ABB review

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The corporate technical journal

Innovation

Power and productivity for a better world™

The cover of this issue of *ABB Review* depicts aspects of the striking architecture of the Yas Hotel in Abu Dhabi. While visitors can hardly fail to notice the building's fascinating design, most will probably not be aware that another great innovation is also contributing to their comfort: ABB's i-bus® KNX building control system.

The products and services of tomorrow's world will rely on the interplay of numerous innovations in different areas of research and development. This issue of *ABB Review* looks at a selection of recent breakthroughs achieved by the company.

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Innovations

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

Dear Reader,

Technology is a defining aspect of modern society. To fathom how much we depend on individual technologies, we need look no further than the manufacturing processes on which we depend or the power-supply that keeps our lights burning. The extent to which tomorrow's world will be different from today's will depend to a significant degree on the technological progress and breakthroughs that will emerge between now and then. Through its research and development labs, ABB is proud to play a central if not defining part in advancing some of the contributing technologies.

In this issue of *ABB Review*, 11 innovations selected from ABB labs across the globe are presented in short articles. Many of these are additionally discussed in greater depth in this, recent and upcoming issues of the journal.

One area that has led to huge changes in recent decades is power electronics. Compact and reliable semiconductor devices are permitting electrical power to be converted with an unprecedented degree of flexibility, efficiency and controllability. *ABB Review* dedicates three articles to drives and converters. One of these looks at the award-winning ACS 2000 drive, ABB's first transformerless medium-voltage drive.

Motors are important to virtually all manufacturing processes, and are customized for numerous different applications. One article looks at ABB's spark-free motors and their significance in explosion protection. In another article, we present ABB's low-loss synchronous motors. Zooming out to the broader picture of energy efficiency, a thought-provoking paper proposes that the CO_2 reduction from raising the efficiency of generating plants is equivalent to an alternative fuel, and shows how ABB products can achieve this.

Process plants use myriad sensors and actuators. Many of these require only small amounts of energy to function, but ensuring the continuity of this supply can present a significant challenge. An alternative to wires or batteries is extracting energy from their environment (eg, from thermoelectric effects or vibrations). *ABB Review* looks at this in an article on energy harvesting.

In the domain of transmission and distribution, ABB has played and is still playing a major role in the development of the IEC 61850 standard for substation communication. *ABB Review* dedicates an article to a significant milestone: the ongoing upgrade of a series of substations in Australia, representing the first commercial implementation of IEC 81850-9-2 LE. This subsection of the standard represents an important step forwards in digital communication in substations. Further articles look at different types of switchgear and at protecting transformers against lightning.

I trust that the innovations presented in this edition of *ABB Review* will raise your awareness of their potential and inspire you to find ways of putting them to good use.

Enjoy your reading!

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

Innovation highlights

The 11 best innovations for 2011

ABB is continuously seeking to further strengthen and expand its product portfolio. Across the world, the company's research and development labs are hard at work creating the technologies, products and solutions that will further raise the productivity, efficiency and flexibility of its customers' operations. The successes scored every year are numerous, and selecting the most notable of these is no easy task. The current selection is a cross section of recent successes. Many of these, as well as other technological achievements, are discussed at greater length in this and forthcoming issues of *ABB Review*.

The slender-armed welder

ABB has added a new model to its mid-range IRB 2600 robot family: the IRB 2600ID. The ID in the name stands for integrated dressing, meaning the arc-welding hose package is routed inside the robot's upper arm and wrist.

Integrated dressing is about more than smart looks. Because swinging cables must no longer be taken into account, the robot's movement is totally predictable. This makes the robot easier to program and permits faster movements. With its slim arm and wrist, the robot can enter restricted spaces, taking on challenges such as circular welds without compromising on quality or speed.

With all hoses and cables firmly secured and protected, exposure to weld spatter is also reduced, increasing the lifetime significantly. Purchasing and exchange costs are reduced by up to 75 percent and up to three production stops per year can be eliminated. Complete weld packages, tailored for the IRB 2600ID, are available from several major arc-welding process equipment suppliers including Fronius, Esab, Binzel and SKS.

