reduced number of outages and reduced average interruption duration for the customer. This is welcomed by utilities at a time when PUCs and government agencies are increasing their scrutiny of SAIDI, SAIFI and other related metrics.

As growing demand for power and a growing number of renewable sources puts additional burdens on the grid, the scrutiny of unplanned outages is expected to continue to increase. The smart utility will leverage technology to better manage faults and outages – and thus cut operating expenses and improve service reliability to ready themselves for the energy industry dynamics of the future.

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The balance of power

Volt/var management improves grid efficiency

GARY RACKLIFFE – The operators of electric power distribution systems are constantly under pressure to increase efficiency, better manage feeder voltages, reduce feeder losses and reduce peak demand. Further, the cost of incremental or peaking generation capacity, as well as siting and environmental considerations, has driven them to find more effective ways to meet capacity requirements using existing equipment. Improving volt/var management on distribution feeders provides an ideal opportunity to meet all these challenges.

Volt/var control is not a new concept for utilities. A great deal of effort, dating back to the development of distribution systems, has been spent countering the impact of reactive power and voltage drop. The effective management of distribution feeder voltages and losses ensures that voltages are kept within the operating bandwidth defined by standards. This means that consumer equipment will operate properly and the power factor can be optimized, allowing reactive losses to be reduced.

Many factors influence volt/var management, such as the type of consumer load, which can be resistive – like traditional lighting – or inductive, as is found in machine motors, for example. The integration of distributed energy resources such as solar photovoltaic (PV), distributed energy storage, electric vehicle charging infrastructure and microgrids to the complexity of distribution grid operations and volt/var management on distribution feeders.

Effective volt/var control has capital investment implications too: The peak demand in a system usually lasts less than a few hundred hours a year. Active demand management on the distribution system, including controlled demand response and volt/var optimization (VVO), can very effectively reduce the peak demand on the whole electric grid. By shaving these peaks, the need for expensive generation capital investment can be reduced.

However, the complexity and the dynamic nature of distribution feeders makes the management of voltage and reactive power extremely challenging.

Active demand management, controlled demand response and VVO can very effectively reduce the grid peak demand.

Voltage regulation

Voltage regulation is one of the most important components of volt/var management and involves the management of feeder voltages under varying load conditions. Substation transformers equipped with load tap changers and line voltage

Title picture
With increasing numbers of renewable sources coming online and customer loads becoming more demanding, power grids are being pushed to their limits. Advanced volt/var management helps utilities tackle this challenge.

The effective management of distribution feeder voltages and losses ensures that voltages are kept within the operating bandwidth defined by standards.

1 ABB power capacitor banks

regulators help control service voltages, primarily for radial distribution feeder systems. Optimized feeder voltages improve power quality by preventing overvoltage or undervoltage conditions and achieve a flatter voltage profile along the feeder.

Generally, power systems require the supply of both real power (watts) and reactive power (vars). Real power, or the active component, is supplied by a generation source and delivers the active energy that does real work for the customer. Reactive power can be supplied by either a generation source or a local var supply such as a feeder capacitor bank or controllable solar PV inverter. The reactive component does no real work, but it takes up part of the energy delivery bandwidth. Reactive power compensation devices are designed to reduce or eliminate this unproductive component of power delivery and reduce losses. Utilities prefer to address var management locally since the delivery of vars through the power grid results in additional voltage drop and line losses. Because the load on feeders varies, utilities meet the var requirements by switching local reactive power compensation devices such as capacitors, connecting them during high feeder loading and disconnecting them during periods of low feeder loading. The capacitor banks can be located in the substation or on the feeders. Optimized var flow improves power factor and can result in substantial expenditure savings in energy, capacity requirements and infrastructure utilization.

The integration of voltage regulation and var management enables conservation voltage reduction (CVR). Here, system demand is reduced by controlled voltage reduction within approved limits at the customer service points. CVR further reduces losses and lowers overall energy consumed, which also reduces generation capacity requirements and emissions. CVR can typically lower demand by 2 to 4 percent – important for utilities that are capacity-constrained or that face peak demand charges in their power purchase agreements.

The benefits of distribution communications

Centralized radio control systems were introduced into utility systems about 30 years ago and have since evolved to two-way communications that have enabled closed-loop volt/var management systems. In addition, more advanced sensors, and communications-enabled controllers for field devices that manage feeder voltages and reactive power flow, are available. These systems continually sample loads and voltages along feeder circuits and switch compensating devices to improve feeder power factor, manage feeder voltages and reduce demand. They also enable automated CVR.

2 PS vacuum switches

3 ABB CQ900 smart capacitor controller

Model-based volt/var management

There are a number of factors driving the use of distribution system models in the operations environment. In the early 1990s, distribution models started to migrate from planning to the operations environment. System connectivity, the location of protective and switching devices, and knowledge of customer location permitted more accurate outage prediction engines. Shorter customer outage times and more efficient use of field crews were the result.

Additional business drivers include demand reduction, energy efficiency, enhanced asset utilization and better distribution situational awareness. Technical drivers today include improved computational power for handling large distribution models and investments by more utilities in advanced geographic information systems (GISs). These drivers, coupled with the availability of cost-effective sensors, intelligent devices and communications, and grid models, have led to the deployment of effective volt/var management systems.

ABB volt/var control solutions

ABB has three volt/var management systems that manage and control voltages and reactive power flow on the distribution grid.

Volt/var management software (VVMS)

VVMS is a scalable system for closed-loop voltage and var control. It continually samples loads and voltages along feeder circuits and, when appropriate, switches compensating devices such as capacitors, line voltage regulators and transformer load tap changers. VVMS can operate as a stand-alone volt/var control solution or it can be functionally integrated with supervisory control and data acquisition (SCADA) or distribution management systems (DMS). VVMS is interoperable with many different SCADA, DMS, control hardware and communications systems. This gives customers a short lead time, capital investment protection and freedom to use the most appropriate hardware and communications products.

DMS 600 volt/var control system (VVCS)

VVCS provides full SCADA system functionality and a VVO application that uses system information from the DMS 600 database and configured thresholds to

CVR further reduces losses, lowers overall energy consumed for generation and reduces emissions.

Model-based volt/var management has had a major impact on operations.

In VVO, the as-operated state of the system, including near real-time updates from SCADA and outage management systems, is used.

4 DistribuSense sensors

determine the optimal capacitor bank and voltage regulator configuration. The VVCS application does not require a full DMS model – it uses measured values reported through SCADA and configured setpoints to determine the optimal solution. It implements this solution with remote automatic or manual control of the capacitor banks and tap positions on the voltage regulators. Also, the VVCS provides tools for comprehensive network topology management using standard GIS models, and provides real-time status data, connectivity analysis and distribution topology representation.

The model-based VVO advanced network application in Network Manager DMS

In VVO, the as-operated state of the system, including near real-time updates from SCADA and outage management systems, is used. Distribution companies are then able to maintain the precise voltage control needed to implement CVR without violating customer voltage limits. Model-based systems can consider changes to the network as they occur, including load and capacitor bank transfers between feeders, and changing load conditions. Optimal solutions are developed that account for circuit topology and the feeder distances that affect voltages and var flow throughout the entire feeder.

This application mathematically optimizes the settings for each device using a GIS-derived model of the grid. The application uses switchable capacitor banks, line voltage regulators and the controllable taps of transformers as the optimization control variables.

Model-based VVO will also enable distribution operators to accommodate new complexities, including increased renewable generation located at distribution voltage levels, more automated fault location and restoration switching schemes, increased system monitoring and asset management processes, and expansions in electric vehicle charging infrastructure.

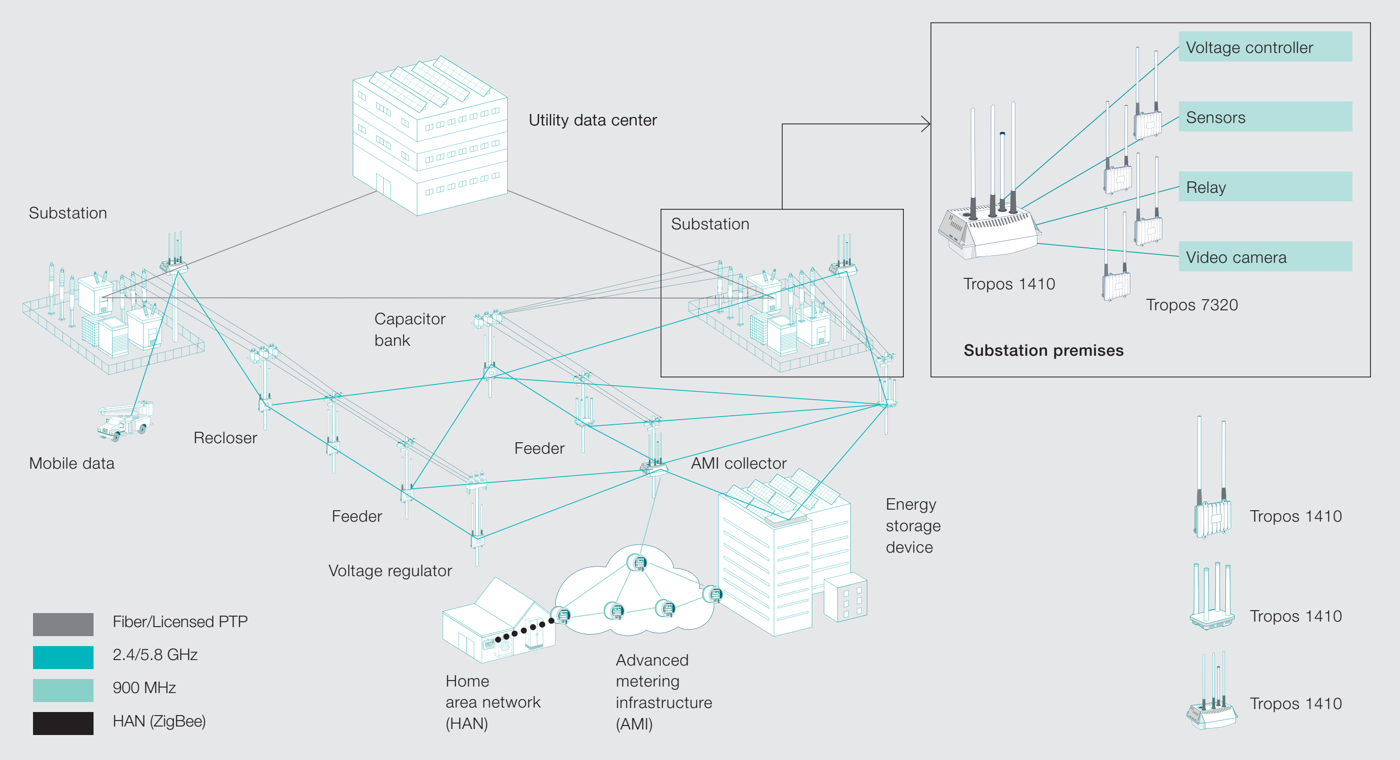
Supporting hardware and infrastructure

ABB supplies a complete portfolio of support hardware and infrastructure for volt/var management.

ABB power capacitor banks provide an economical way to apply capacitors to a distribution feeder system to provide voltage support, lower system losses, release system capacity and eliminate power factor penalties → 1. The banks are factory pre-wired and assembled, ready for installation.

The PS vacuum switch is a solid-dielectric vacuum switch suitable for use in distribution systems up to 38 kV ungrounded (grounded: 66 kV) → 2. The switch has been specifically designed and tested in accordance with ANSI C37.66 for heavy-duty operation in capacitor-switching applications with the harshest climatic conditions.

5 Tropos wireless solutions



ABB's CQ900, the next generation of smart capacitor controllers with two-way communications, is designed specifically for capacitor applications and advanced volt/var management applications → 3.

The ABB DistribuSense™ current and voltage sensor product family enables increased feeder intelligence and drives timely decision-making for volt/var control and CVR applications → 4. ABB's latest in outdoor sensing technology, the DistribuSense WLS-110 sensor, combines VLS-110 voltage monitoring with state-of-the-art, precision-cut, split-core current transformer technology.

Wireless communications systems

ABB's Tropos provides an industry-standards-based wireless IP broadband network → 5. It includes outdoor, mobile and indoor mesh routers. The patented Tropos mesh operating system was built from the ground up to meet the challenges of mission-critical outdoor network deployments. It has directional radio for point-to-point and point-to-multipoint communications and a carrier-class centralized management and control system. Using these building blocks, Tropos systems are used to construct the most resilient, scalable, high-performance and secure networks for utilities, municipalities, mining and industrial customers.

Benefits

Volt/var management helps utilities move from blind operation to feeder management with multiple measurement and control points, end-to-end instrumentation on the feeders, and closed-loop control for automated optimization. The increasing penetration of variable, renewable generation sources, and the increasing diversity and variability of loads, are creating fertile ground for volt/var management.

Utilities are also running closer to their limits than ever before, making the ability to optimize within operating parameters extremely important. OG&E, a large American utility, for example, is at the forefront of implementing model-based VVO to combat these challenges. VVO enables OG&E to maximize the performance and reliability of their distribution systems while significantly reducing peak demand, minimizing power losses and lowering overall operating costs.

If a vertically integrated utility can also optimize power factor, they have to generate less power to satisfy demand. This also benefits the environment in terms of reduced fossil fuel consumption. Further, good power factor control avoids having to pay financial penalties for out-of-specification operation. Strategies such as CVR can reduce costs even more: Overall system demand reduces by a factor of 0.7 to 1.0 percent for every 1 percent reduction in voltage. From a consumer perspective, this reduces the energy they consume. From a utility perspective, it reduces the amount of power they need to generate or purchase from a generator. There is an obvious benefit associated with reduced operating costs, but to the extent these strategies can be implemented to defer investment in new generation capacity or to address reduced capacity due to old generating assets being taken offline, the benefits can be enormous.

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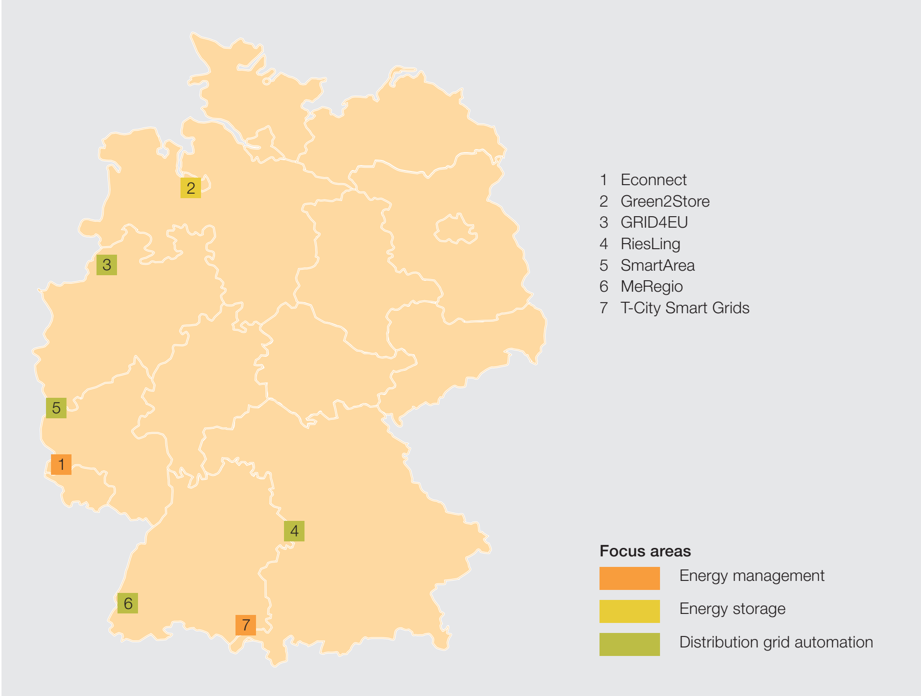
Smarter distribution

How to increase the capacity of distribution grids to host distributed generation

BRITTA BUCHHOLZ, MARTIN MAXIMINI, ADAM SLUPINSKI, LEYLA ASGARIEH – Energy systems are undergoing a major transformation driven mainly by higher shares of distributed generation. With millions of small and fluctuating generators feeding into voltage levels below 132 kV, the need to increase the capacity of distribution grids to host distributed generation requires new solutions. Some of these have been developed by ABB in collaboration with German grid operators and academia. The first solution focuses on a smart planning approach that supports grid operators in modernizing distribution grids economically over a period of time. The next step is innovative distribution grid automation for intelligent secondary substations and distribution voltage regulation. And finally, ABB, using asset management software such as NEPLAN® Maintenance helps the operator to meet tough technological challenges while keeping costs to a minimum.

Title picture
Solar, wind and biogas plants generate more energy than consumed in various regions in Germany.
The picture shows the village of Freiamt in the Black Forest. (Photograph Luca Siermann)

1 Overview of ABB smart grids pilot projects in Germany



The capacity of distribution feeders is defined by national or local grid codes and current practices of distribution system operators. However, several factors, such as thermal rating; voltage regulation; fault levels; power quality; reversal power flow and islanding; and protection schemes limit hosting capacity and many countries have proposed possible methods of overcoming this limitation [1]:

- Changing the topology of the grid, grid enforcement and/or new installations
- Short-circuit current as an ancillary service
- Voltage regulation and reactive power compensation
- Power control of distributed generators
- Adaptation of protection schemes
- Future options such as wide-area control, storage, load management and active elements

In Germany, the electricity system has been designed with high reserve capacities, meaning many grids can host additional generation. However, for most grids a limiting factor concerning grid capacity is voltage level. On top of this, fluctuations in wind speed and solar irradiation lead to fast voltage changes. Under these conditions, keeping the voltage within defined boundaries and avoiding flickers becomes quite a challenge. To stabilize voltage and provide reactive power from distributed generators, grid operators in Germany mainly consider two guidelines for compliance to their local grid code:

- The technical guideline from the German Association of Energy and Water Industries (BDEW) concerning the connection of plants to the medium-voltage network; the guideline is applicable to all generators with a capacity of 100 kW or higher [2].
- Compliance with the VDE network-connecting regulation, VDE-AR-N 4105, is mandatory for all generators with an installed capacity below 100 kW [3].

The German Renewable Energy Act of 2012 requires all distributed generators with a capacity higher than 30 kW to participate in the feed-in management of the distribution system operator, who can then reduce active power by remote control in case of grid stability problems. In August 2014, the new Renewable Energy Act became effective, enhancing participation of distributed generation in the market and encouraging a reliable forecast of generation [4]. New European network codes prepared by the European Network of Transmission System Operators for Electricity (ENTSO-E) are currently in the process of becoming European law [5]. In its "Ancillary Services Study 2030" the German Energy Agency, dena, says that the very high penetration of distributed and renewable resources requires a new systemic approach for the development of the whole energy system over all voltage levels [6].

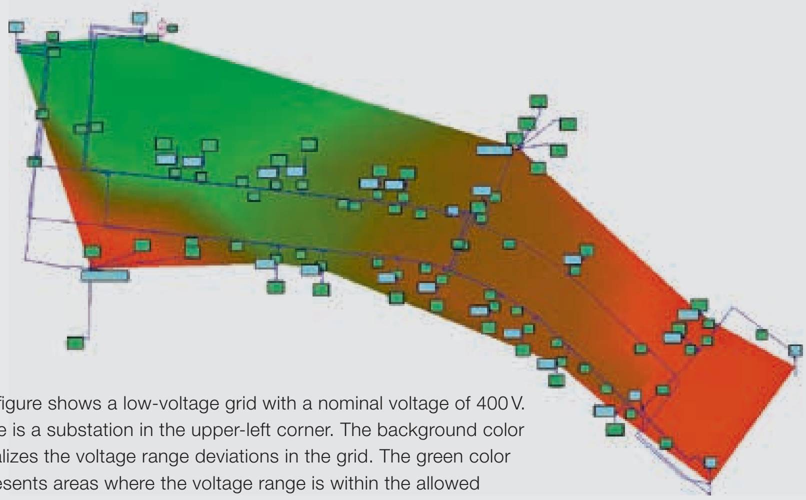
The high penetration of distributed generation puts increased pressure on maintaining and even increasing reliability and availability.

Pilot projects with grid operators and academia[1] have resulted in innovative solutions from ABB to operate and con-

Footnote

1 In partnership with grid operators such as RWE Deutschland AG, Westnetz, E.ON Mitte, STAWAG, Stadtwerke Duisburg, Netze BW and EnBW ODR, and academia such as TU Dortmund and Stuttgart University.

2 Screen shot of NEPLAN® software



The figure shows a low-voltage grid with a nominal voltage of 400 V. There is a substation in the upper-left corner. The background color visualizes the voltage range deviations in the grid. The green color represents areas where the voltage range is within the allowed voltage range. Considering a voltage range of eg, ±10 percent, the red color reflects areas which are below or above this value. Voltages below 360 V or above 440 V occur in areas which are far from the substation and have a high DER infeed and low load or in areas with no DER infeed and high load. The voltage deviation is due to a mismatch between production and consumption.

FIONA is a remote monitoring and control unit for intelligent secondary substations and provides enough information about the 20 kV / 0.4 kV transformer with only a few measurements.

trol distribution grids with high shares of distributed generation in Germany. Some of these are described in the following sections → 1.

Tools to handle increasing complexity

In the past, it was easy to calculate load flows and voltage levels in a distribution system where power was distributed from higher to lower voltage levels. Nowadays, the grid collects and distributes energy at the same voltage level, making calculations more complex. To determine if a generator can be connected without violating limits, software tools are becoming more important for all voltage levels. One such tool, NEPLAN is being further developed so that planners can quickly react to requests from customers to connect their generators to the grid → 2. This would help postpone or even avoid investments in grid extension by using the existing infrastructure to its maximum. However, as the infrastructure reaches its limits, asset reliability and availability become even more critical. In addition regulators are demanding flat maintenance spending despite grid extensions. Another tool, ABB's Asset Health Center, helps grid operators understand the risk of failure in each of their critical distribution assets, avoid asset failures and at the same time minimize their maintenance expenses.

Increasing grid capacity in Rhineland Palatinate

In 2011, RWE Deutschland AG demonstrated in an award-winning project how an active voltage regulator, the PCS100 AVR, based on ABB power electronics, could stabilize voltage levels in the 20 kV grid and at 20 kV / 0.4 kV transformer stations. By decoupling fluctuations at voltage levels of 110 kV, 20 kV and 0.4 kV, the capacity of the grid to host distributed generation was increased significantly, which in turn generated significant cost savings for the grid operator mainly at the 20 kV level. Between 2010 and 2013, ABB successfully implemented a total of 10 PCS100 AVRs in 20 kV / 0.4 kV transformer stations [7]. In fact the base product AVR is now well established on the market and is known for its very high power quality in industrial and commercial applications.

The project teams concluded that the typical requirements of a distribution system operator regarding voltage regulation at 110 kV / 20 kV and 20 kV / 0.4 kV transformer stations are lower than those of industrial applications and can be met with the more economical solution of an on-load tap changer. The Power Engineering Society of the German Association for Electrical, Electronic and Information Technologies e.V. (VDE-ETG) recommends distribution voltage regulation as an economically smart asset [8].

ABB's "smart planning" approach essentially transforms an existing low-voltage grid into a smart grid step by step.

3 The Smart-R Trafo voltage controlled distribution transformer

Based on these conclusions, ABB developed a voltage-controlled distribution transformer known as Smart-R Trafo[2] to match the requirements of distribution system operators ➔ 3. It is based on an economic on-load tap changer that changes voltage in five steps and provides adequate power quality for distribution grids. Smart-R Trafo is expected to become a standard asset for distribution grid operators in Germany and other markets.

Monitoring and control in Bavaria

The high penetration of distributed generation puts increased pressure on maintaining or even increasing reliability and availability, which in turn affects outage time. To optimize assets and reinforcements, information on the measured load – rather than assuming an unrealistic maximum load or making calculations based on the worst-case scenario – becomes even more important. To address these requirements and further embed voltage regulation in a distribution automation offering, ABB developed a new set of solutions as part of what is known as the RiesLing project[3] [9].

The first, FIONA, is a remote monitoring and control unit for intelligent secondary substations and provides enough information about the 20 kV / 0.4 kV transformer with only a few measurements ➔ 4. Added to this is the PCS100 AVR with wide-area voltage regulation so that the voltage measured at distributed points is kept within the allowed bandwidth.

New predictive operation features were developed and introduced into the network control system to predict in advance congestion on the 20 kV level. These features provide the flexibility to change topologies or allow customers to respond by adapting their consumption behavior in the future [10].

Smart planning in Aachen and Duisburg

Despite the fact that voltage regulation is widely acknowledged as an economic solution to modernize the grid, implementing it in standard planning and operation is not so straightforward. For many distribution system operators, knowing when their grid will reach its operating limit is a challenge because they do not know the time, size and type of requests made to their grids. After the introduction of the Renewable Energy Act in Germany, many grid operators were overrun by a very high number of private requests to connect generators with a short response time.

To overcome this barrier and to enable quick decisions, ABB has developed the "smart planning" approach, which essentially transforms an existing low-voltage grid into a smart grid step by step according to the current requirements [11].

Footnotes

2 Presented at the Hannover Industry Fair in April 2014.

3 In partnership with Netze BW, EnBW ODR AG and T-Systems.

4 ABB's remote monitoring and control unit known as FIONA

The grids are first classified using a few structural features, such as the number of housing units and points of common coupling, the radius of the secondary distribution grid, and penetration of photovoltaic systems (PV) in the grid.

If distributed generation doesn't reach a critical point, the request for connection can be granted without further network calculations. A grid is classified as potentially critical, then proceeds to the observation phase where the voltage level in the secondary substation is measured. By using the grid's fingerprint (taken by measurement determination or a grid calculation) as reference, the voltage level of the local grid is estimated. It has been validated in various real grids that the estimated (fingerprint-based) voltages at the critical point in the feeder and the actual measured values in the various distribution grids only differ by a maximum of ±2 V (less than 1 percent). If, during this phase, the grid reaches the maximum permitted voltage limit, the respective secondary substation has to be extended in the next phase with, for example, a voltage regulator or a voltage-controlled distribution transformer.

Incentive regulation

Energy market liberalization and the introduction of incentive regulation have increased the pressure on system operators to reduce their costs while ensuring a high level of service reliability. This means shifting the focus from purely technical issues to technical and economical ones. To achieve this balance, a maintenance plan that fits the used assets as well as the network operation is essential.

ABB's asset management tool, NEPLAN Maintenance, is approved software for establishing maintenance plans, for example, reliability-centered maintenance as well as long-term asset simulations. A budgeting evaluation tool is available that calculates the costs for various maintenance strategies.

Distribution systems play a major role in the ongoing transformation of energy systems. The solutions developed by ABB together with German grid operators and academia support grid operators by technically and economically improving their already existing installations. In the near future further automated (predefined) functions will be able to control primary devices to optimize grid operation.

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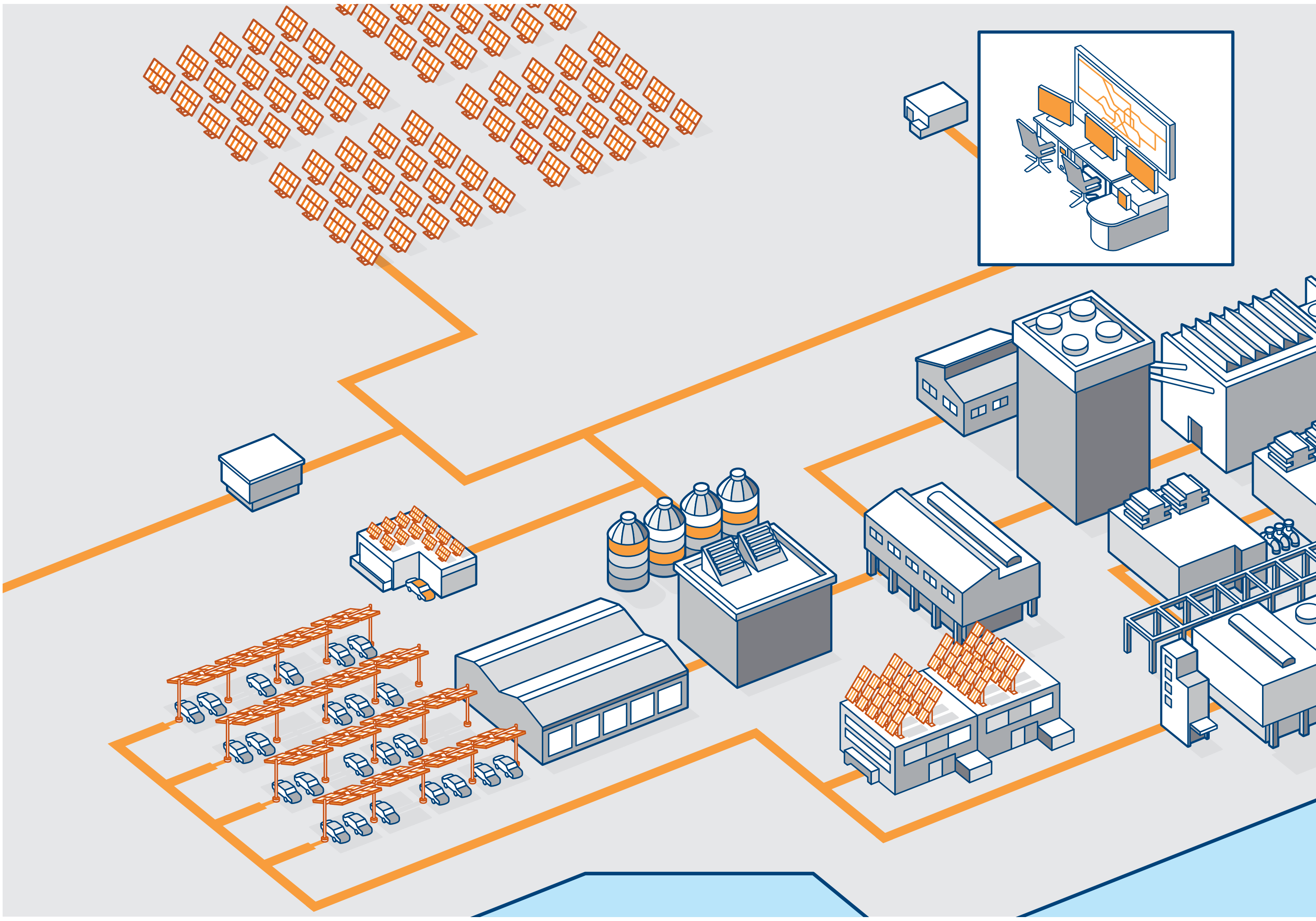
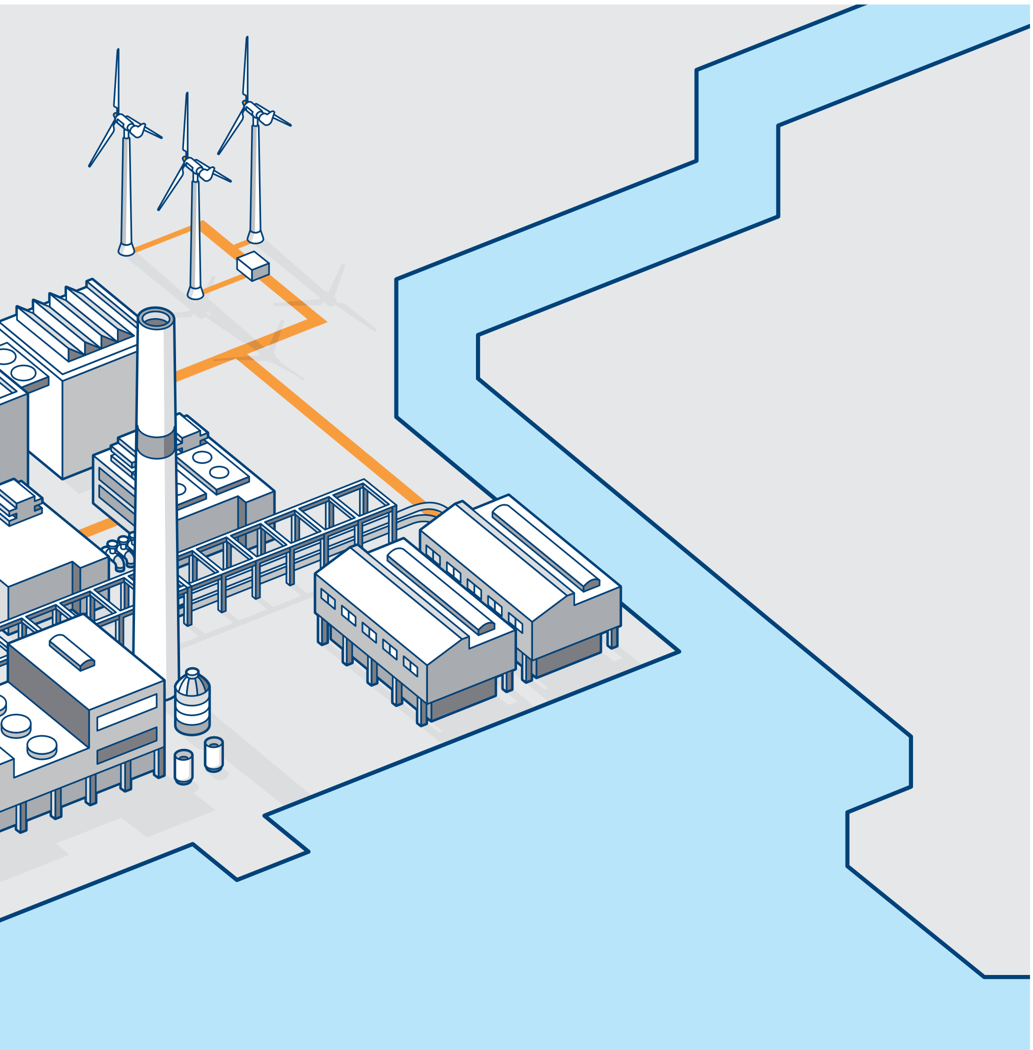


Active Site

ABB's Active Site optimizes the connectivity between microgrids and the macrogrid

PHILIP JUNEAU, DIRK JOHN – The rapid spread of decentralized generation (such as rooftop photovoltaics) is fundamentally changing the way electricity distribution works. Many sites, ranging from college campuses to industrialor military complexes, now feature extensive generation and storage and are thus developing into local grids that are almost miniature versions of the outside grid. These sites can (partially)cover their own needs while utilizing their outside connection to source what they cannot themselves generate (or offload the excess). This is where ABB's Active Site technology comes in: An Active Site can control and optimize the microgrid and its interface to the macrogrid, ensuring an optimization of energy usage and costs while permitting the microgrid to participate fully in what is often called the smart grid.



Microgrids are basically smaller versions of the traditional power grid.

Decentralized generation using renewable technologies has opened new possibilities for industrial sites to control their energy assets locally. Advantages include energy efficiency, ensuring power stability and quality as well as interfacing with the external power grid in a beneficial manner. This more or less independent energy model is referred to loosely as a "microgrid." Multiple definitions of this term are used in industry and academia, but ABB has defined it as follows: "A microgrid is an integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to or 'islanded' from the existing utility power grid."

Title picture
Optimizing energy generation, exchange, storage and consumption across multiple buildings/objects

Footnote
1 See also the article on microgrids on pages 54–60 of this edition of *ABB Review*.

A microgrid includes generation, a distribution system, consumption and storage, and manages them with advanced monitoring, control and automation systems.[1]

Microgrids are basically smaller versions of the traditional power grid. Types of microgrids include:

Many sites, ranging from college campuses to industrial or military complexes, now feature extensive generation and storage.

- Isolated autonomous microgrids, found for example on islands with no connection to the main grid.
- Weakly connected microgrids can be found at the ends of the lines of larger traditional power grids, or in facilities that can go "off-grid" when desired.
- Semi-autonomous microgrids, located in remote mainlaind locations such as remote communities, research stations, defense bases and industrial sites.

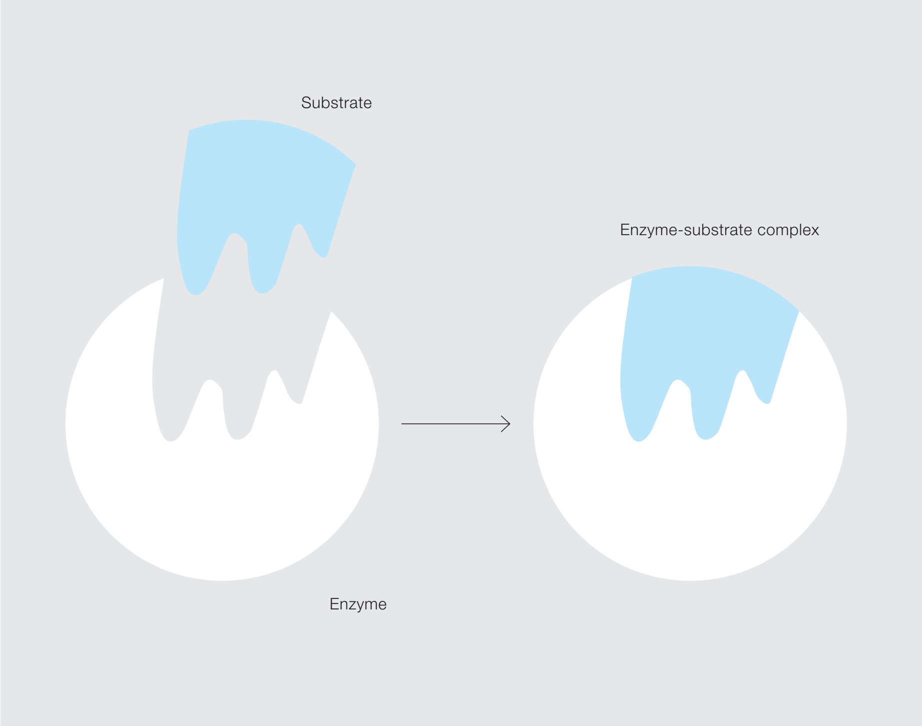
All microgrids have total power ratings between 100 kW and 50 MW.

Active Site
ABB's term, Active Site, has its origin in biology, where an active site is the small portion of an enzyme to which substrate molecules bind to undergo a chemical reaction. The reaction can only occur when a substrate collides with and slots into its unique and matching active site → 1.

In the context of connectivity of microgrid sites, ABB uses the term Active Site to describe the "technology substrate" that

An Active Site enables the site's owner or operator to move from a "passive" to an "active" role by deploying an advanced monitoring and control system.

1 In biology, an active site is the "custom fitting" link between the enzyme and substrate.



bonds a site (ie, the substrate) to the macrogrid (ie, the enzyme) thereby permitting the site to operate as a semi-autonomous microgrid. An Active Site optimizes the deployment of on-site (renewable) generation and storage, site-wide monitoring and controlling and communication with the power grid.

ABB's Active Site technology will be targeted at facility microgrids that, for example, can be found on industrial sites, university campuses and military complexes. These microgrids are connected to but can be managed independently of the macrogrid. Distribution microgrids, which are a part of the power provider/utility network of meshed grids, may be handled differently and are not considered in this article. The technology's applicability, however, does merit further evaluation.

The creation of an Active Site is an ongoing development requiring a stepwise approach.