The IRB 2600ID has a very small footprint. Its swing base radius is only 337 mm and its base width 511 mm. For arc-welding applications, the reduced risk of interference with other robots allows for productive, high-density installations with 50 percent more robots, and up to 50 percent higher output from a production cell.

For more information on robots from ABB, please visit www.abb.com/robotics

First commercial IEC 61850-9-2 LE installation

IEC 61850 is a standard that supports both communication between devices and data sharing in substation automation. The IEC 61850-9-2 section of the standard describes the sharing of analog values on the process bus. ABB is currently installing the world's first implementation of a process bus according to this section.

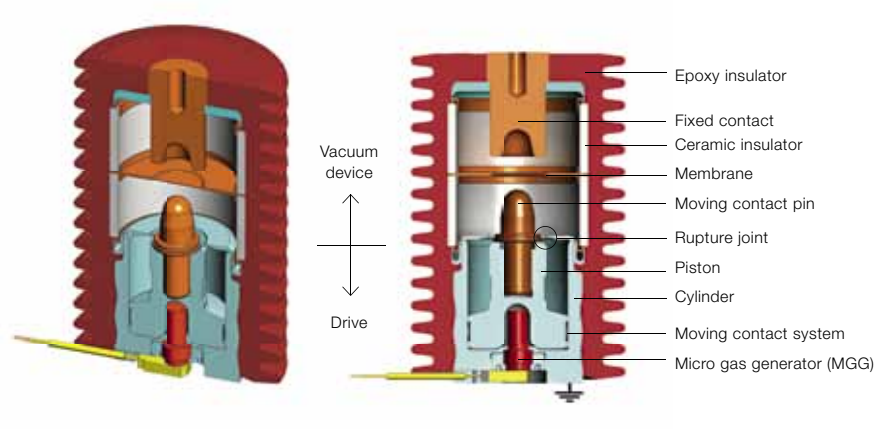
A process bus is the communication network between primary equipment (such as instrument transformers) and secondary equipment (such as protection and control devices) of a substation-automation system. It transmits analog data to the secondary equipment, where it is used for efficient protection and control of the entire substation. Prior to the emergence of the new standard, this communication would typically have required extensive copper cabling.

IEC 61850-9-2 LE has numerous advantages. As the bus is optical, risks caused by high voltage are reduced. Maintenance is also simplified as electronic components can be exchanged without having to shut down the entire system. The introduction of IEC 61850-9-2 LE is being accompanied by the introduction of a powerful testing and diagnosis toolbox.

For more information, see "Sharing values" on pages 73 of this issue of *ABB Review*.

Speed and safety in switchgear

The technologies from ABB's well-known and fast-acting vacuum interrupter and the world's fastest limiting and switching device, the Is-limiter, have been cleverly combined to form an arc-fault protection system for new (internal arc classified) and older generation medium-voltage switchgear that operates in the ultrafast range.



The system operates on the principle that the uncontrolled release of energy from an internal arc fault is prevented by rapid metallic 3-phase earthing. Characterized by a significantly low impedance, this type of connection causes the short-circuit current of an arc fault to commutate immediately to the fast-acting and innovative earthing switch and extinguish the arc.

The new ultrafast earthing switch (UFES) contains three complete primary switching elements (each consisting of a two-part vacuum chamber embedded in epoxy resin), and a quick release electronic unit for the rapid and reliable detection of fault currents and arc light intensity in the compartment. With an extremely short switching time of less than 1.5 ms, this device will ensure all arcs are extinguished almost immediately.

In technical terms, system availability and operator safety are greatly enhanced for rated voltages up to 40.5 kV and rated short-time withstand currents (1s) up to 63 kA. From an economic point of view, downtime and repair costs resulting from faults will be drastically reduced while system availability will increase.

For more detailed information about ABB's ultrafast earthing switch, please see "S3 – Speed, safety and savings" in *ABB Review* 2/2010, pages 84–87.

Compact and green GIS

ABB has launched its 72.5 kV ENK series of gas-insulated switchgear (GIS). Notable attributes include a 25 percent smaller footprint compared with existing products with similar performance, and a 50 percent reduction in the amount of SF_6 gas used.