An Active Site enables the site's owner or operator to move from a passive to an active role by efficiently employing state-of-the-art technology via an advanced monitoring and control system; it provides a mutually beneficial relationship with the smart grid, specifically:
- Increasing overall site energy efficiency while at the same time reducing power grid line losses by sizing and locating the generation adjacent to the site demand.
- Providing localized energy generation and storage to seamlessly operate in an autonomous fashion, balancing out voltage and frequency while prioritizing supply for critical loads.
- Ensuring grid stability via control approaches based on frequency drops and voltage levels at the terminal of each device (ie, reducing bottlenecks).
- Enabling scalability by facilitating the use of many small generation, storage and load devices in a parallel and modular manner to scale up to higher power production and/or consumption levels.
- Promoting both energy autonomy and accountability to provide sustainable benefits to the local community (ie, reduced carbon footprint, green power, etc).
- Identifying predictable and lower energy costs to allow economic

2 ABB's process framework for implementing an Active Site.

Building/site energy plan	Ascertain energy profile and requirements	Implement facility measures	Monitor and control building	Monitor and control site	Intelligent connection to grid
	Profile and requirements defined ↓	Assets optimized ↓	Building optimized ↓	Site optimized ↓	
Actions	– Determine energy profiles (main meter) – Measure and analyze pertinent sub-systems – Determine baseline – Determine optimal and compliant building operation – Assess energy savings potential	– Define facility improvement measures for building systems (eg, HVAC, lighting, DER-renewables, energy storage, etc.) – Calculate economic benefits (energy and operational savings) – Select and implement improvements	– Design and install an: – energy monitoring system (metering) and Integrate: – HVAC, lighting and other controls/ information systems into a central BEMS (building energy management system) – Monitor and control	– Integrate all DER and facility BEMS's into an Active Site energy management system – Establish site operation and load prioritization (ie, balance local supply and site demand) – Operate site (grid Interface ready)	– Evaluate existing energy supply contracts for procurement savings – Discuss and optimize contracts with energy provider(s) ("win-win" approach)
Outcomes	– Energy transparency – Energy baseline established – Asset status/condition – Compliance status to standards/regulations – Facility optimization potential	– Improved asset and building value – Reduced energy and operational costs – Extended lifetime of assets – Reliable facility operation	– Holistic view for pro-active building management – Transparent energy and operations to identify additional potential and engage occupants – Demand response capability	– Holistic view for pro-active site management and seamless operation – Combined energy profile for site-wide energy optimization/savings – Demand response capability for grid interface	For Active Site owner: – Energy independence – Predictable energy costs – For energy provider: – Enables scalability via a virtual power plant – Grid stability – Reduces generation demand – "negawatts"

decision-making to be programmed into standard operating protocols.

- Reducing the need for capital expenditures for new central power generating plants and improving the overall grid network efficiency (ie, energy avoided/saved or "negawatts")
- Encouraging innovative solutions that allow for new business models in a dynamic power market.

Rolling out an Active Site

The creation of an Active Site is not something that can be accomplished overnight. It is a process requiring a stepwise approach. ABB uses a process framework → 2 to collaborate with its customers and its channel partners in a systematic fashion.

The first and most important step is to meter for a distinct period all energy mediums: electricity, natural gas, steam, water, petrol, etc. both on a macro (main meter) and micro (system/asset) level. This will ascertain the building's energy profile and help understand the operational aspects of the building and overall site energy requirements.

Once this data is acquired and analyzed, facility improvement measures can be evaluated, selected, designed and implemented based on the owner's building/site energy plan in order to match the expected economic benefits and returns. These measures may include building automation (HVAC[2]), lighting, etc.), industrial automation, distributed energy resources (DER) such as solar, wind, combined heat and power (CHP), and energy storage and electrical vehicle charging. This process will most likely require a few iterations based on the energy plan's budget and timing.

After the implementation of the improvement measures, the monitoring and control phase begins. This not only verifies the results versus the target, but also identifies additional improvements and/or operational issues. Integration of the different building and process control systems and the pertinent information systems (eg, maintenance management) may also be necessary for a holistic overview.

As soon as all buildings are optimized and aligned to the site generation and storage capacity, an Active Site energy-management system is used to integrate all of these systems and thus to better monitor and control the site. All of the site's operational parameters (ie, system/ load prioritization and requirements) can be monitored and controlled together

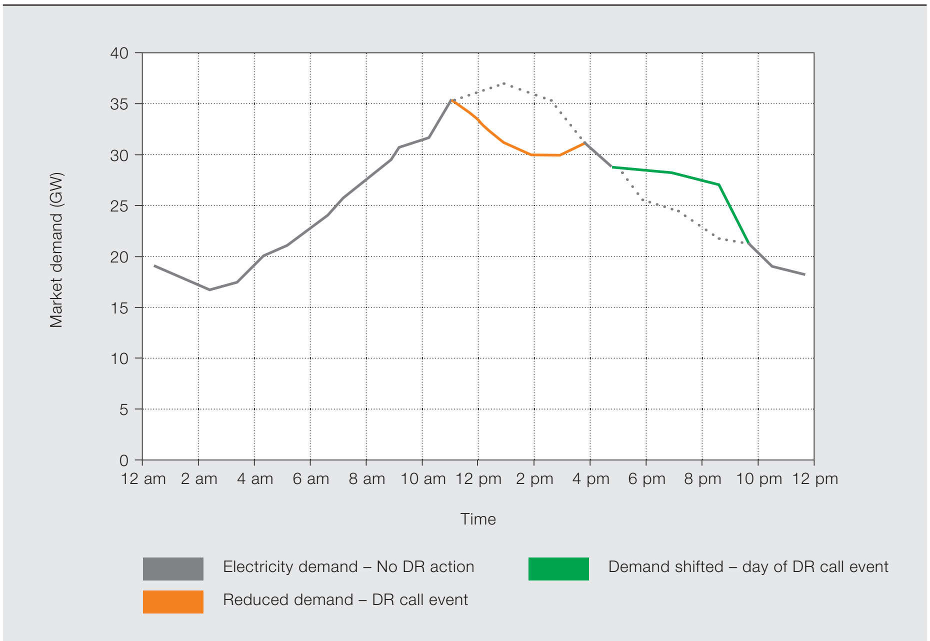
The monitoring and control phase verifies the results versus the target, but also identifies additional improvements and/ or operational issues.

Footnote

2 HVAC: heating, ventilation and air conditioning.

The interconnection and communicational aspects between the site and the energy provider need to be agreed.

3 Shifting of consumption or use of storage can help reduce peaks by shifting grid-side demand.



with the energy storage and production parameters (electrical and thermal) permitting compensation for demand or supply fluctuations across the entire site, whether these fluctuations are scheduled, requested or unexpected. For example, when demand is too high, the system can switch off non-critical loads in lighting, HVAC systems and ancillary equipment (eg, pumps, fans) and utilize the most cost effective site generation and storage.

Overall, an Active Site contributes to the management of the macrogrid by predictively and dynamically participating in its overall demand needs.

Now that the site has become an Active Site, an intelligent connection to the grid is possible and the site can become an active participant in the overall macrogrid. The interconnection and communicational aspects between the site and the energy provider for all modes of operation ie, transfer to islanding mode, site reconnection to the power grid, energy storage recharge mode, and step-down of site generation upon reconnection to the grid needs to be agreed upon with the energy provider. This is a matter of regulation, standardization and contractual agreement. Overall, the benefits to the site owner are the predictable and optimized energy costs. The benefit to the energy supplier is scalability for that region, as an Active Site can participate in the virtual power plant (VPP) model, which contributes to both a stable grid and reduces centralized generation demand (ie, negawatts).

Overall, an Active Site contributes to the management of the macrogrid by predictively and dynamically participating in its overall demand needs. By being able to predict the site's capabilities through analysis, simulation and planning, the site becomes an active player supporting the ever changing needs of the macrogrid.

In a more isolated approach, an Active Site can also be beneficial to the macrogrid by controlling the overall site demand by employing demand reduction/shifting and energy storage usage at the appropriate times. An example can be seen in → 3: When the peak demand reaches 35, the demand is reduced (or shifted to a later period) and thus a peak energy (and cost) reduction is achieved.

4 Microgrids are basically smaller versions of the traditional power grid, with generation, distribution, storage and consumption.

In Germany there are a significant number of sites having an ideal "Active Site energy consumption."

On the other hand, when it becomes more advantageous, the loads which were shifted can be energized to perform their original tasks (or, in some cases store energy to be curtailed during peak demand).

For what type of applications would an Active Site offer the greatest advantages? Simply put, the answer is a site whose owners attach high value to:

– Access to reliable, secure power (energy security)
– Control over their energy supply and demand (energy independence)
– Cost savings, both energy and operational (energy efficiency)
– Cost benefits by playing an active role on the energy market

From a market perspective, there are industrial sites such as chemical plants with significant energy demand where dedicated systems are already being deployed or integrated as part of a complete control system. But industrial sites, such as food and beverage, paper and printing, electrical/electronic manufacturers, vehicle construction, etc. that have a diverse range of functional buildings (ie, process, office, warehousing, logistics, etc.) are ideal candidates.

In Germany, for example, there are a significant number of sites having an ideal "Active Site energy consumption," which ranges between 2 and 20 GWh/year and the electrical part of the energy consumption ideally being above 50 percent. It is estimated that there are 24,000 sites in this category → 4.

With the technology, market needs and all of the benefits presented herein, there is nothing standing in the way of site owners to begin an Active Site process, either independently or jointly with their energy providers. ABB is ready and able to accompany this process. The company welcomes inquiries and feedback and hopes to hear from interested candidates soon.

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No grid is an island

Communication technologies for smarter grids

MATHIAS KRANICH – Smart grids gather information and reach conclusions, but to react appropriately to changes in the generating and transmission environment, the systems and the people behind them need a complete view of the network status. Collating the information requires robust communications, because not knowing what is happening makes decision-making difficult. With more than half a century of experience integrating communication systems, ABB can solve the technical challenges to making the smart grid a reality. Physical networking needs a variety of different solutions, such as ABB's FOX fiber optical multiplexers, AFS Ethernet switches, ETL Powerline Communication and Tropos 802.11 mesh wireless networks.

Mission-critical communications are dependent on Quality of Service (eg, latency) rather than bandwidth.

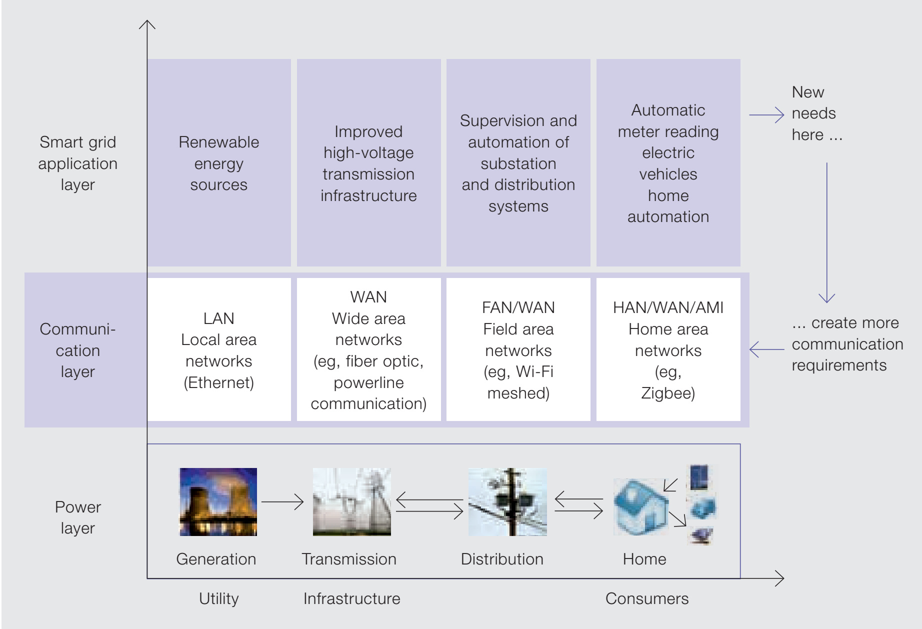
The geographical scale of transmission and distribution networks presents a unique challenge to maintaining reliable communications. The size of most networks is a challenge in itself, but the topological layout can make the provision of redundant rings or looped connections difficult to implement, and with such critical infrastructure fail-safe connectivity is essential ➔ 1.

Title picture
Long-term investment is needed to give utility grids the intelligence they need. With plenty of experience, ABB can solve the technical problems involved in making the smart grid a reality using products that ensure operational information is shared across the grid.

The term "critical communications" immediately conjures images of engineers battling at control room desks to reroute power in the face of overwhelming disaster. In fact most communication is more sedate, though nonetheless critical. The messages that really matter, and upon which the safety of the network depends, are generally sent, received, and acted on in less than a blink of an eye. Such communications are dependent on Quality of Service (eg, latency) rather than bandwidth. The mission-critical messages themselves are tiny, but must be delivered within a predictable timeframe. These days, many networks on higher voltage levels are already laced with fiber connections that are mapped into redundant loops, and ABB's FOX multiplexers can ensure those messages are delivered on time with its Powerline Communication (PLC) backup links for important high-voltage lines ➔ 2. But in the more remote regions of the world, pure Powerline networking is heavily used. In many places, rather than run fiber out to a spur from the loop, it makes better economic

A smart substation can generate several tens of megabytes of data a second, and dealing with this requires some careful thought.

1 Communication requirements evolve with smart grids



sense if PLC – or in special cases microwave – is the technology used. To ensure that such remote stations are not cut off from the smart grid, ABB's range of Electrical Transmission Line (ETL) PLC equipment will carry up to 320 kb/s, while microwave solutions need line-of-sight to provide higher capacities up to 622 Mbit/s → 3.

Because a failing communications network can have serious implications, protecting the network becomes just as important as protecting the services being delivered.

But if such capacities aren't needed for emergency messages, what is taking up all that cabling capacity? Equally important to the long-term viability of the utility network are the routine messages that report the operational status of transformers, the temperature of circuit breakers, the viscosity of cooling oil, as well as many other environmental factors affecting the grid. This data needs to be aggregated and analyzed by software that can spot developing trends and highlight conjunctive events, showing the impact of new machinery or excessive loading. This analysis lets central operations spot developing problems, schedule remedial work before anything breaks and generally keep watch over the state of the network.

A smart substation can generate tens of megabytes of data every second and dealing with this requires careful thought. Of course, the wide-area network does not have to carry all that data; data, gathered by high-capacity Ethernet (managed with ABB's AFS switches to ensure IEC 68150 compliance) over intra-substation fiber, is fed into the substation's intelligent electronic devices (IEDs) and remote terminal units (RTUs), which take out repetitive and redundant information. But when half a dozen substations are linked, the network load and potential for failures start to build.

Maintenance and administrative traffic is also an essential part of the smart grid but it can also place a considerable load on the communications infrastructure. If communication is used only during an emergency, or to give instructions to field staff via the engineering order wire (EOW), then the bandwidth required is quite minimal. The provision of intranet into substations and the interconnection of office local area networks (LANs) via operational networks drive the band-

2 ABB's FOX multiplexers ensure messages are delivered on time

According to the Electric Power Research Institute (EPRI), a major part of a smart grid investment will be in the communications infrastructure, which could also lead to substantial cost savings.

width requirement easily to several tens of megabits per second.

Communication – the smart grid enabler

A failing communications network can have serious implications beyond the obvious reduction in network visibility. The autonomous capability of the smart grid is dependent on the ability of the sensing components to exchange information, such as in the case of distance protection for direct breaker tripping, where a breaker needs to know what was sensed remotely before deciding where the line should be cut to isolate a fault. It may be more complicated when the supervisory control and data acquisition (SCADA) system, for example, has to decide how to respond to a suddenly-silent or misreporting IED. Therefore, protecting the communication network becomes just as important as protecting the services being delivered.

FOX615 is a multiservice multiplexer, which allows direct connection of all utility-specific applications to the multiplexer without external converter boxes.

When networks experience massive breakdowns, the communications network cannot afford to be part of that failure. With limited resources, and public safety often at risk, the network needs to be able to tell a utility where to send staff and what parts of the network are still operational, thereby keeping outages to a minimum and reducing costs while increasing safety.

The Electric Power Research Institute (EPRI) has been looking in detail at the cost of a smart grid.[1] According to EPRI, a major part of a smart grid investment will be in the communications infrastructure, which could also lead to substantial cost savings. To illustrate this point, the Philadelphia utility, PECO, avoided 7,500 engineer visits in 2005 alone thanks to smart grid communications, which verified if a customer-reported outage was genuine.

Footnote

1 http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001022519

ETL 600 provides communication that can keep running in the most challenging environments, such as transmitting over more than 1,000 km without using repeaters.

3 ABB's ETL Powerline routers can carry up to 320 kb/s while ensuring that remote stations are not cut off from the smart grid.

The smart grid challenge

As part of the smart grid concept, communication should no longer be limited to operations within a single company. To gain a view of the entire grid, a transmission system must talk to a distribution system, generators must be able to read demand from customer premises, and communication networks need to be seamlessly integrated so decisions can be based on the whole grid rather than parts of it. This integration runs counter to how the industry has evolved to date. Fragmentation has been created to drive competition, but for the smart grid, this fragmentation presents a greater challenge. Diverse communication equipment and strategies need to be integrated to achieve the goal of an intelligent grid.

National utilities and governments demand compatibility in preparation for integrated communications. Standards such as IEC 61850 ensure compatibility within the utility, and ABB has been intimately involved in drafting those standards for decades. Communication between utilities is equally important and therefore ABB has been equally supportive in creating the Inter-Control Center Communications Protocol (ICCP, also known as IEC 60870-6) to provide communication between utilities, both upstream and downstream. ABB has already deployed gateway software ensuring that its customers can integrate their systems to the benefit of the smart grid itself.

Smart grid communication technologies

ABB has decades of experience building communication networks, from the early deployments using ripple signals to control water boilers and streetlights, to the development of PLC, laser-driven fiber optics, and the mesh-radio techniques blanketing the smart city of the future.

While ripple is no longer in use, PLC technology is still being used, with the ETL600 providing communications that can keep running in the most-challenging environments, such as transmitting over more than 1,000 km without the use of repeaters. These days, PLC is often deployed as a backup system, running in parallel with fiber-optic lines, especially where the geography makes a redundant ring of fiber impractical.

If fiber is available in a network, optical networks are deployed. While circuit-based SDH systems are mainly used in a transmission system [1], low-voltage distribution systems typically require less Quality of Service and may run based on packet-switched Ethernet networks. Considering the harsh utility environment and specific utility applications, these solutions require special product design (eg, fanless, extended operational temperature). ABB's FOX and AFS family provide the required utility features for SDH as well as for Ethernet → 4.

4 ABB's FOX (in cabinets) support multipurpose networks with utility-specific solutions.

Governments and the general public see clear advantages in an intelligent grid and ultimately, political will and long-term investment is required to give utility grids the intelligence they need.

Often, there is no communication media available, which in turn leads to the use of wireless solutions. An overview of the main principals can be found in *ABB Review* 1/2013 [2]. The challenges imposed by the smart grid can be best met by standardized 802.11 WiFi technology, which provides sufficient bandwidth to combine different applications and co-run different operators in one network. ABB's Tropos 802.11 product line enables highly reliable industrial-grade mesh 802.11 systems that simultaneously support various applications over one unified network. Even IEC 61850 generic object oriented substation events (GOOSE) messaging can be realized for low-voltage applications via this solution. More details on the specific protocol securing high network availability can be found in *ABB Review* 4/2013 [3].

Governments and the general public see clear advantages in an intelligent grid, but some utilities have been slow to embrace its advantages, in particular when considering decreasing energy prices and the fact that they may end up working closely with companies they've considered competitors, suppliers or customers. These problems can be addressed with international standards, such as IEC 68150, with multiservice platforms like ABB's FOX or Tropos platforms, which will support multipurpose networks with utility-specific solutions like ETL PLC, as well as AFS Ethernet switches. These solutions can smooth the way, but it can be difficult for utilities to build a business case. Ultimately, political will and long-term investment is required to give utility grids the intelligence they need.