The ENK series features advanced plug-and-switch technology and an intelligent secondary interface to meet future smart grid requirements. Further notable new features include its greater ease of operation, such as ready access to the operating mechanism from the front panel, and the current transformers located outside the gas compartment.

With its plug-in busbar connections and shipment of complete, factory-tested bays, the ENK GIS can be easily and quickly installed on-site. It is rated for a nominal voltage of 72.5 kV, is available for up to 2,500 A rated current and 40 kA short circuit in versions conforming to IEC and IEEE standards.

The compactness and modularity of GIS makes it ideal for installation in locations where space is constrained, such as in cities. Even indoor installations are possible. ABB also offers GIS for offshore and mobile applications. The company pioneered the first high-voltage GIS in 1965 and is the global leader in high-voltage GIS technology, with more than 20,000 bays installed and in operation around the world.

Wireless and autonomous

In the process industry, sensors relay information that is used to help maximize reliability and availability. Sensors require wiring for power and communication, a factor that adds to the cost and complexity of installation. While batteries are used to power many wireless devices, exchanging them at regular intervals may offset the savings of having wireless sensors in the first place. Here energy harvesting (EH) can provide a solution.

EH is the process by which energy derived from sources external to the device is captured and converted into electrical energy to supply low-power electronics. Typical energy sources include hot and cold processes, solar radiation, and vibration and kinetic energy from flowing media or moving parts.

EH can be a discontinuous process or there may be times when the EH system supplies more energy than is actually needed. In any case buffers (eg, special capacitors, primary or secondary cells) are needed to overcome times when the harvesting device is unable to supply enough energy for the sensor node. An appropriate power management system is also required for a truly autonomous power supply.

Research at ABB has realized a complete autonomous temperature transmitter using a fully integrated EH system. Thermoelectric generators have been integrated into the device, which also includes a smart energy management solution when the process temperature is insufficient to generate enough energy.

For more information about energy harvesting please refer to “Harvest time” on page 47 of this issue of *ABB Review*.

System 800xA version 5.1

Since being first released in 2004, ABB's Extended Automation System 800xA has been adopted by more than 6,000 customers. The system has improved operator effectiveness, achieved seamless control solutions and integrated diverse and usually separate systems. Version 5.1, released in 2010, introduces further enhancements, improving performance, usability and operator effectiveness.

One area where Version 5.1 presents notable advantages is in engineering and change management. The Task Analysis Tool permits the evaluation of an application prior to its downloading, showing, among others, latency and conflicts. The Detailed Difference Report highlights modifications made in control applications and graphics.

The new version also includes a new member of the AC800M controller family, the PM891, with approximately three times the clock speed (450 Mhz) and four times the memory of its predecessor, making it the most powerful controller in its class. Virtualization reduces the physical number of PCs by as much as 75 percent. This significantly lower footprint also reduces energy consumption and maintenance requirements.

Improvements in alarm-management capabilities include new alarm shelving and analysis features and improvements in alarm share functionality. Security and connectivity are also enhanced.

These changes reflect but a small part of the overall improvements introduced to System 800xA with Version 5.1.

System 800xA Version 5.1 will be discussed in greater depth in an upcoming edition of *ABB Review*.

eVolving breakers

New and advanced technologies are enabling the development of highly integrated and versatile products. One such device, the eVD4 automatic circuit breaker, enables easy, flexible and reliable medium-voltage switchgear projects. This breaker is a major step forward in terms of performance, simplicity (it is characterized by a small number of highly reliable components and can be customized with a wide range of easily and rapidly installed accessories) reliability in a vast range of applications, safety and cost effectiveness.

The eVD4 is based on ABB's VD4 mechanically actuated vacuum MV circuit breaker, and features the specially designed Relion®-based RBX615 intelligent electronic device (IED) as well as modern current and voltage sensors. The RBX615 unit guarantees the general protection of overhead and cable lines and distribution substation busbar systems, and is suitable for any radial distribution network. The technology used to develop the sensors has helped to reduce equipment size, improve performance and increase standardization. This combination of sensors and IED enables the accurate and reliable monitoring and registering of network parameters while providing better protection for both operating personnel and the substation equipment.