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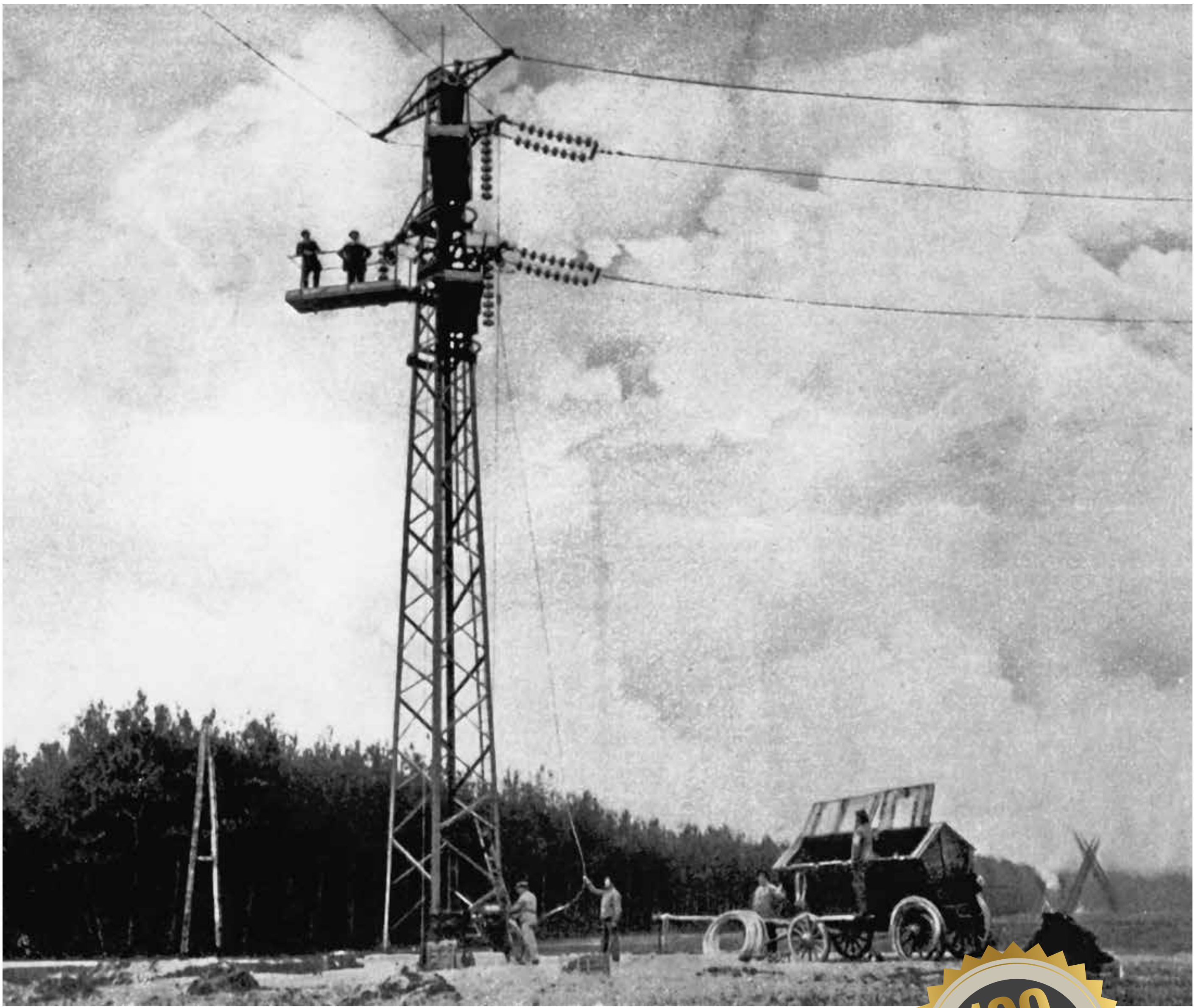


Entering a new epoch

A brief history of the electric power supply

JOCHEN KREUSEL – Electricity can be found everywhere, from the ubiquitous and mundane applications that are so easily taken for granted to the largest and most complex of systems. The electricity supply has in little more than a century become the most important enabler of human activity and business. Without it there would be no secure supply of clean water or food. There would be no information technology. Productivity would be inadequate to meet the basic necessities of the planet's population. The ongoing growth in importance and scope of the electrical grid has been accompanied (and enabled) by the development of the systems that assure its continuity and reliability. Despite fundamental transformations along the journey from early island networks to the continent-wide synchronized three-phase AC grids that emerged in the second half of the 20th century, the basic principles underlying these systems remained largely unchanged. However, recent developments are bringing new and fundamental changes.

1 Brown Boveri & Company switchgear (1936)

Electrical energy was first discovered in a DC form and its early applications in communications, transmission and lighting used low-voltage DC. It is thus no surprise that the first urban distribution networks were also DC. Even the first long-distance transmission of electricity (57 km between Miesbach and Munich in Germany, in 1882) used DC technology. These early efforts predated the emergence of three-phase AC technology, whose development was to start in Europe and which was to be advanced in the United States by Nikolas Tesla and George Westinghouse.

The main driver for the transition to the three-phase AC system was the possibility of converting voltages in transformers. Transformer made it possible to transmit power at low-losses by converting to voltages too high for direct use in applications. This transmission efficiency made using larger centralized power plants possible and thus introduced economies of scale. Another important advantage of AC was the better interruptibility of short-circuit currents – even today high-voltage DC power switches exist only as prototypes. And last but not least, the very simple conversion of electrical energy into mechanical energy and vice versa in induction machines was a major advantage of AC.

In 1891 on the occasion of the International Electrotechnical Exhibition in Frankfurt, Germany, the successful transmission of three-phase AC was demonstrated over a distance of 176 km between Lauffen and Frankfurt. The demonstration was a collaboration between AEG and Maschinenfabrik Oerlikon. It was realized under the leadership of the three-phase pioneer Mikhail Osipovich Dolivo-Dobrovolsky of AEG. Maschinenfabrik Oerlikon's contribution was led by Charles Eugene Lancelot Brown, who was later to become one of the founders of Brown, Boveri & Company (BBC).

The breakthrough of the three-phase AC system in the United States came about when the lighting of the Chicago World's Fair in 1893 was entrusted to George Westinghouse. Westinghouse significantly undercut Thomas Edison's DC bid. His victory was a decisive factor in AC winning the "War of the Currents."

Electrical energy was first discovered in a DC form and its early applications used low-voltage DC.

The emergence of long-distance supply systems

In the first half of the 20th century, previously stand-alone island networks were progressively interconnected to larger and ultimately national grids. A structure emerged for power systems that still holds its own today: It features system-wide interconnectivity → 1, a meshed high-voltage transmission level connecting to subordinate regional high-voltage networks, and underlying medium- and low-voltage distribution networks extending across both city and rural areas. The reasons for merging the local island networks are the higher efficiency of larger power plants, the lower reserve power capacity and the use of location-bound primary energy sources, especially hydropower and lignite. The transportation of

Title picture
Construction of BBC's first 110 kV line (between Karlsruhe and Mannheim, Germany, 1914)

The Chicago World's Fair held in 1893 was the breakthrough of the three-phase system in the United States.

these in their primary form is not economical due to their low energy density → 2. Because the electrical power supply was recognized early on as a key economic infrastructure and a natural monopoly, virtually all countries either nationalized or regulated it at an early point.

With the emergence of large systems commenced the mode of operation that is still valid for all of the major electrical energy supply systems in the world → 3. The two main requirements the system must fulfil are that it must assure a balance between supply and demand (as shown on the left hand-side of the figure) and the specified voltage parameters must be maintained at the transfer points (right hand side).

The challenge of operating such a large, geographically distributed and composite system in real time without the availability of today's high-performance communication technology was approached by deploying a comprehensive planning process using such tools as unit control and load distribution and with the objective to minimize remaining uncertainties. The latter must be managed in real time. Control of remaining deviations takes advantage of the fact that the frequency is available almost instantaneously across the system. Mismatch between consumption and generation can be measured using the resulting deviation in frequency, which provides a signal for appropriately equipped control power plants to modify their output and correct the mismatch.

Largely independent of these power management activities is grid control. Grid control uses the control settings of the transformers located between the different high-voltage levels and those between the high- and medium-voltage level as well as the reactive power infeed from the power plants to adjust the load flow and grid voltages. Voltage regulation normally ends at the medium-voltage level. The connection between the medium- and low-voltage levels uses transformers with fixed ratios.

2 Hydropwer has a strong geographic dependency and thus often requires long-distance transmission.

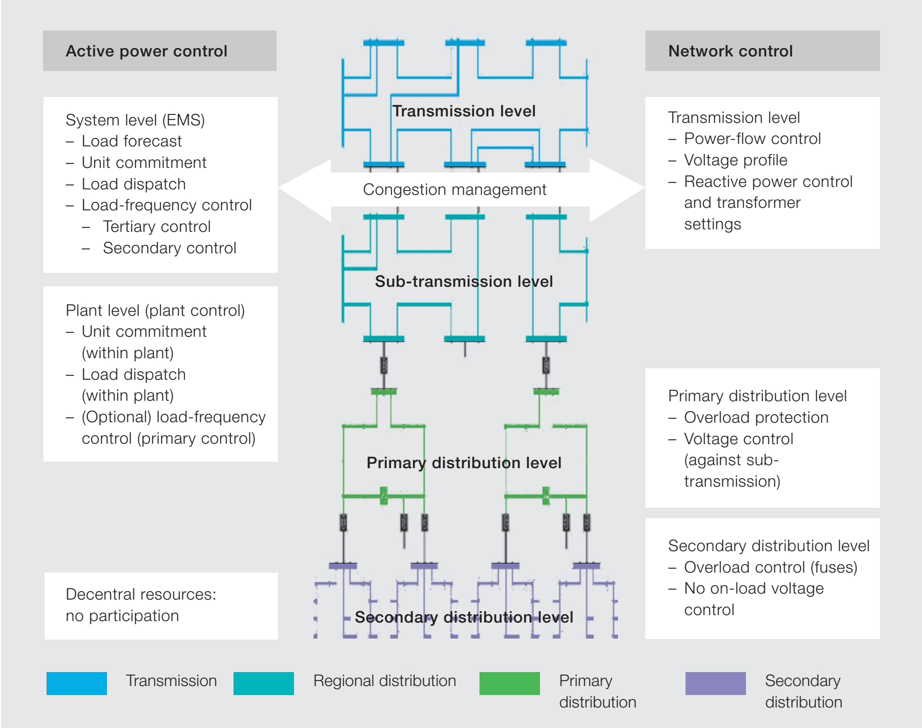
In principle these two processes are separate. However in practice they are interrelated because of the use of plants for the local control of reactive power, and because transmission bottlenecks require power plants to be operated outside of the system-wide operating cost optimum.

The final important statement contained in → 3 is that the operation of large interconnected synchronous grids on the primary distribution level is achieved with a small number of centrally placed elements such as large power plants and switching facilities. For example, in typical European network structures, switching facilities on the primary level represent less than 2 percent of the total switchgear.

In the early years of the 20th century, a structure emerged for power systems that still holds its own today.

In the second half of the 20th century, national grids were interconnected across borders to form transnational synchronous grids. These developments were driven by the quest for higher prof-

3 Main functions in the electrical supply system



Today China has the largest synchronized power system in the world and is still rapidly evolving.

itability and greater security of supply. In Europe, the creation of the Union for the Co-ordination of Production and Transport of Electricity (UCPTE) in 1951 laid the foundation for the emergence of a European synchronously operated system. The technical implementation began with the connection of the grids of France, Switzerland and Germany at the "Star of Laufenburg" (Switzerland) in 1958 – long before the idea of a European electric market was born. Today one single synchronous grid stretches from Portugal to Poland and from the Netherlands to Turkey. It has now also been synchronized with Morocco, Algeria and Tunisia ➔ 4.

Parallel to the emergence of the interconnected continental European system, the Scandinavian Nordel system was created as was the Interconnected Power System (IPS) of the (then) Soviet Union and the countries in its sphere of influence. The latter is to date the world's geographically most extensive synchronized system in the world. A slightly different approach was adopted in North America: Although synchronous systems were created covering several states, synchronous operation was not extended across the continent. Today, there are three synchronously operated areas interconnected by HVDC couplings. Presently, China has the largest synchronized power system in the world (in terms of power) and is still rapidly evolving. The key data of some important synchronous grids are compared in ➔ 5.

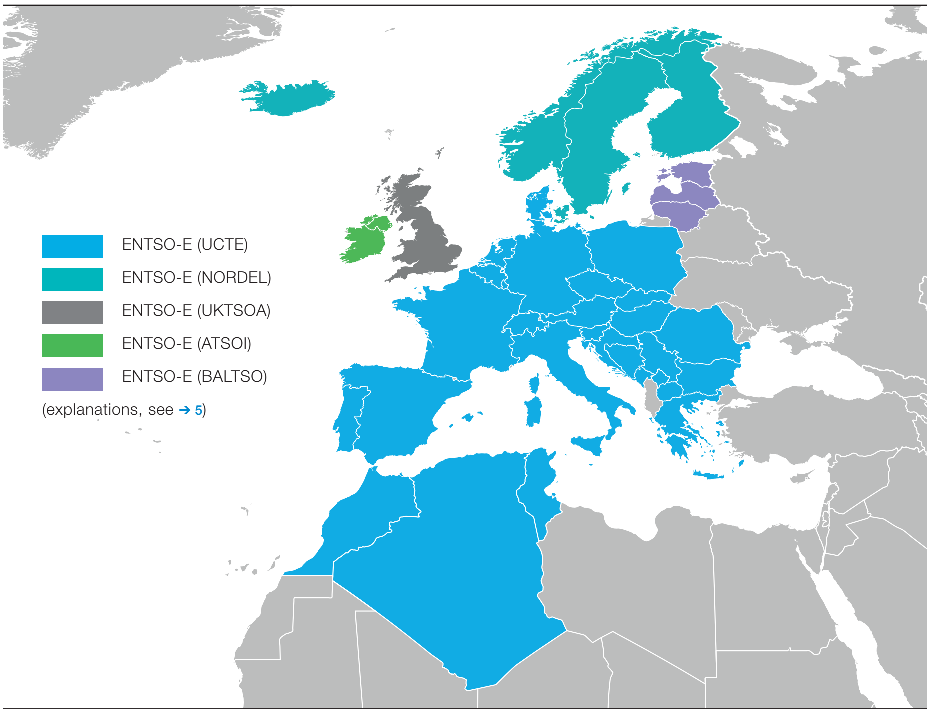
The different maximum voltages in these transmission networks reflect the different geographical size of the systems. Because reactive power requirements limit the maximum stable operable length, long-distance transmission requires either high-voltage or low frequencies.

High-voltage direct current transmission

Although the benefits of AC technology led to its ubiquitous adoption, the growth in size of synchronous grids also highlighted its drawbacks. Systems began to approach the limits of stable transmission, especially where cable transmission was used (introducing highly capacitive reactive-power requirements). The importance of submarine cables in the Scandinavian countries prompted these to begin looking into high-voltage DC transmission (HVDC) in the 1920s. The pioneer of this technology, August Uno Lamm, spent more than 20 years working on this challenge at ASEA. The first commercial link went into operation in 1954, connecting the island of Gotland in the Baltic Sea to the Swedish mainland grid ➔ 6.

In the second half of the 20th century, national grids were interconnected across borders to form transnational synchronous grids.

4 The main synchronous grids of Europe



5 Key data of selected synchronous grids

System	Year and source	Installed net generation (GW)	Peak load (GW)	Annual consumption (TWh)	Highest transmission voltage (kV)
ENTSO-E (ATSOI[1])		16,5	6,2[6]	34,9	400
ENTSO-E (BALTSO[2])		9,4	4,6	26,0	330
ENTSO-E (UCTE[3])	2013 [1]	816	420	2.553	400 (750[7])
ENTSO-E (NORDEL[4])		87,4	66,1	350	400
ENTSO-E (UKTSOA[5])		84,2	66,7	366	400
IPS	2007 [2]	337	215	1.285	750 (1.150[8])
United States (Western)	2012 [3]	326	151	885	500
United States (Eastern)	2011 [4]	743	578[6]	1.069	765
United States (ERCOT)	2010 [5]	108	65	358	345
China	2010 [6]	966	673	4.200	1.000

Footnotes

1 ATSOI: Synchronous grid of the island of Ireland, asynchronously connected to UKTSOA.
2 BALTSO: Synchronous grid of the Baltic countries, synchronously connected to IPS.
3 UCTE emerged as organization of Continental European transmission operators after the liberalization of the electrical supply in Europe and dissolution of UCPTE, becoming part of ENTSO-E in 2009.
4 NORDEL: Synchronous grid of Scandinavia, asynchronously connected to BALTSO und UCTE.
5 UKTSOA: Synchronous grid of Great Britain (mainland of England, Wales and Scotland), asynchronously connected to ATSOI und UCTE.
6 Sum of the peak loads of participating countries (ENTSO-E) or regional systems (Eastern Interconnection)
7 471 km 750-kV-Link as connection to IPS.
8 Ekibastus–Kokshetau line in Kazakhstan.

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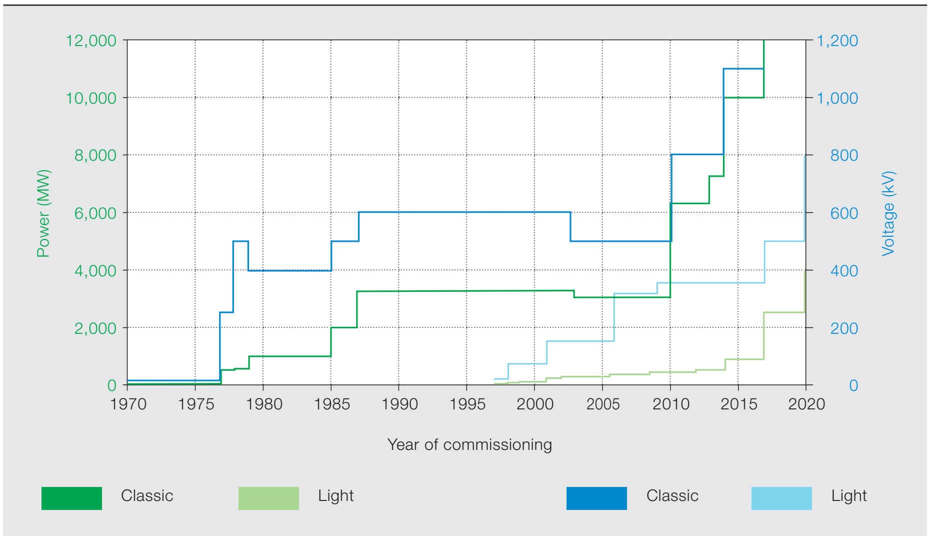
6 The Gotland control room in the 1950s

Liberalization led to a separation of the electric power business and the operation of the network infrastructure.

7 Development of HVDC parameter



During the subsequent decades, HVDC transmission established itself as the technology of choice for transmitting high power over long distances. The construction of increasingly large hydroelectric power plants has remained the main driver of HVDC development → 7 – for example, Cahora Bassa in southern Africa, Itaipu in South America, and since the 1990s, several large projects throughout China. The current peak values are (in different systems) 6,400 MW, 2500 km and 1100 kV DC.

Liberalization of the electric energy supply

Towards the end of the 20th century, many countries began to question the requirement for a full vertical integration of the electricity industry. The discussion first arose in the United States, the United Kingdom and Scandinavia, culminating in the liberalization of the electric energy supply in those countries. Later Australia and the European Union followed suite. In countries in which the power supply had been state-owned, this step also led to its privatization. Despite these parallel developments, the actual motivations for the change were not uniform. Reasons included the wish to attract private investment into the energy supply, the desire to improve the quality of supply and the objective of reducing energy prices through competition.