The eVD4 circuit breaker is fully compliant with the IEC 61850 standard and GOOSE functionality, which in turn ensures compatibility with new substation communication systems.

For more detailed information about the eVD4 breaker, please see "The smart eVolution" on page 18 of this issue of *ABB Review*.

ABB's DC fast charger

DC (direct current) fast chargers are becoming widely acknowledged as a key enabler for e-mobility. Unlike AC charging, which relies on a smaller charging converter inside the car and is suitable for charging overnight, DC fast chargers move the charging converter out of the car and into the infrastructure where it can be shared between many vehicles. This allows high-power charging without burdening individual vehicles with significant additional weight and cost, and has the added benefit of several means to manage the utility grid impact.

ABB's activities in e-mobility infrastructure took a significant step forward with the successful certification of ABB's CHAdeMO-compliant DC fast charger in early November 2010 and the subsequent installation at the first pilot site, the Hong Kong Science and Technology Park, with utility partner China Light and Power.

The CHAdeMO standard is the most widely accepted for DC fast charging. It has been endorsed by numerous large vehicle manufacturers, and the first mass-market DC fast-charge-capable vehicles based on the standard were released in 2010, with more to come in 2011 and 2012.

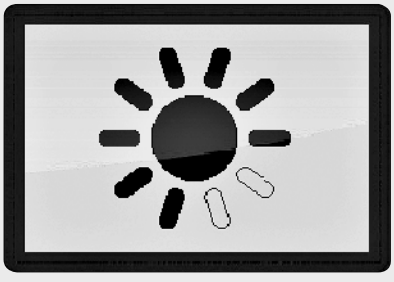
ABB worked together with CHAdeMO certification engineers from the Tokyo Electric Power Corporation to achieve this milestone. Through this group effort, certification was achieved in record time, and the pilot installation completed only two days later.

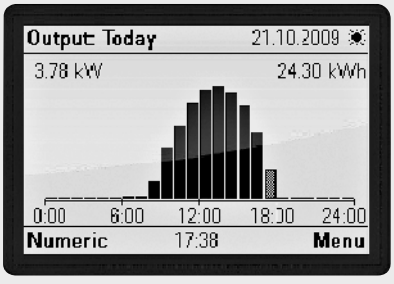
The new ABB DC fast charger proved its performance immediately as the primary fast-charging point for the vehicles of the Hong Kong EV parade following EVS-25 (the World Electric Vehicle Symposium and Exposition) in Shenzhen, fast charging seven of China Light and Power utility's Mitsubishi "i MiEV" vehicles in a row.

For more information on electric vehicle charging, see "Dawn of a new age" on page 77 of *ABB Review 2/2010*.

The power plant for at home

ABB has already established a market presence for inverters that connect large photovoltaic arrays to the grid. But what about smaller facilities, such as panels fitted on the roofs of residential and commercial buildings? ABB's new string inverter combines an easy-to-use interface and simple installation with high performance and advanced protection, enabling users to not only contribute toward their own electricity needs, but also to feed power into the grid.





An inverter installed at home must be so simple that all members of the household can understand it. ABB's string inverter comes with an intuitive remote display unit. This starts with the very simple sun symbol whose ray count reflects the brightness of the sun, permitting the inverter's activity to be verified instantly and at any time. For the investment-minded user, the unit can display histograms, logging production over time.

A third level of complexity is made for engineers and reports on numerous technical details. The string inverter comes with state-of-the-art surge protection and a very compact design.

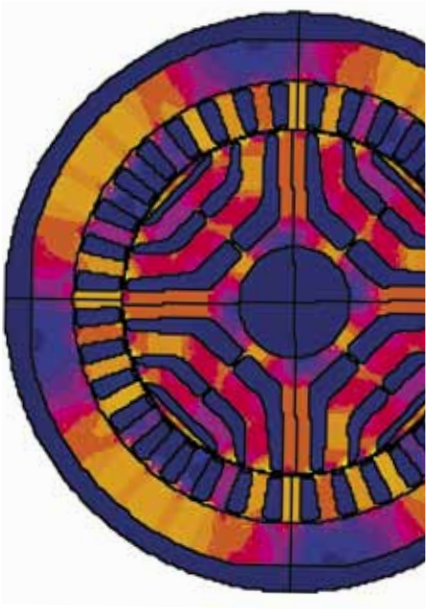
ABB's string inverter will be presented more fully in an upcoming issue of *ABB Review*.