Liberalization required a separation of the electric power business and the operation of the network infrastructure. Although the networks were still treated as natural monopolies and therefore regulated by the state, the generation of electrical energy became a competitive market. However, different countries opted for different manifestations of this liberalization. In Europe, end customers can participate in the competitive market directly by choosing between different suppliers. In North America, in contrast, territorial monopolies remain on a distribution level, with competition being limited to the wholesale level.

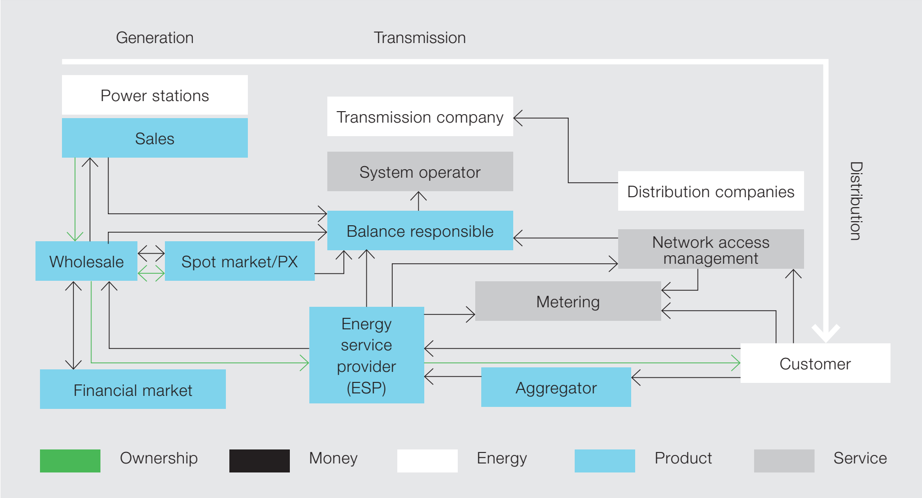
Liberalization also introduced new market roles, not only in the area of commercial optimization and interaction with customers but also in ensuring a continued stable operation of the system. These roles are shown in → 8 along with the basic technical functions retained from the previous setup. Liberalization effectively ended integrated planning of power stations and networks, both in terms of development and operation. Real competition between the power plants of different locations requires a greater transmission capacity than is required for an integrally planned system. However, it calls for operational coordination between market players and standards for cooperation.

Electricity supply 2.0

Since the beginning of the new millennium, many countries have moved towards strong support and promotion of new renewable energy sources, ie, mainly solar and wind → 9. While this rapid development has introduced technical challenges for grids, it has also contributed to a strong reduction in energy cost, especially in photovoltaics. The result is that in an increasing number of countries

Since the beginning of the new millennium, many countries have moved towards strong support for solar and wind energy.

8 Technical and commercial roles in an electricity market with full retail competition



9 The huge growth of wind and solar energy of recent years has created new challenges.

energy can be provided at a price below that paid by consumers on the low voltage network. Because photovoltaics displays an almost linear cost structure (without significant economies of scale in the investment costs) it is having a fundamental impact on the economics, and hence also the structure, of the electricity supply. The main characteristics of this impact, from a technical systemic perspective are:

- A greater geographic separation between generation and consumption is introduced to systems previously built mainly around fossil fuels or nuclear energy and which previously balanced consumption and generation on a regional level. This development is driven primarily by strong location-dependent primary energy sources such as wind and water.
- Distributed generation is increasing mainly because of photovoltaics and combined heat and power and will cause a significant share of generation to be covered by a very large number of small units.
- Volatile production from wind and solar energy is leading to faster and larger supply-side fluctuations of only limited predictability.

These three changes have technical implications in all aspects of the supply and use of electrical energy → 10. Two changes are particularly noteworthy: the growing importance of long-range and high-performance transmission networks and the integration of highly-distributed elements, both on the production side and on the consumption side (smart management of consumption).

10 Effects of the main drivers for change on different parts of the electrical energy supply chain

Driver	System affected				
	Conventional generation	Transmission	Distribution	System operation	Application
Remote generation		– FACTS[1] – Trunk transmission – Overlay network, HVDC		– Stabilization with FACTS[1]	
Distributed generation			– Automation – Voltage regulation	– Communication – Control – Virtual power plants	
Volatile generation	– Partial load – Flexibility	– Trans-regional leveling – Overlay grid / HVDC – Bulk storage	– Distributed storage	– Demand response – Virtual power plants – PMU/WAMS[2]	– Storage (in applications) – Demand response
New loads (E-mobility)			– Charging infrastructure	– Demand response	

Footnotes

1 FACTS: Flexible AC Transmission Systems

2 PMU/WAMS: Phasor Measurement Units / Wide Area Monitoring Systems

With the large-scale installation of renewable generation, the ability to effect long-distance compensation of different primary energy sources is increasingly advantageous, for example in the form of connections from North Africa and the Middle East to Europe [1]. Such a very-long-distance transmission network is expected to be installed as an additional layer over the existing high-voltage grids as a so-called overlay network. With the introduction of its DC circuit breaker in 2012, ABB removed the last major technical hurdle to achieving this with HVDC technology [2].

More and more devices are found in systems that either require DC or are neutral with respect to frequency.

Of all the changes ahead, distributed generation will probably have the most far-reaching effects. With a large portion of the generating capacity being connected at the distribution level, this new phenomenon must be integrated into the system management. Furthermore, in the case of solar energy, the pronounced infeed peaks call for congestion management on the distribution level. To achieve active coordination, up to three orders of magnitude of additional components will be needed than was the case in past systems. Information and communication technology will play a crucial role. Efficient information gathering and its consistent use for planning, operation and maintenance will be crucial for the economic operation of decentralized networks.

There is another change afoot, not caused by renewable energy, but by technical developments: Although in the early days of electrification, three-phase AC was predominant both on the production and on the application side, now more and more devices are found in systems that either require DC or are neutral with respect to frequency. Examples on the consumption side are electronic devices, LEDs, batteries and inverter-driven motors, and on the production side, solar cells. There is therefore a growing economic case for DC distribution. ABB recognized this and has, for example, developed offerings for data centers [3] and ships [4]. The three-phase AC world is becoming increasingly hybrid not only on the transmission level, but also in distribution.

These developments are bringing about changes in the fundamental principles of electrical energy supply and challenges principles that have stood unchanged since the very early days of AC. It is therefore no exaggeration to speak of the transition into a new phase: Electricity 2.0.

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Microgrids

The mainstreaming of microgrids using ABB technologies

CELINE MAHIEUX, ALEXANDRE OUDALOV – For years local power generation has been the standard form of delivering power to islands, remote communities or industrial sites. However, several factors, including power supply reliability, environmental concerns and economic constraints, are forcing energy service providers and end customers to take another look at self-powered, grid-independent alternatives, such as microgrids. Microgrids can now incorporate renewable power, reduce costs and enhance reliability. Today they can also be used as black start power or to bolster the grid during periods of heavy demand. As a result, microgrids are increasingly being adopted. Significant cost reductions of renewable distributed generation such as solar photovoltaics (PV) and wind, along with the development of efficient energy storage technologies and the availability of affordable wide-area communication infrastructure, have helped make microgrids more feasible. ABB continues to develop technologies that are redefining the electricity supply chain.

A microgrid may be made up of many different generation and storage mixes and grid connectivity formats.

A microgrid is considered an integrated energy system consisting of distributed generation, storage and multiple electrical loads operating as a single, autonomous grid either in parallel with or "islanded" from the existing utility power grid. By this definition a microgrid may be made up of many different generation and storage mixes and grid connectivity formats, as well as cover a vast range of sizes. Therefore, microgrids can look very different. A typical microgrid may have a structure and components as shown in → 1. This definition allows for several classes of microgrids that are defined by the type of customer served, the motivations for building and the region of the world in which they are operating → 2.

Title picture
Microgrids are mainly targeted for remote areas and islands, often integrating renewable energy sources.

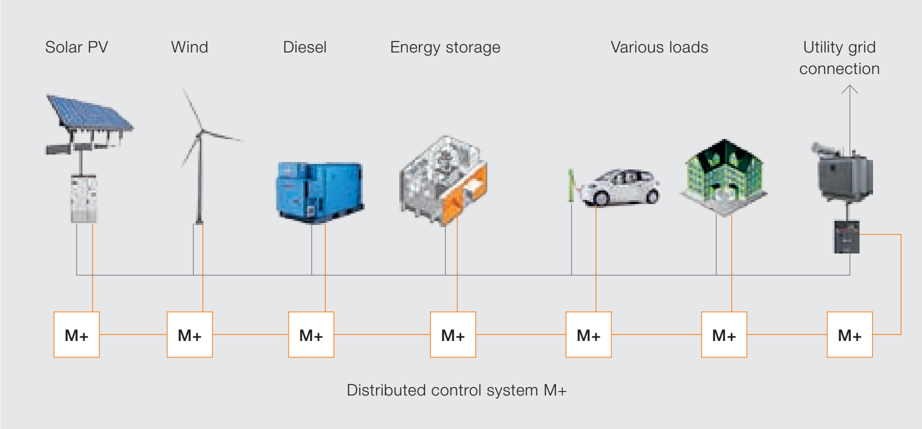
In many respects, microgrids are smaller versions of a traditional power grid. However, microgrids differ from traditional electrical grids by providing a closer proximity between power generation and power use, resulting in increased power supply reliability. Microgrids also integrate renewable energy sources such as solar, wind power, small hydro, geothermal, waste-to-energy, and combined heat and power (CHP) systems.

Microgrids differ from traditional electrical grids by providing a closer proximity between power generation and power use.

A microgrid control system performs dynamic control over energy sources, enabling autonomous and automatic self-healing operations. During normal or peak usage, or during a primary power grid failure, a microgrid can operate independently of the grid and isolate its local generation and loads without affecting the grid's integrity. Microgrids interoperate with existing power systems and information systems and have the ability to feed power back to the grid to support its stable operation.

A microgrid control system performs dynamic control over energy sources, enabling autonomous and automatic self-healing operations.

1 Typical microgrid structure and components



Successful installations

ABB's modular and scalable microgrid integration platform is a result of state-of-the-art technology development and practical experience obtained during more than two decades of designing and building microgrids worldwide. The ABB microgrid solution includes two key elements. Firstly, ABB's network control system solution, Microgrid Plus, which uses distributed agents controlling individual loads, network switches, generators or storage devices to provide intelligent power management and efficient microgrid operation. This solution is teamed with ABB's PowerStore™, which is a flywheel- or battery-based grid stabilization technology that enables high penetration of renewable power generation by providing synthetic inertia and grid-forming capabilities.

Combining these technologies allows 100 percent peak penetration of renewables in wind-diesel and solar-diesel power systems, maximizes fuel savings and enables the microgrid to automatically connect to or disconnect from the utility grid without interrupting critical loads.

A few notable examples of successful installations of ABB's microgrid technology illustrates its solutions and its value to customers.

Microgrids have the ability to feed power back to the grid to support its stable operation.

Marble Bar

The world's first high-penetration, solar photovoltaic diesel power stations were commissioned in 2010 in Nullagine and Marble Bar, in Western Australia. The projects include more than 2,000 solar modules and a solar tracking system that follows the path of the sun throughout the day ➔ 3.

PowerStore grid-stabilizing technology and the Microgrid Plus power management solution ensure that the maximum solar energy goes into the network by lowering diesel generation down to the minimum acceptable level or switching it off completely. When the sun is obscured, PowerStore covers the loss of solar power generation as the Microgrid Plus system ramps up the diesel generation ensuring the network has an uninterrupted energy supply. The solar energy systems generate over 1 GWh of renewable energy per year, supplying 60 percent of the average daytime energy for both towns, saving 405,000 L of fuel and 1,100 t of greenhouse gas emissions each year.

Faial Island

In 2013 ABB commissioned a microgrid control solution that enabled the island of Faial in the Atlantic Ocean to add more wind energy to its power mix without destabilizing the network. Faial is one of nine volcanic islands in the Azores, about 1,500 km from the mainland. The island of 15,000 inhabitants has an electricity network that operates as a self-con-

2 Key microgrid drivers per class and region

	Europe	North America	Latin America	Asia Pacific	Africa
Commercial and industrial	Cost, Reliable & secure power supply	Cost, Reliable & secure power supply		Reliable & secure power supply	
Government institutions and campuses	Environment	Cost, Reliable & secure power supply		Reliable & secure power supply	
Community	Environment, Cost	Cost, Reliable & secure power supply		Cost, Reliable & secure power supply	
Remote villages	Cost	Cost	Cost	Electrification, Cost	Electrification, Cost
Islands	Environment, Cost	Environment, Cost	Cost	Cost	
Remote mines and constructions	Cost, Reliable & secure power supply	Cost, Reliable & secure power supply	Cost, Reliable & secure power supply	Cost, Reliable & secure power supply	Cost, Reliable & secure power supply
Military		Cost, Reliable & secure power supply			

Electrification · Environment · Cost · Reliable & secure power supply

The microgrid market is rapidly developing, with commissions occurring around the world in a variety of application segments.

tained microgrid, powered by six oil-fired generators producing up to 17 MW of electric power. The local power utility, Electricidade dos Açores (EDA) has installed five wind turbines as part of its effort to boost capacity by more than 25 percent and minimize environmental impact on the island, where tourism is an important industry → 4. The Microgrid Plus control system calculates the most economical configuration, ensures a balance between supply and demand, maximizes the integration of wind energy and optimizes the generators so that the entire system performs at peak potential. The integration of wind energy combined with ABB's innovative solution saves an estimated 3.5 million L of fuel per year and has the potential to reduce annual carbon dioxide emissions by around 9,400 t.

SP AusNet

A microgrid with a battery energy storage capacity of 1 MH / 1 MWh as well as 1 MW diesel generator power is a pilot project for SP AusNet's electricity distribution network in Victoria, Australia → 5. The battery system and smart inverter are the primary energy source, while the diesel generator acts as backup to extend the capacity available. Scheduled to be completed by the end of 2014, the system will comply with the distribution grid codes when grid connected, transition into island mode when the network controller gives the command, and switch back to grid-connected operation without any power supply interruption. ABB's scope of supply includes the design, engineering, construction, testing and supply of the ABB PowerStore-Battery System and a 3 MVA transformer to be integrated with the diesel generator. The plant is managed by ABB's Microgrid Plus control system and implemented as a transportable power station consisting of seven outdoor containers and kiosks.

Looking forward

The microgrid market is rapidly developing, with commissions occurring around the world in a variety of application segments. Microgrids are shifting their focus from technology demonstration pilot projects to commercial projects driven by solid business cases. A recent Navigant Research report has identified over 400 microgrid projects in operation or under development globally.[1] The same study forecasts that the global annual microgrid capacity will increase from 685 MW in 2013 to more than 4,000 MW by 2020. North America will continue leading the microgrid market and the Asia Pacific region will likely emerge as another growth area by 2020 due to the huge need to power the growing populations not served by a traditional grid infrastructure.

Footnote

1 "Microgrids Global Market Analysis and Forecasts Report," Navigant Research, Boulder, CO, Dec. 2013.

Energy storage plays an important role in microgrid stabilization and in renewable energy time shifts that bridge peaks of power generation and consumption.

3 Marble Bar microgrid in Australia

4 Wind-diesel microgrid on the island of Faial, in the Azores

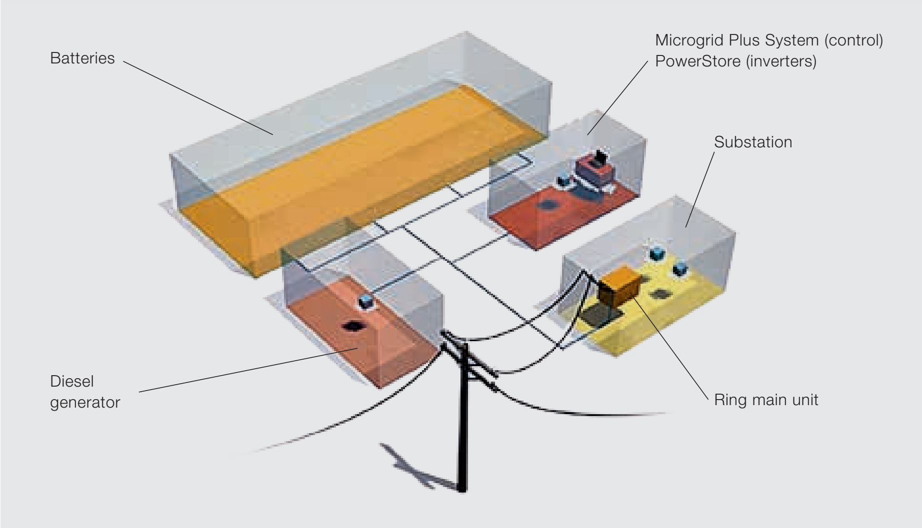
As the microgrid market continues to evolve, ABB is developing new technologies to address the challenges still being faced. Though surmountable, the challenges are varied and complex.

Energy storage

Energy storage plays an important role in microgrid stabilization and in renewable-energy time shifts that bridge peaks of power generation and consumption. Yet the two functions require very different technologies for energy storage.

The microgrid stabilization apparatus must provide a very fast response while possibly being called several times per minute. This results in high power output but very small stored energy. However, with renewable-energy time shifts the system should be capable of storing energy for a few hours to bridge the peaks of energy production and consumption. In order to meet these different requirements a hybrid system design with a combination of underlying storage technologies with different performance characteristics (cycle life and response time) may be the better choice → 6. A hybrid energy storage system will combine the benefits of each storage media and will have a lower total cost compared with the individual units. ABB is analyzing the advantages and disadvantages of such a system and developing control solutions for the technology.

5 Schematic diagram of SP AusNet microgrid, Victoria, Australia



6 Hierarchy of hybrid energy storage and its analogy with computer memory functions

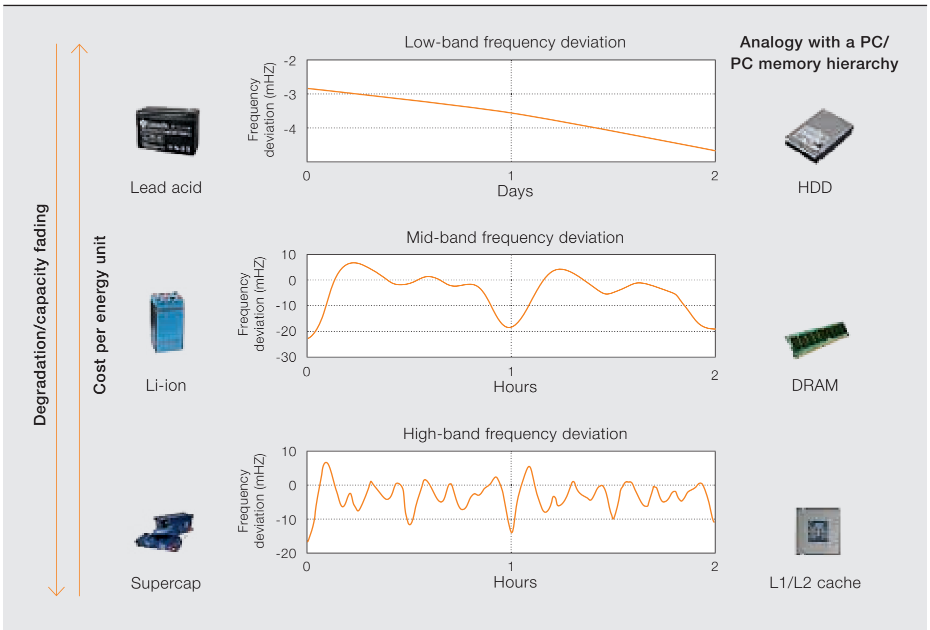


ABB is analyzing the advantages and disadvantages of a hybrid energy storage system and developing control solutions for the technology.

Protection system

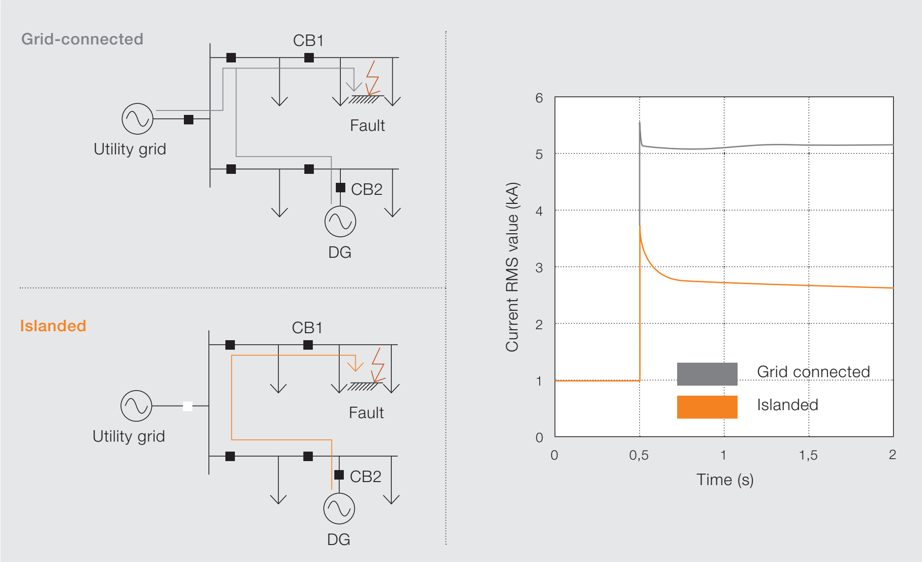
A protection system must respond to utility-grid and microgrid faults. With a utility-grid, fault protection should immediately isolate the microgrid in order to protect the microgrid loads. For the fault inside the microgrid, protection should isolate the smallest possible section of the feeder.

Problems related to selectivity (false, unnecessary tripping) and sensitivity (undetected faults or delayed tripping) of a protection system may arise because the level of short-circuit current in the islanded operating mode of a microgrid can drop substantially after a disconnection from a utility grid → 7. ABB is researching different approaches on how to deal with this problem – either with grid automation devices or by using a dedicated fault source.

When a microgrid is protected by IEDs (intelligent electronic devices) that support multiple setting groups, the settings can be switched in real time according to the actual state of the microgrid based on the preset logic. Frequently microgrids can be protected by fuses, which have been dimensioned based on fault current levels supplied by the main grid. In this case at least one local energy resource must deliver a fault current high enough to ensure sensitivity and selectivity of protections. Such a fault current source will detect a short circuit based on a local or remote voltage measurement

An accurate forecast of available renewable energy and loads (both electric and thermal) will play an important role in the economic dispatch of a microgrid.

7 Fault current level variation in grid-connected and islanded modes



and rapidly release a large amount of energy generating the required level of current to blow a fuse.

Energy management

Thermal loads usually represent a considerable part of total energy use by end consumers. There is a large potential for cost savings particularly with regard to combined heat and power (CHP) systems, which allow consumers to realize greater efficiencies by capturing waste heat from power generators. It is also much easier and cheaper to store thermal energy compared with electric energy. Therefore, coordination between thermal energy storage and other thermal sources, and between thermal and electrical systems must be considered for cost-effective microgrid energy management. ABB is working to develop an energy management system with this functionality. An accurate forecast of available renewable energy and loads (both electric and thermal) will play an important role in the economic dispatch of a microgrid.

Tools for modeling

How a system is modeled is of great importance during all phases of development – from the conceptual design and feasibility study through construction and testing of the microgrid project. For example, when an existing diesel-based backup power supply is extended with a large amount of fluctuating renewable energy resources, stable operation of the microgrid cannot be guaranteed. In order to optimally dimension a grid-stabilizing device such as PowerStore and to tune its control parameters, the dynamic behavior of legacy diesel gensets has to be known. Usually an accurate dynamic generator's response is evaluated during field trials followed by a process of tuning the parameters of all controllers causing delays during the commissioning phase. But this situation will be avoided once a microgrid controller is developed that can learn about a response of a controlled unit (eg, an old genset) and share this information with other controllers for automatic tuning of their parameters.

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Further reading
ABB Renewable Microgrid Controller MGC600, http://new.abb.com/power-generation/microgrids-solutions

Resource management

An end-to-end architecture for energy storage in the grid

STEPHEN CLIFFORD – Many discussions about renewable energy ultimately lead to a debate about energy storage. The broad range of energy storage options available is testament to the fact that there is no one-size-fits-all technology – each has its particular advantages and disadvantages. Selecting the right technology for an application requires a deep understanding of the functional demands to be placed on the storage system and, in turn, the demands that the storage system will place on the grid. Taking any of these energy storage media and building an efficient, reliable and durable grid energy storage system demands a range of technologies and competences, from power electronic conversion, through system-level and grid-level control, to forecasting and optimization. Ultimately achieving the desired functionality of energy storage in the grid necessitates an end-to-end architecture for the integration of all these elements with each other and with the grid.

Energy storage has been a feature of electricity generation, transmission and distribution for well over a century. The introduction of the rechargeable lead acid battery in the early 1880s was later followed by pumped-hydro storage facilities, in which water was pumped uphill in times of low load so it could be released to drive turbines in times of high load. However, a lot of storage reserve nowadays is provided by running power stations below capacity, to be quickly ramped up on demand – so-called spinning reserve.

Today, a move to “fuel-free” power generation, in the form of wind and solar power, means that the way in which energy storage is provided needs to adapt.

Today, a move to “fuel-free” power generation, in the form of wind and solar power, means that the way energy storage is provided needs to adapt accordingly [1,2]. Focus must be placed on the energy storage options that are already available, such as battery and pumped-hydro storage. This is indeed happening, with, for example, a renaissance in pumped hydro [3,4]. Equally, modern batteries can store more energy, deliver more power, last longer and need little or no maintenance. Thanks to developments in power conversion with power electronics, these batteries can be seamlessly integrated into both AC and DC grids [5].

Key technologies

For successful energy storage, several other technologies are needed in addition to the storage technology itself. These can be considered as three distinct layers: power technology, control and “smartness.”

The power technology layer must ensure the safe, stable electrical connection of the energy storage media to the grid, encompassing the storage media, power electronic conversion and the AC grid connection or substation. Next, all elements of the energy storage system and the substation must be controlled locally to ensure safe, precise operation and the ability to execute commands from the grid-level control. With the power technology and control layers in place, the “smartness” layer is needed to determine and schedule the optimum state for each asset in the grid. Binding these three layers together is the end-to-end architecture needed to achieve true energy storage in the grid ➔ 1.

Storage media

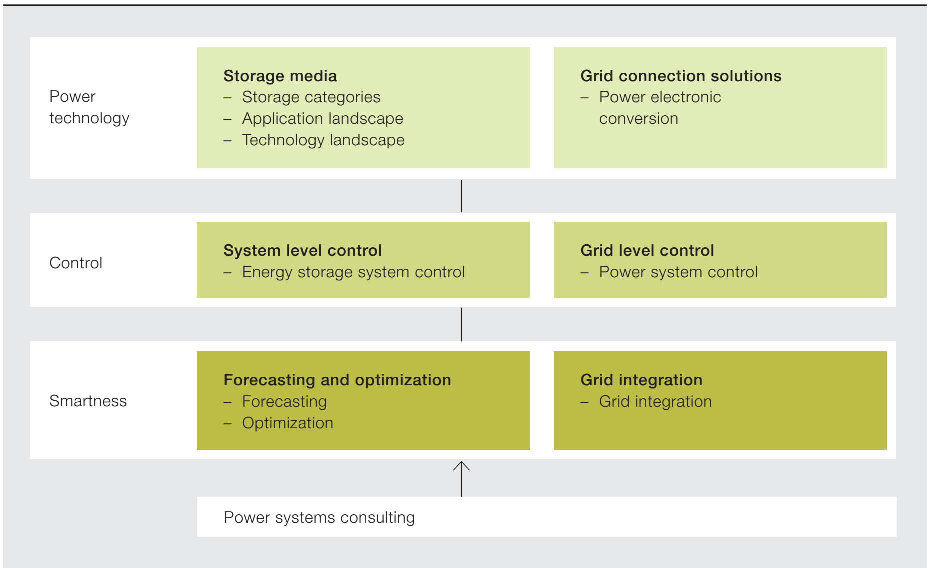
The basic function of energy storage in the grid is to allow energy generated at one time to be used at another. The duration for which the energy storage system may need to continuously charge or discharge is perhaps the main difference between the various energy storage applications and has a strong influence on the choice of storage media ➔ 2.

Power electronic conversion

Many energy storage technologies work with DC natively – for example capacitors, supercapacitors and batteries. To connect these to an AC grid, power electronics are needed for the conversion step. In addition, even those energy storage technologies that are natively AC – for example, pumped hydro and flywheels – rely on power

Title picture
Storing energy in a power grid is not just a matter of configuring some batteries or supercapacitors. A whole chain of interlocking technologies are needed to form a comprehensive and efficient energy storage system.

1 Key technologies that implement the end-to-end architecture of energy storage in the grid



Energy storage has been a feature of electricity generation, transmission and distribution for well over a century.

electronics to optimally integrate them into an AC grid.

System-level control

Once electrically tied into the grid, an energy storage system must be effectively controlled. A range of control hardware and software is needed to suit all energy storage applications, ranging from distributed control systems for applications such as microgrids, through dedicated power generation control systems for pumped-hydro storage plants.

Grid-level control

Once integrated locally into the grid and effectively controlled, the benefit of an energy storage system can only be felt grid-wide if it is managed in concert with all other generators, loads and other storage systems. The network management system needs to be capable of managing and optimizing assets that are energy-limited as well as power-limited. This optimization must be based on economic as well as technical criteria.

ABB offers all of the solutions to achieve this. The ABB Ventyx Network Manager™ is a versatile control center solution for managing the grid. The generation management system (GMS) within Network Manager – SCADA (supervisory control and data acquisition)/GMS – enables bulk storage facilities such as pumped hydro or larger battery energy storage facilities to be scheduled and dispatched directly along with all the other power stations in the grid.

Where there are many smaller storage systems and distributed energy resources – such as rooftop solar – distributed throughout the grid, the Ventyx demand response management system (DRMS) can be used to consolidate them into a virtual power plant. The generation management system can then schedule and dispatch this virtual power plant as it would a conventional plant.

Forecasting and optimization

Not only will loads need to be forecast, but as the proportion of intermittent, volatile generation increases, the ability to accurately forecast generation will become essential.

The Ventyx Nostradamus solution is able to take data from many different sources such as weather forecasts, historical renewable generation data and load data, and learn the relationships between them. Having learned these relationships it can then produce rolling forecasts of the state of the grid hours and days ahead.

Technology validation

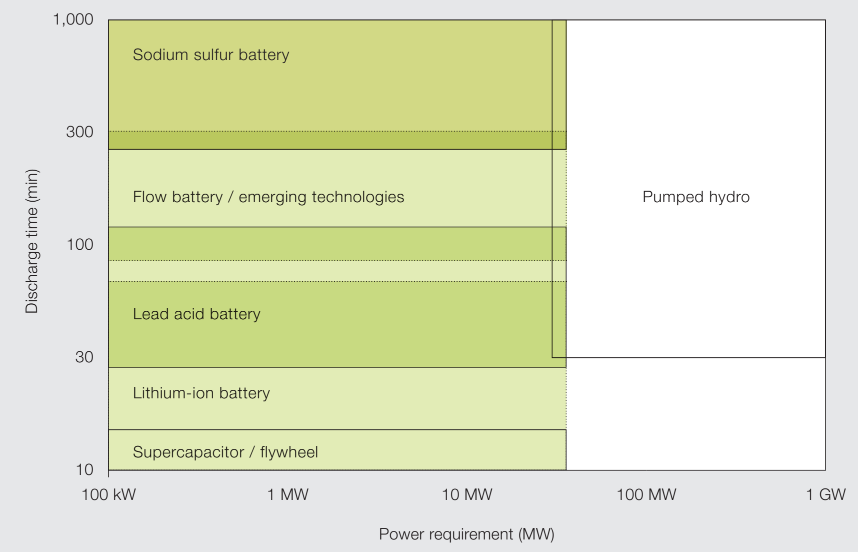
All of the enabling technologies for energy storage are mature and have been demonstrated and proven in real grid conditions. Indeed, most technologies such as power electronics and control technologies are also widely used elsewhere in the grid today.

Battery energy storage

In 2003, ABB applied battery storage technology to create a spinning reserve for an electric authority in Alaska, in the

For successful storage, several other technologies are needed in addition to the storage technology itself. These can be considered as three distinct layers: power technology, control and "smartness."

2 Energy storage technologies vs. most appropriate power and discharge time ratings



United States. A power converter system solution, using nickel cadmium batteries, supplies power at 27 MW for 15 minutes and 46 MW for 5 minutes, which allows ample time for local generation to come online.

In 2011, ABB partnered with a Swiss utility to commission the largest battery energy storage system of its kind in Switzerland. This 1 MW lithium-ion battery facility can absorb or discharge power for 15 minutes. It is integrated into the distribution network and is being used to evaluate performance in key areas such as balancing peak loads and intermittent power supply, and the viability of the solution for grid optimization.

Not only will loads need to be forecast, but as the proportion of intermittent, volatile generation increases, the ability to accurately forecast generation will become essential.

Pumped-hydro energy storage

ABB has been developing technologies and providing solutions for the hydroelectric power industry for more than 125 years. In that time, ABB has supplied power and automation equipment for more than 300 hydroelectric power plants all over the world, from small installations of 1 or 2 MW to 10 GW giants.

At a pumped-hydro storage plant in the Swiss Alps, for example, ABB is retrofitting a variable speed drive (VSD) system based on the full converter concept → 3. At 100 MW it is the largest VSD of its kind in the world.

Flywheel energy storage

ABB partnered with an Australian electricity generator, network operator and retailer, and others to build the world's first high-penetration solar diesel hybrid power station. ABB's (flywheel or battery based) PowerStore™ technology and automation system (M+) enable the power station to achieve consumer use penetration levels of 65 percent per annum and instantaneous penetration levels up to 100 percent.

Grid-level control, forecasting and optimization

The ABB Ventyx Network Manager control center solution has accumulated well over 400 references around the world over the last 25 years. The SCADA/GMS generation management system within

3 ABB has recently retrofitted a 100 MW converter to the Grimsel pumped-hydro plant in the Swiss Alps.

Understanding all of these pieces of the puzzle and how they fit together is key to defining an end-to-end architecture for energy storage in the grid.

Network Manager is therefore a well-proven solution, capable of managing pumped hydro energy storage alongside all other forms of power generation.

In Germany, ABB partnered with a university and an infrastructure and energy services provider in a project to demonstrate the ability of an energy management system to integrate renewables, energy storage, combined heat and power (CHP) systems, and electric vehicles into the grid. ABB's solution involved implementing the Ventyx DRMS to create the virtual power plant and ABB's MicroSCADA Pro to implement local monitoring and control each of the individual resources.

End-to-end architecture

The need for energy storage in the grid has always existed, but in the past has largely been provided by the storage of fuel for fossil-fuel power plants and by keeping a proportion of capacity of power plants in reserve. With a move to wind and solar power, the grid must adapt to store electrical energy after it has been generated.

Each energy storage technology has its own particular pros and cons that need to be fully understood and, once installed, each technology needs to be controllable for the full benefit to be exploited.

With the physical assets and the ability to control them in place, the ability to make the right decisions on how best to manage them becomes critical. This requires accurate forecasts of the state of the grid and of the storage systems themselves. To accomplish this, new levels of intelligence are called for.

Understanding all of these pieces of the puzzle and how they fit together is key to defining an end-to-end architecture for energy storage in the grid.

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Further reading

www.abb.com/smartgrids

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Plugged in

Analyzing the cost efficiency of emissions reduction with shore-to-ship power

PETR GURYEV – Maritime shipping accounts for approximately 4 to 5 percent of the world's total emissions, with emissions from ships at ports comprising about 7 percent of a ship's total emissions. In recent years, attention has turned to reducing port-side emissions. Of the technologies available for port-side emissions reduction, including LNG (liquefied natural gas), scrubbers and purified fuels, shore-to-ship power is the most effective solution available. Only shore-to-ship power allows complete emissions reduction at ports by connecting to electricity from the grid, which is often cheaper and much cleaner to produce. ABB has been supplying shore-to-ship solutions since 2000, when it delivered the first-ever high-voltage shore-to-ship connection to the port of Gothenburg, Sweden.

1 Typical segment requirements at port

Shipping segment	Average nominal power (kW)	Number of visits at the same port (p.a.)	Time at port per visit (h)	Investments*	
				Ship (thousand $)	Port (thousand $)
Cruise (250+m and regional voyages)	10,000	16	15	1,170	6,500
Cruise (250+m and global voyages)	10,000	2	15	1,170	6,500
Ro-ro/ro-pax/ferry	1,500	156	6	975	1,430
Container (2,500+ TEU feeder service)	1,200	52	9	1,040	1,430
Container (5,000+ TEU global service)	2,500	8	24	1,040	1,430
Tanker	1,200	20	24	780	1,430
Bulk	800	5	168	520	650
AHT/WSV (anchor handling tugs/well stimulation vessels)	80	80	24	78	195

*For the electrical infrastructure to connect one ship at a time

2 Cost efficiency of investments in shore-to-ship power projects in ECAs among different segments to reduce port SO_2 emissions

Since that first shore-to-ship connection, many more successful connections have followed. To spur further development of shore-to-ship power projects, some governments provide subsidies or regulative and fiscal incentives. Almost every project implemented worldwide has received a certain level of subsidy from either public authorities or supporting funds. In North America the development of shore-to-ship power projects fell to the cruise and container segments, enforced legislatively by the state of California in the United States and later financially supported by the US and Canadian governments. The direct trade route for container ships between East Asia and the west coast of the United States, where shore-to-ship power requirements are already in place, is driving new shore-to-ship power projects in Asia in the same segment. In Europe the majority of the projects is in the ro-ro/ro-pax/ferry[1] segment, which is driven more by business reasons than legislation.

Different types of ships have different needs at port, spend varying lengths of time there, and have different power requirements – ie, each ship type has a unique annual emissions profile. Furthermore the investment costs for the different segments vary for both ship and port infrastructures. Thus shore-to-ship power projects in the different shipping segments will have varying emissions reduction cost-efficiency. Because of this, an accurate method of measuring and analyzing the cost efficiency of emissions reduction is needed.

Typical parameters of the major maritime shipping segments are shown in → 1. Cruise and container segments are separated into two subsegments with different port visit profiles and, in the case of container ships, different power requirements.

The annual energy consumption by a ship in port can be calculated with the following formula:

Energy [kWh] = Power at port [kW] · number of port visits [times] · time at port [h]

Assuming that all ships have new generators and use similar fuel – MDO/MGO (marine diesel oil/marine gas oil) – the emissions reduction at port per annum can be calculated with the following formula:

Emissions [g] = Energy [kWh] · Fuel emissions [g/kWh]

Title picture
In 2012 ABB supplied Sweden's fifth largest port, the port of Ystad, with its turnkey shore-to-ship power solution for ro-ro/ro-pax/ferry vessels.

Footnote

1 Ro-ro (roll-on/roll-off) is the type of ship used to transport wheeled cargo, usually cars and large trucks. Ro-pax is a ro-ro ship with passenger-carrying capacity.