The low-loss motor

The streamlined rotor structure of ABB's synchronous reluctance motors eliminates rotor cage losses, therefore increasing efficiency and compactness. The possibility of achieving standard power and torque levels at merely a low class-A temperature rise (60 K) improves the lifetime of the motor insulation, and lengthens the bearing lifetime or greasing intervals.

Synchronous motors controlled by variable speed drives are increasing the energy efficiency of many industrial applications. What most applications have in common is the need for their motor to be as efficient as possible and to have the longest possible lifetime while simultaneously not increasing maintenance demands or failures. ABB's synchronous reluctance motors (often called a SynRM) employ the magnetic principle of reluctance. They are physically smaller in size, helping machine builders to design smaller, lighter, and more efficient equipment. The motor is inherently safe in operation since, without magnets, no back-EMF voltage is induced, and over-voltage protection of the converter becomes superfluous. Additionally, the possibility of high speed operation helps to eliminate mechanical power transmission elements such as gearboxes. This eventually enables the integration of the motor and the load equipment.

For more information, see "Motoring ahead" on page 56 of this edition of *ABB Review*.



Busch-iceLight

In the same way that lighting affects a photograph, so too can lighting affect the mood of a room. Equipped with innovative LED technology and a host of options for light direction and intensity as well as color temperature and appearance, Busch-Jaeger has, in collaboration with the renowned architect and designer Hadi Teherani, developed a new lighting system for both residential and office buildings.

Busch-iceLight is a modular, versatile lighting system that can be used as an information or orientation light or to create ambience in a room. Small as a light switch and using the same style plates as light switches and power outlets, the system can be adapted to match the look of existing electrical installations.

The lighting element can be adjusted in five different directions to precisely define the light direction and beam. Two settings are available for the color temperature of the light, ie, warm white or neutral white. And light intensity can be switched to either 100 percent or 25 percent intensity using a 350 mA / 5 W converter or a 40 mA / 0.15 W night-light converter. As a directional orientation light or an illuminated building information system, Busch-iceLight ensures comfort and safety. Numerous high-quality design sheets and special pictograms are available, making the system adaptable to users' needs.

Busch-Jaeger is a member of the ABB Group.

CLEEN innovations

How collaboration is supporting ABB's research and development work

JUKKA TOLVANEN, TERO AHONEN, JUHA VIHOLAINEN – In the past, innovations like the light bulb and the telephone often originated from individual people like Thomas Alva Edison and Alexander Graham Bell. Today, innovations still need innovative people to surface, but rather than a one-man show, cooperation and consortiums of various competences are often required for the development of new ideas. Within ABB, there is already a huge technical competence, and the potential to utilize global presence combines with knowledge of customer needs worldwide. ABB also benefits from cooperation with companies and universities in the development of new technology and services.

According to the well-known saying, “two heads are better than one.” In the fields of engineering and technology, development of new ideas may require diversity of know-how and therefore cooperation between different companies and organizations. For instance, innovations on how to improve the energy efficiency of electrical systems clearly require technical expertise, but also economical and social expertise in order to obtain totally new and feasible products and services.

Respectively, technical expertise may be required from several areas of engineering, requiring the participation of several companies. As a single company may hold world-class competence only in certain areas, cooperation between different companies and organizations can be the most feasible approach for new ideas and innovations, which may cover several different business segments.

Consortium provides foundation for research

Even though cooperation can be feasible, certain rules need to be fixed beforehand. For instance, intellectual property (IP) and financial issues need to be clear from day one in order to ensure sustainable and mutually beneficial cooperation.