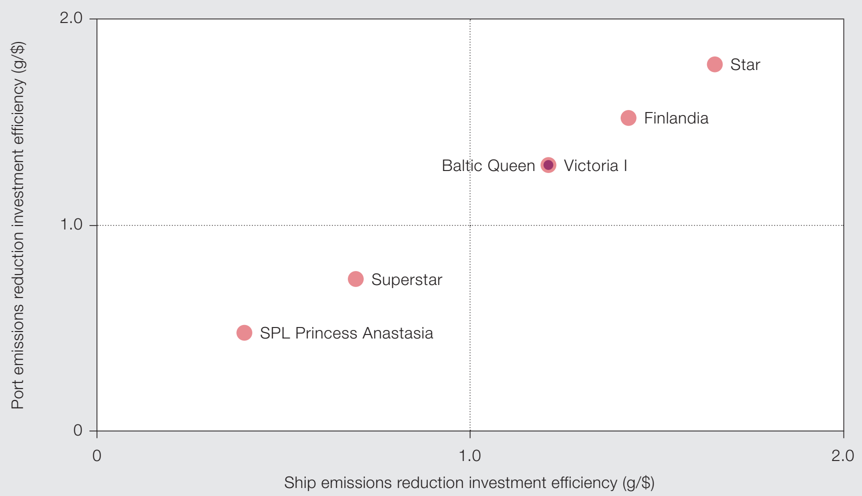
The emissions reduction cost-efficiency ratio shows how much port emissions can be reduced annually for each dollar spent on capital investment for shore-to-ship power installations on ships and at ports.

3 Ro-pax ships visiting the port of Tallinn in Estonia on a regular basis

Shipping line	Vessel	Estimated port visits (p.a.)	Average (weighted) time at port (h)	Investments	
				Ship side (thousand $)	Shoreside* (thousand $)
St. Peter Line**	SPL Princess Anastasia	50	7.5	780	650
Tallink Silja	Victoria I	180	8	975	910
Tallink Silja	Baltic Queen	180	8	975	910
Eckerö	Finlandia	600	3.75	975	910
Viking Line	Viking XPRS	734	5.6	975	910
Tallink Silja	Star	1,095	3	975	910
Tallink Silja	Superstar	1,095	1	975	910

* Investments are lower because ships do not need frequency conversion.
** Investment costs are considered for the LV shore connection.

4 Efficiency of investments in shore-to-ship power projects for regular ro-pax/ferry ships in Tallinn to reduce port SO_2 emissions*



* The Baltic Queen and Victoria I have the same level of investment efficiency to reduce emissions at port.

As SO_2 is considered one of the most harmful exhaust gases, it has been used by ABB for shore-to-ship power benchmarking. The maximum sulfur content of 0.1 percent has been set by legislation in Emission Control Areas (ECAs). The maximum emissions of SO_2 in ECAs is 0.41 g/kWh.[2] The efficiency of investments in shore-to-ship power projects among different segments to reduce SO_2 emissions at port are shown in ➔ 2.

Cost efficiency of shore-to-ship power is identified as the ratio of annual emissions at port to capital investments in electrical infrastructure onboard or at port. Assuming that ships' generators are the same age among segments and consume the same type of fuel at port (MDO/MGO), their fuel emissions also can be assumed to be the same. The emissions reduction cost-efficiency ratio shows how much port emissions can be reduced annually for each dollar spent on capital investment for shore-to-ship power installations on ships and at ports.

The cost efficiency to reduce emissions with shore-to-ship power for the ro-ro/ro-pax/ferry segment is one of the highest for ship and port investments. The emissions reduction directly depends on energy consumption. If for each kWh of shore power, the port or ship would be able to earn or save a fixed amount of money, the efficiency of investment ratio can be used as a benchmark for payback period among different segments. The shortest payback period for a shore-to-ship power project for port and ship infrastructure would be for the ro-ro/ro-pax/ferry segment. It should be noted that this framework is based on a typical profile of shipping segments, but there might be projects in which ships would have better or worse emissions reduction cost efficiency.

On March 26, 2014 the European Commission adopted the "implementing decision" to establish a Multi-Annual Work Programme for financial assistance in the field of the Connecting Europe Facility (CEF) transport sector for 2014–2020, supporting the development of the Trans-European Transport Network (TEN-T). There are 64 core ports identified by TEN-T guidelines;[3] these ports are eligi-

Footnotes

2 For purified fuel with a sulfur content of 0.1 percent, as identified by the ABB business case tool. For areas outside Emission Control Areas, the maximum content of sulfur in the fuel is 3.5 percent; the maximum emissions of SO_2 is 14.35 g/kWh.

3 As identified by: European Commission. (2013, September). *The Core Network Corridors*. [Online]. Available: http://www.tentdays2013.eu/Doc/b1_2013_brochure_lowres.pdf

5 The Port of Ystad in Sweden utilizes shore-to-ship power to keep emissions down.

Shore-to-ship power is a well-established solution for complete emissions reduction from ships at port.

ble for financial support for shoreside electricity projects set in line with Motorways of the Sea[4] priorities. Such shore-to-ship power projects could receive up to 20 percent[5] of the funding, according to the CEF regulation, provided adequate cost-benefit analysis is implemented. Based on the framework identified above an example of a cost-benefit analysis was done for regular ro-pax ships at the Estonian port of Tallinn ➔ 3.

The Port of Tallinn authority is considering installing shore-to-ship power and, assuming a limited budget, the investment should be allocated to the segment with the highest emissions reduction cost efficiency. The ferry routes between the Baltic states, Finland and Sweden are highly competitive; shipping lines often rotate vessels from one shipping route to another based on market demand and company performance. It is therefore hard to predict long-term schedules for particular ships and how long they will stay at a port on a regular basis. Analysis of the emissions reduction cost efficiency is based on intermittent schedule results, which were acquired in June 2014. The Tallink Europa is excluded from the analysis due to rear use of the ship; the Viking XPRS is also excluded because it is LNG-driven and the emissions footprint at port is already reduced. The investment costs are calculated for the turnkey electrical installation. The parameters of the ro-pax ships visiting the port of Tallinn on a regular basis are shown in ➔ 3.

Of the ships visiting the port of Tallinn only the Princess Anastasia has the power outlet capable of accepting shore power, and only in low voltage with a maximum capacity of 2,700 kW / 0.4 kV. The shore connection panel was installed onboard this ship for connection in Stockholm where electricity is much cheaper due to reduced excise duties (see "Clean air in the docks" in *ABB Review* 3/2014). The average nominal power requirements for the Princess Anastasia are assumed to be 2,000 kW. According to a survey performed by ABB the average nominal shore-power requirement for the Victoria I and the Baltic Queen also can be around 2,000 kW with a peak of 2,500 kW. Estimating that all other ships will require on average nominally 1,500 kW, the Tallink Star will demand 1,200 kW due to night stays at the port when the power requirements are much lower. The port of Tallinn is located in an ECA where SO_2 emissions from fuel are capped at 0.41 g/kWh. Assuming the ships using MDO/MGO emit this same amount, the efficiency of investment to reduce port emissions with shore-to-ship power can be determined ➔ 4.

The best environmental benefits

Financial support is a well proven means of stimulating development of environment-oriented and capital-intense projects. With the financial support available to develop TEN-T infrastructure for ports, it is important to allocate funds to the most cost-effective projects. Shore-to-ship power is a well-established solution for complete emissions reduction from ships at port ➔ 5. Although the efficiency of investments in shore-to-ship power infrastructure can significantly vary among ship types, as a general rule ro-ro/ro-pax/ferry ships have the highest cost efficiency and thus are recommended for prioritized implementation in TEN-T port infrastructure.

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For more information about ABB's shore-to-ship power offering, visit www.abb.com/ports or write to shore-to-ship@ch.abb.com

Footnotes

4 Motorways of the Sea is a TEN-T project that "aims to promote green, viable, attractive and efficient sea-based transport links." See www.mos-helpdesk.eu

5 According to the Commission Implementing Decision C (2014) 1921

Further reading
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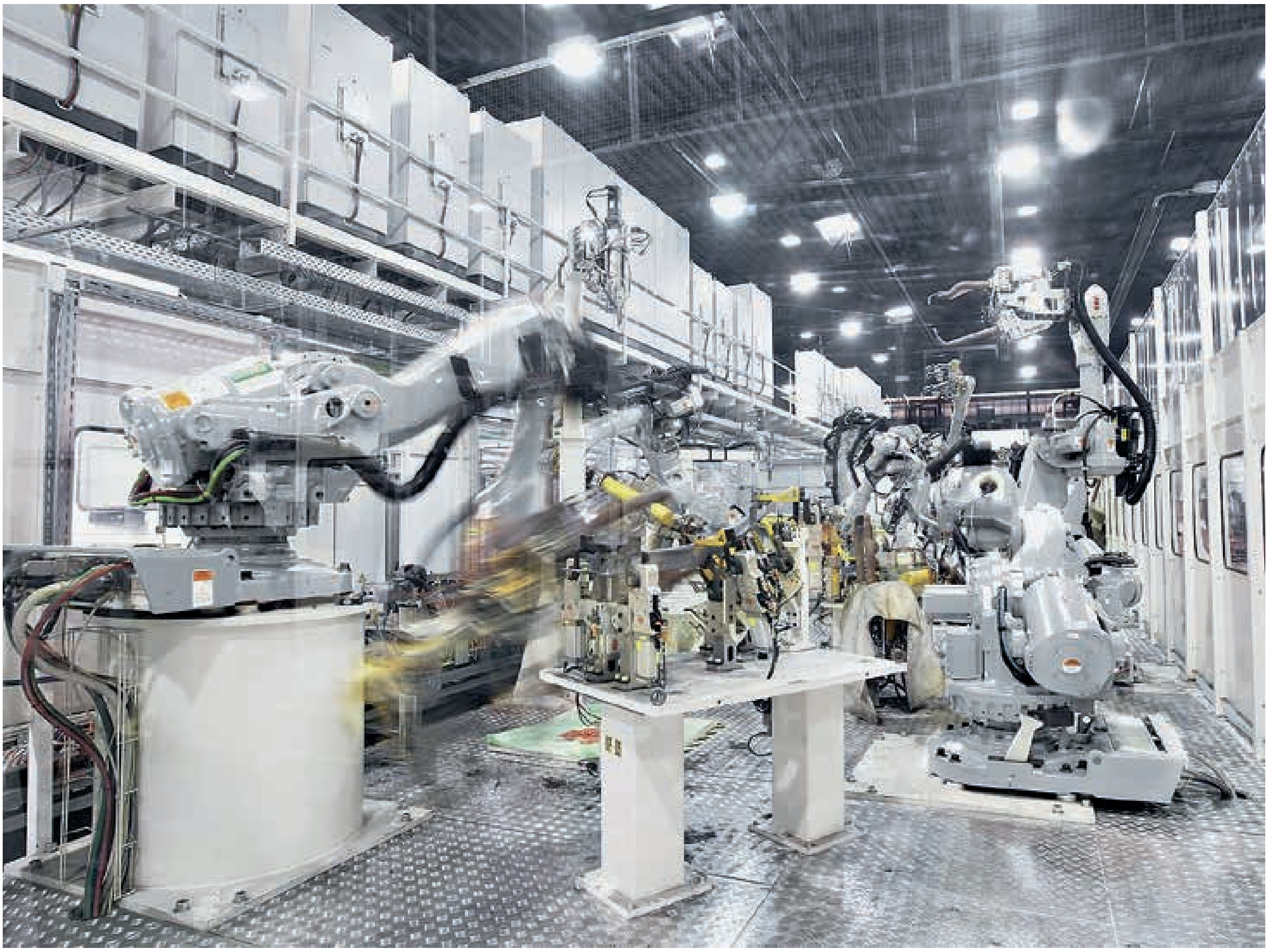
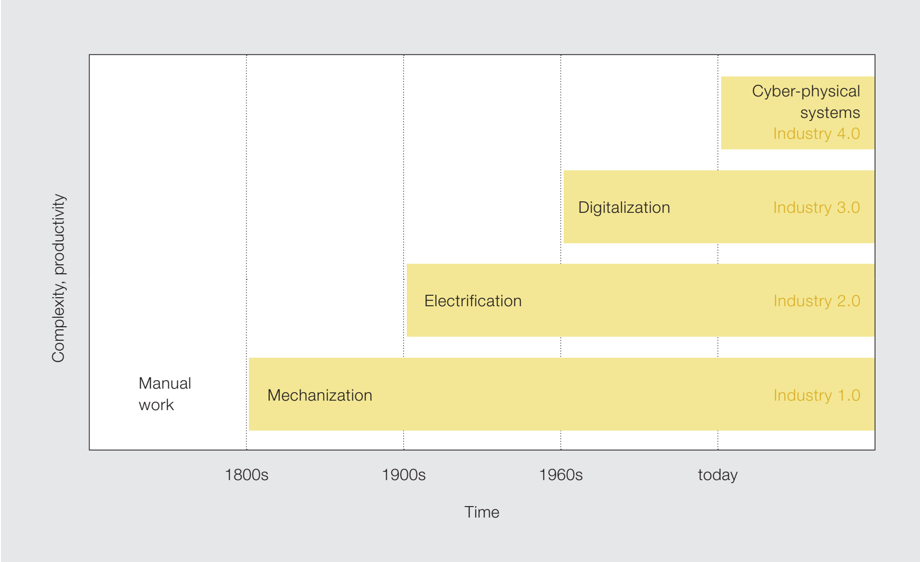


A new era

ABB is working with the leading industry initiatives to help usher in a new industrial revolution

MARTIN W. KRUEGER, RAINER DRATH, HEIKO KOZIOLEK, ZIED M. OUERTANI –
A new era of industrial innovation is upon us. Referred to as the fourth industrial revolution, the deeper meshing of the digital world with the world of machines holds the potential to bring about profound transformation to global industry. This new industrial stage, where the Internet meets production, is a major topic of discussion at production and process industry conferences and meetings. The Industry 4.0 initiative is one of several projects working to bring the fourth industrial revolution to fruition. ABB is collaborating with the Industry 4.0 initiative group and the respective working groups of related industrial associations[1] to investigate the impact of this new and highly anticipated industrial stage as well as the technical feasibility of bringing it to ABB's customers.

1 Industrial revolutions and respective enabling technologies



The world is on the threshold of another industrial revolution – this one a result of the convergence of the global industrial system with the power of advanced computing, analytics, low-cost sensing and new levels of connectivity permitted by the Internet.

The industrial revolution began when manual labor was replaced with mechanical power, starting late in the 18th century, with the invention of the mechanical loom.

This revolution continued to develop in stages over the next 150 years, with further mechanizations and through the combination of steam and water power. The second stage dates to the emergence of electrification and automation. At every stage productivity accelerated sharply beyond what had preceded.

Title picture
Robotics is just one area in which ABB is moving toward the fourth industrial revolution.

Footnotes
1 The working groups include associations such as VDMA, ZVEI, and BITKOM.
2 The automation pyramid groups the devices and systems of a production environment into levels.

The third, and most recent, industrial revolution stage began in 1969 with the first digital and freely programmable control systems, which replaced the traditional hardwiring of analog logic and control programs. This stage built the foundation of today's automation pyramid[2] and modern process control systems and has continued right up to the present day. An overview of these industrial revolutions is presented in → 1.

The next industrial stage

The arrival of the Internet in the consumer world in the 1990s brought unprecedented change to daily life: social networks, online TV and almost instant access to huge amounts of information.

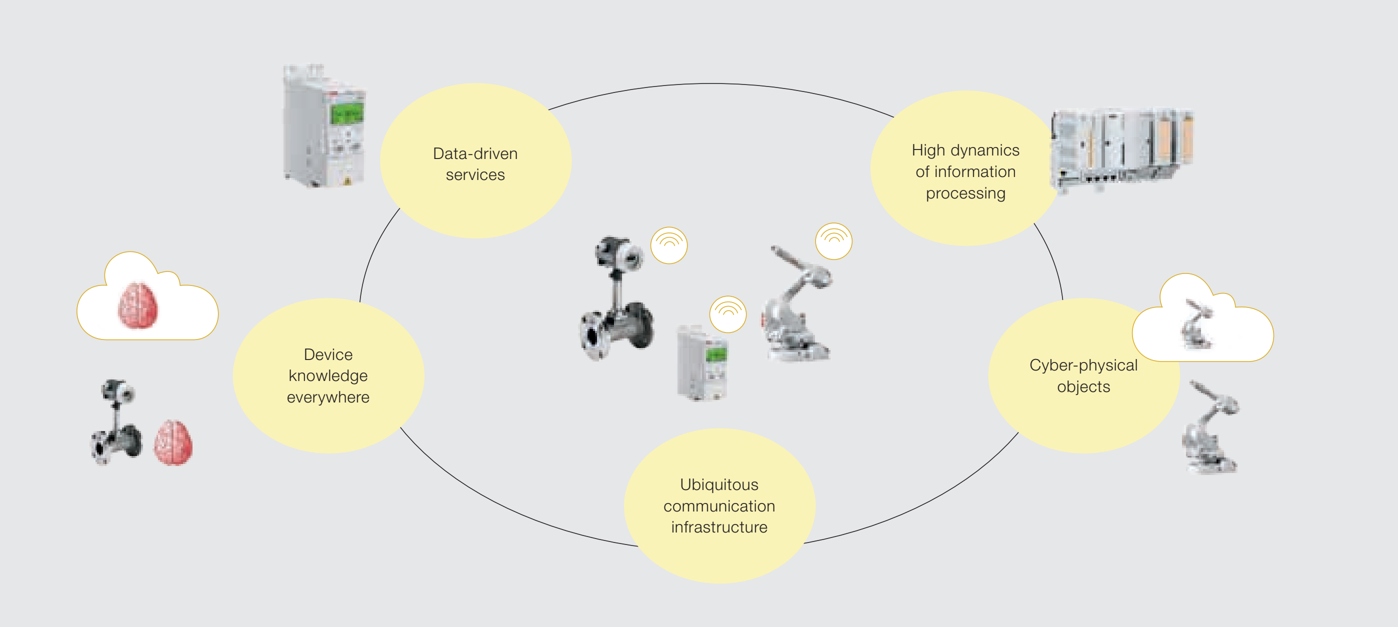
A similar revolution is now expected in industry, as government and industrial consortiums around the world see a trend of increased utilization of Internet technology in industrial production systems. Devices in the production environment are increasingly being (wirelessly) connected to each other and a network, eg, a private network or the Internet. Eventually industrial production systems will be capable of autonomously exchanging information, triggering actions and controlling each other more independently.

The working groups developing this new concept are widely diverse, so the description of the concept, and even its name, varies. For example, the name Industry (Industrie in German) 4.0 was conceived by the German-led working group, while in the United States a similar initiative is called Industrial Internet [1,2]. Both initiatives are based on technologies associated with the Internet of Things (the ubiquitous connection of all devices to the Internet, eg, watches, cars, fridges) and cyber-physical systems, a combination of physical objects and software systems. The initiatives mark efforts aiming to prepare global industry for what is expected to come. Besides actively participating in the related initiatives and committees, ABB's research and development projects are shaping the technical possibilities for the future.

The initiatives mark efforts aiming to prepare global industry for what is expected to come.

Technical drivers for Industry 4.0

A number of technical developments are driving the efforts of Industry 4.0 [3] → 2. Communication infrastructure will become ubiquitous throughout industrial production facilities as it becomes cheaper and readily available. This network availability



2 Technical drivers of Industry 4.0

Devices, machines, facilities and plants will be able to store knowledge about themselves beyond the physical representation.

builds the basis for tasks such as data acquisition, engineering, operation, maintenance and advanced services.

Once a network is in place, more devices, machines, facilities and plants will be connected, either on the Internet or on a private company network. All connected physical objects will be represented by data objects in the network. As a result, these data objects form a second virtual identity within the cyber world, the cyber-physical objects. These objects will be easy to locate, explore and analyze and will hold information about their functionality as well as their requirements.

Devices, machines, facilities and plants will be able to store knowledge about themselves beyond the physical representation and directly at the data object in the network. Each will publish updates on their current status, history, related documentation or technical requirements in the network. Such information can then easily be updated by the device's owner, service technician or parent system.

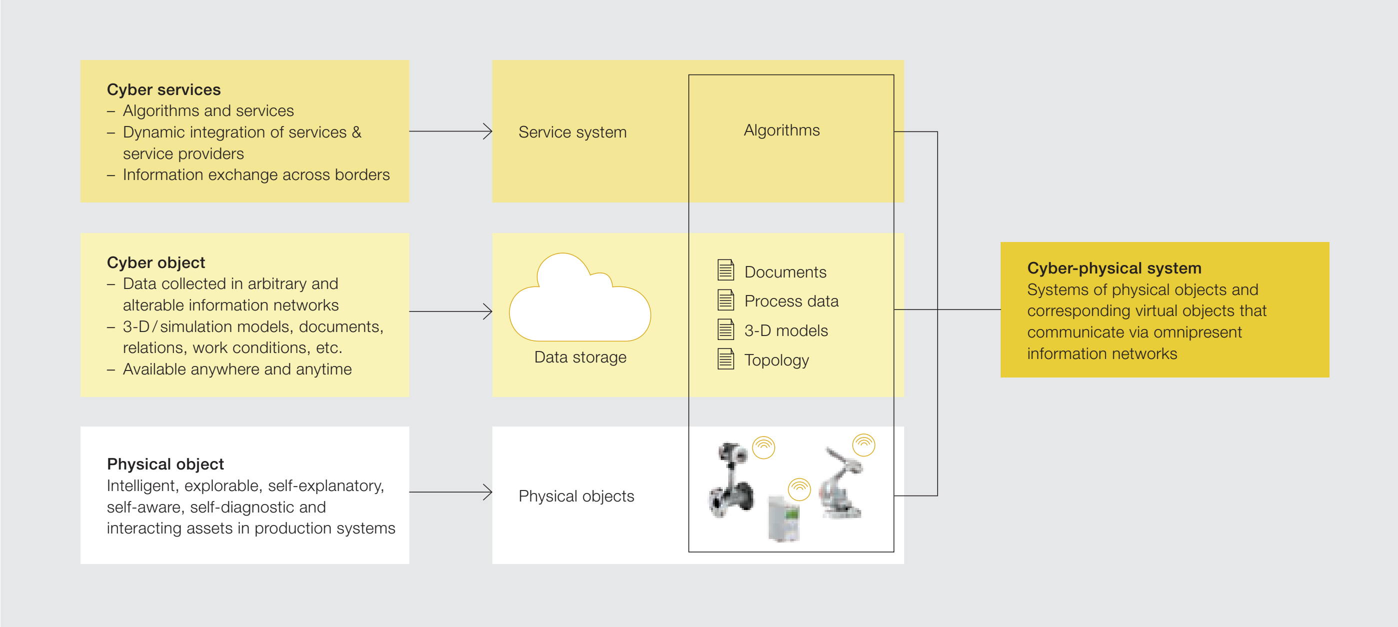
As part of a cyber-physical system, intelligent algorithms and embedded software will be able to explore these new data sets to generate value-added services that would not have been feasible or economical before → 3. This field is a topic of ongoing research [4], but from today's perspective, remote or data-driven services mark the first steps toward these new services.

The increasing level of integration of cyber-physical objects in an Internet-technology-enabled network will inevitably lead to higher levels of information processing. This will then open new doors for widely known concepts from the consumer market to enter the business-to-business market such as plug and play, eg, plugging a USB mouse into a computer with drivers being automatically downloaded from the Web and always kept up to date, or plug and produce, eg, exchanging an old device with an equivalent new one, which then functions automatically, without the need of manual engineering, commissioning or servicing.

All connected physical objects will be represented by data objects in the network.

Cyber-physical systems have been present in the business-to-consumer market for some time. One application of the concept is the purchasing of gas by consumers from German gas stations. Gas prices are submitted to a central data repository, where all gas stations are represented as data objects in the network.

3 Cyber-physical system



4 Industrial demands on the fourth industrial revolution

The value of isolated data objects alone is minimal. However, with the advances of mobile technologies and smartphone applications, millions of users can now make informed decisions for purchasing gas by consulting the current gas prices at their individual locations. In this example the architecture of the cyber-physical system breaks down in the following way: the physical object (gas station), the cyber part (the data object with prices) and the software layer (the smartphone apps).

Industrial demands

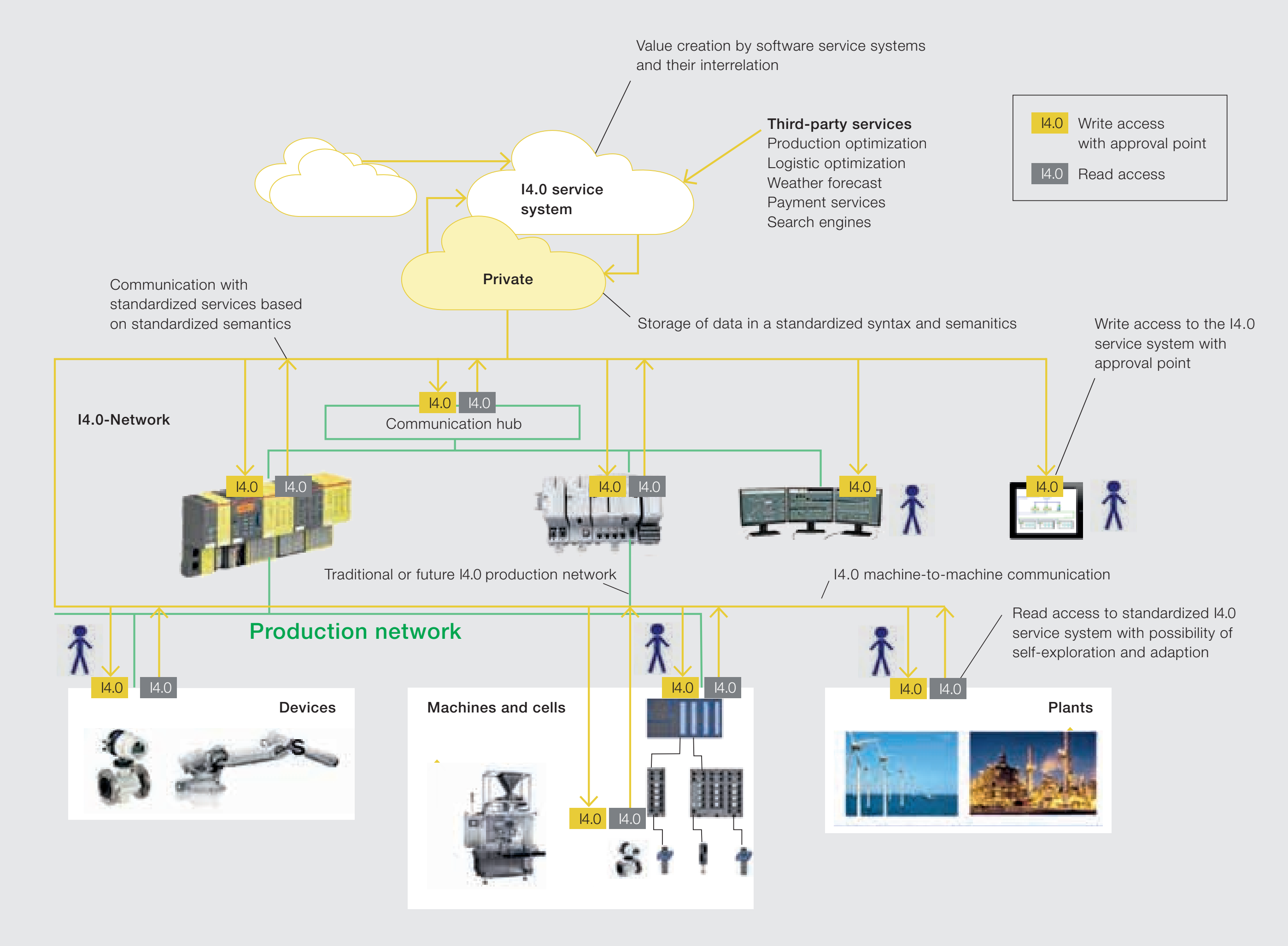
The introduction of communication and Internet technologies into industrial production has tremendous potential to increase productivity and flexibility, but it also raises concerns, in particular for plant owners, who combine investments, know-how, production capabilities and profit in their plants. Among the current visions of Industry 4.0, the value propositions still need to be identified. To create a sustainable acceptance of the next industrial revolution, some practical requirements need to be fulfilled → 4.

- In order to protect investments, new technology needs to be incrementally introduced into existing production facilities, making sure not to disrupt the existing machines and technology.
- To maintain stability Internet technologies must not disrupt production, neither through network outages nor through intended remote access to assets.
- The access to plant-specific data must be carefully controlled by the plant operator. Write access to production-relevant assets, machines and facilities needs an additional audit to cross-check the validity of the intervention in the context of the running production.
- As always, security is a vital aspect. Unauthorized access to data and services needs to be prevented to ensure information security and to control critical aspects of the production facilities.

Furthermore, production systems in general have stronger requirements on non-functional properties, such as availability, real-time capability, reliability, robust-

As part of a cyber-physical system, intelligent algorithms and embedded software will be able to explore these new data sets.

5 ABB's integration topology of Industry 4.0



Production systems in general have stronger requirements on nonfunctional properties.

ness, life cycle, productivity or cost compared with IT systems in other markets. ABB is taking these customer requirements into consideration in all of its Industry-4.0-related research and development projects.

Integration topology

To facilitate the further development of Industry 4.0 ABB has developed an integration topology that has been adopted by the German Industry 4.0 initiative [4]. The topology will allow an incremental introduction of new technology and production processes.

The core of the integration topology is the separation of the established production network from the new Industry 4.0 network → 5. From the technical aspect the separation can be implemented by either physically separated networks or logically separated networks within existing Ethernet-based networks. As shown in → 5, the green production network symbolizes an automation system that fulfills the industrial requirements on availability, reliability, sustainability and security. The yellow Industry 4.0 network enables new services and provides added value to the user. The production is not dependent on the Industry 4.0 network, therefore failures of the network will not interrupt production.

In the first step of an implementation of the topology, assets, devices, production lines and factories are connected to the Industry 4.0 network with read-only access (yellow markers). Authenticated participants can read, for example, device IDs, diagnostic data, parameters or production data. This data will form the foundation of future Industry 4.0 value-creation processes. In a second step, write access will be introduced with an approval instance to avoid unintended effects on the running production.

The topology will allow an incremental introduction of new technology and production processes.

The data of the yellow Industry 4.0 network is collected in a private, secure storage system. Access to this data is controlled by the data owner, eg, the plant operator. Publication of this data to the Industry 4.0 services system is controlled by interfaces and permission systems. Added value can be created either by services within the private data system, or through third-party services within the Industry 4.0 services system.

This integration topology addresses the industrial requirements of investment protection, system stability, controllability and data security issues. The German Industry 4.0 steering committee has published this topology under the Industry 4.0 umbrella [4].

What needs to come

Many components comprising the fourth industrial revolution are not new. Cloud technology, network devices, communication interfaces and data-driven services are well established in many markets. However, in order for the next stage to move forward, a number of agreements and principles need to be established, such as:

- Cross-vendor agreement of standardized syntax and semantics to identify, collect and store data
- Cross-vendor agreement of standardized services based on standardized interfaces, communication and semantics
- Introduction of principles such as, eg, self-exploration or plug and explore to facilitate cross-vendor value creation
- Availability of services to create added value from the cross-vendor availability of data
- Interlinking of services with other third-party services
- Availability of data throughout the value chain and supply chains in real-time
- Dynamic, partly autonomous adaptation of production services to changes in environmental parameters (eg, plug and produce of replacement devices or update of software during continued production)
- Reorganization of production processes to systematically exploit data and services

This new industrial revolution is a phenomenon that will flourish. The key to bringing added value to the customer lies in better understanding the requirements for standardization enabling the interaction of the Industry 4.0 technologies. It is also important to investigate application cases in different industrial ecosystems to confirm the potential of the trend [5]. New business opportunities will emerge for ABB customers, consolidating their competitive advantages in existing markets and also facilitating new market entries. ABB is developing business cases and investigating the technical feasibility of the next industrial revolution based on its product portfolio. Substantial participation in standardization work is being carried out, while aiming for a better understanding of what customers want and the challenges they are facing.

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Wheel appeal

A robot expert on wheels offers remote support

ELINA VARTIAINEN, VERONIKA DOMOVA – In nearly every branch of industry, expert human resources are becoming spread ever more thinly. The question then arises as to how to make the best use of the resources available. One innovative approach that is rapidly gaining popularity is the telepresence robot. Located on an industrial site, this robot provides a virtual expert presence by channeling content-rich two-way communication between a remote expert and local personnel. ABB has developed a concept for an industrial telepresence robot called "expert on wheels." This robot aims to make ABB experts more effective in solving maintenance and service tasks in collaboration with local field-workers at customer sites.

Low-cost computing, wireless connectivity and high-quality real-time video capabilities have facilitated a significant growth in telepresence robots. These robots provide a sense of a physical environment – through video and audio feeds – to a person who controls the robot remotely. This can enable an expert to be "present" in distant locations, whether it be a conference, meeting or factory, without actually travelling there. The robots generally make remote workers more available by allowing them to steer the robot, look around with a camera and have a conversation with their colleagues.

Telepresence robots have a particular potential to establish collaboration sessions in industrial settings – for example, in situations where a local worker in the field needs guidance from a remote expert. Here, the expert can get a better situational awareness by using the robot to look around. If the robot also enables the expert to make virtual annotations for the field-worker, he has a good means of guiding the field-worker through complex maintenance tasks.

Title picture
The ABB "expert on wheels" provides a remote expert with a local footprint.

1 The robot has a sturdy base mounted on rubber-covered wheels, which provide excellent traction. Vents prevent overheating.

The expert controls the robot remotely from a Windows-based desktop application in which he can steer the robot and see the camera picture.

ABB has looked into this opportunity and has designed a first concept of a telepresence robot for the industrial environment. The concept aims to enable remote ABB experts to be more effective in solving maintenance and service tasks together with field-workers located at customer sites.

Design considerations

In order to develop a concept prototype, researchers at ABB studied similar solutions in other markets and research communities to determine practices, experiences and commonly agreed requirements for telepresence robots [1, 2]. Among other things, the findings showed that video streaming can improve the situational awareness of the remote expert when the developed system:

- Provides a wide field of view
- Clarifies what the shared visual space is
- Provides mechanisms to allow people to track one another's focus of attention
- Provides support for gesturing within the shared visual space

The robot is a stand-alone device that can move around on its mobile wheeled platform, show the environment using a video camera and project annotations onto the equipment under investigation using a projector.

2 The robot's projector displays the remote expert's annotations on the appropriate object.

Another common concern was the excess water, dust, etc. encountered in some industrial settings. To combat this, the outer design of the robot should be monolithic, and water- and dirt-proof. Further, the limitations brought about by poor Internet connectivity at some industrial sites should be tackled by automatic algorithms that adjust video quality accordingly.

The prototype

The design challenges were addressed in a telepresence robot proof-of-concept. The robot, dubbed "expert on wheels," is a stand-alone device that can move around on its mobile wheeled platform, show the environment using a video camera and project annotations onto the equipment under investigation via a projector. The expert controls the robot remotely from a Windows-based desktop application in which he can steer the robot and see the camera picture. He can annotate the video display with the symbols and text to be projected.

The process of offering remote guidance is implemented in a wizard-style application, which makes its use straightforward. The wizard-style approach was selected because the collaboration session requires a set of steps that usually follow one another in a certain order:

1. Position the robot
2. Select the target object or area of interest on the video
3. Match the projecting area with the area selected in the previous step
4. Draw the annotations

3 The anti-scratch cover has dedicated holes for the projector, camera, speaker and microphone.

In order to augment the reality with the overlaid annotation from the expert, the robot uses a compact projector embedded in its body.

Once the local worker has positioned the robot and switched it on, the remote expert takes over. He can reposition the robot to obtain a different view, if necessary. The field-worker's hands remain free. The robot also includes a speaker and a microphone so that the remote expert and the field-worker can converse with each other.

Implementation

The robot's base is a mobile platform built on wheels, which can be steered in any direction, rotated and instantly stopped ➔ 1. The heart of the robot is a Windows-based minicomputer that contains a network card, memory and processor. The robot's software controls all the interfaces, enables connectivity, processes commands from the remote expert and streams 2-D high-quality video from the camera back to him. In order to augment the reality with the overlaid annotation from the expert, the robot uses a compact projector embedded in its body to "draw" on the equipment being inspected ➔ 2. The system uses a semi-automatic algorithm to synchronize the coordinate system of the camera with the coordinate system of the projector. Future releases will feature a synchronization that will be done automatically and implicitly for both users. To support the wireless functionality and mobility of the robot, it has a rechargeable battery with a two-hour runtime capacity.

The outer shell of the robot has been designed for industrial environments. It has a protective anti-scratch plastic

The outer shell is a protective anti-scratch plastic cover with dedicated holes for the projector, camera, speaker and microphone.

cover with dedicated holes for the projector, camera, speaker and microphone → 3. It also has special openings for ventilation to protect the robot from possible overheating. The mobile platform has a metallic body with a load capacity of 20 kg and rubber-covered wheels for good traction.

Special attention was paid to the startup time of the robot since every second of waiting could be costly. At the moment, the robot starts or restarts with a single press of a button and takes no more than a few seconds to be up and running and ready for a remote collaboration session.

First impressions

The prototype was evaluated in a power plant to get initial feedback on the concept and its applicability to industrial settings. The overall impression was that such a concept could indeed be offered by ABB as a service to its customers. They could use such a robot when they need assistance or troubleshooting guidance for ABB equipment or other service-related issues.

The feedback also indicated that such a concept could offer significant benefits for general maintenance or service tasks. For instance, the robot would offer the field-worker an extra pair of eyes and ears. Furthermore, it could be used alone to supervise certain areas that are disagreeable for humans and flag issues that need special attention. The robot could also be used to project cumbersome-to-carry manuals when a field-worker needs to look at documentation.

The concept has also sparked ideas for future development. For example, a mobile platform faces terrain-related challenges – such as a rough environment, doors and stairs – so one consideration might be to replace the wheeled solution with an easily transportable tripod. Also, the audio should be connected to a wireless headset to improve sound quality, as a speaker is difficult to hear in noisy environments. Furthermore, the camera should have night vision to see better in the dark and perhaps thermal vision to monitor equipment and notice overheating problems.

Tomorrow's robot

The "expert on wheels" concept demonstrates a high potential to improve remote collaboration in maintenance and service tasks in industrial settings. The evaluation confirmed that remote collaboration between field-workers and ABB remote experts could significantly benefit from such robots. On the other hand, the concept still has a set of open questions that concern, for example, the look and feel of the robot and exact functional features. These open issues will be addressed in the near future by ABB in further investigations.

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Publisher
ABB Review is published by ABB Group R&D and Technology.

ABB Technology Ltd.
ABB Review
Affolternstrasse 44
CH-8050 Zurich
Switzerland
abb.review@ch.abb.com

ABB Review is published four times a year in English, French, German and Spanish. *ABB Review* is free of charge to those with an interest in ABB's technology and objectives. For a subscription, please contact your nearest ABB representative or subscribe online at www.abb.com/abbreview

Printer
Vorarlberger Verlagsanstalt GmbH
AT-6850 Dornbirn/Austria

Layout
DAVILLA AG
Zurich/Switzerland

ISSN: 1013-3119

www.abb.com/abbreview

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