One solution to deal with these issues is to have a common research center or community to manage R&D activities. In Finland, the strategic center for science, technology and innovation in the energy and environmental sector (CLEEN Ltd.) has been founded to catalyze international and cross-industrial cooperation in the energy and environmental technology fields. As a limited company owned by global companies and the most relevant national research institutes and universities, CLEEN facilitates cooperative knowledge building and the creation of innovative solutions, technology and services that are beyond the R&D capabilities of a single company or area of industry [1]. Two-thirds of CLEEN’s 44 owners are private companies including several global technology and market leaders, like ABB, Metso and Wärtsilä. ABB is one of the founders and an active member in CLEEN’s operations that has provided new possibilities for cooperative research with other companies, organizations and research institutions.

This kind of joint venture also improves the possibility of receiving external funding, which is often essential for wide research consortiums executing long-term (eg, three to five years) research. In Finland, the main public sponsor is the Finnish Funding Agency for Technology and Innovation (Tekes). Tekes supports a consortium of companies and research institutes with its new innovation program. This kind of support enables a change in the innovation culture from a one-company show to network-based open innovation.

Modern cooperation between companies and universities

CLEEN is part of a major overhaul of the Finnish innovation system. To advance this goal the Finnish government has initiated six centers for strategic science, technology and innovation that are exclusively owned and run by industry and academia. CLEEN is the one that concentrates on energy and environment.

According to Tommy Jacobson, CEO of CLEEN, the company strives to enhance open innovation between companies, universities and research institutions. It works as a network through which the participating international companies can conduct R&D work gaining new knowledge on a faster and deeper basis than would be possible by acting alone.

Jacobson explains that cooperation is more strategic for the companies involved when they allocate their own R&D human resources for several years and are willing to share their results, rather than just allocating funding for outsourced proprietary R&D. Such industry involvement also ensures wide interfaces for knowledge transfer, innovations and guidance.

An effective way to develop the programs has been found: First the companies define the theme that they consider important for their future businesses and for which they would be willing to allocate their own resources and share the deliverables. Then the universities and research institutes respond to this market pull with their research initiatives, creating a reciprocal science push. Jacobson points out that this also saves resources at the universities as they do not have to waste time on completing research applications that typically have a low success rate, but instead receive feedback that is immediate, interactive and iterative.

> CLEEN Ltd. has been founded to catalyze international and cross-industrial cooperation in the energy and environmental technology fields.

One major research area focuses on the energy markets and smart grids. Here the main contributors are Nokia Siemens Networks and ABB. Other areas on the agenda are, for instance, efficient energy use and distributed energy systems.

Smart grids and energy markets

A smart grid delivers electricity from many suppliers to consumers using two-way digital technology and an intelligent monitoring system that keeps track of the electricity flows in the system. Smart grids enable controllable multidirectional power flows on both a local and long-

1 Smart grids and energy markets (SGEM)

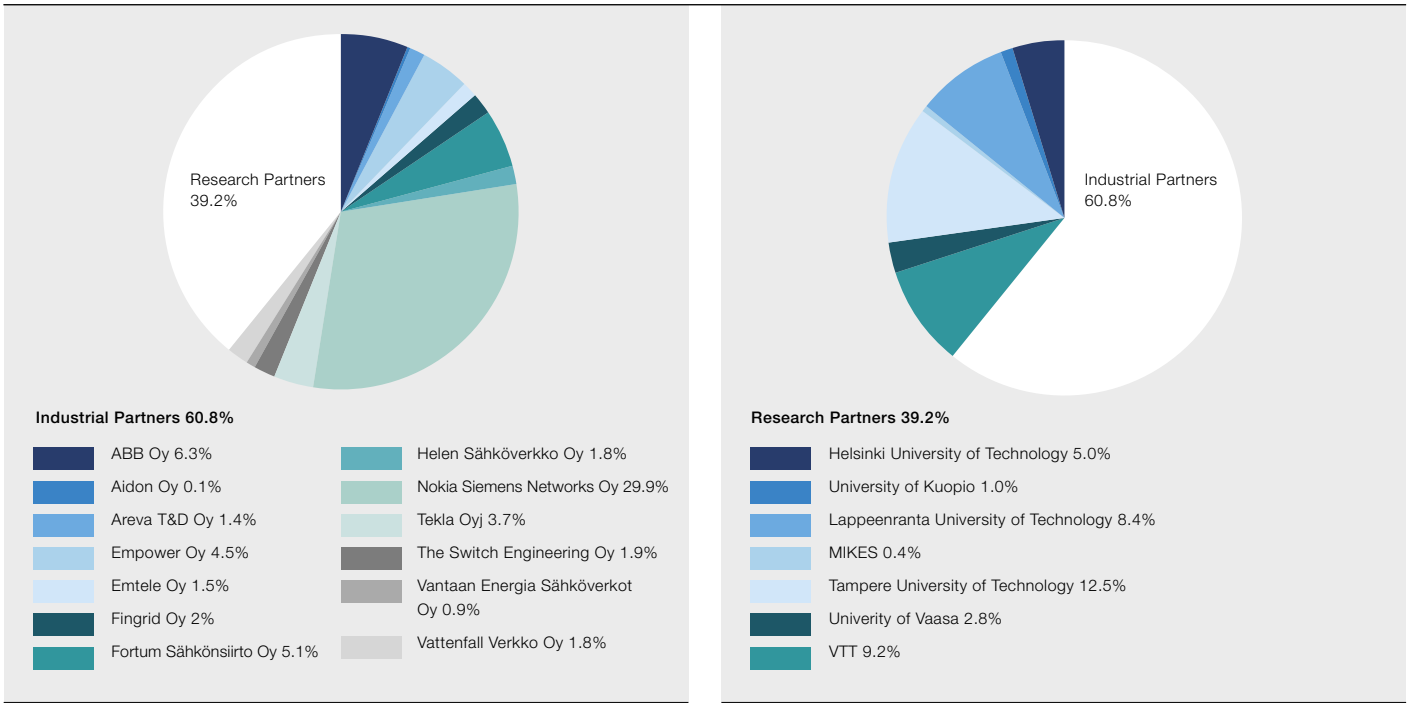


ABB is one of the founders and an active member in CLEEN's operations.

distance scale. Compared with traditional electric grids, smart grids enable more efficient use and control of distributed electricity generation, and the intelligent use of electric car batteries as a part of the electrical distribution system. Research topics in the smart grids and energy markets (SGEM) program are:

- Future infrastructure of energy systems
- Intelligent management and operation of smart grids
- Customer gateways
- Development of energy and emission services allowed by the smart grid technology

The goal of the SGEM research consortium is to develop international smart grid solutions that can be demonstrated in a real environment utilizing Finnish R&D and innovation infrastructure. At the same time, the benefits of an interactive international research environment will accumulate know-how of the world-leading information communication technology (ICT) and smart grid providers. This consortium program has several participants from industry, research institutes and universities as shown in → 1. The industrial participants cover the areas of electricity generation and distribution, telecommunications and information technology. The research partners consist of five Finnish universities and two research institutes (MIKES, VTT). The time frame of this project is five years.

Efficient energy use

The efficient energy use (EFEU) program focuses on the development of methods that can improve the energy efficiency of devices and systems. The target sectors are industry and service where approximately 60 percent of the total produced energy is consumed. The primary goals of the research program are to:

- Develop new methods, business processes and systems that help to achieve radical improvements in energy efficiency
- Develop new methods that produce significant energy efficiency improvements with minor investments
- Create a national R&D network for energy efficiency development

Due to the cross-scientific nature of the topic, the expertise and active participation of different parties – such as the manufacturing industry, device manufacturers, service companies, engineering companies, universities and research organizations – is required. The time frame of the research work is three to 10 years before the product phase or service phase. The main results of the research will be innovative system concepts, dimensioning rules, methods for measuring and evaluating the system's energy efficiency, and energy-efficiency-related solutions and services. The research ideas will be piloted in demonstrations and will be later used in more application-oriented development work.

2 Research facilities at LUT for pumping systems

Innovations via academic research

Besides consortium programs, direct collaboration between industry and universities can be a fruitful source of innovation and new technology. Often cooperation between universities and industry provides synergy for both parties, as universities may have and suggest interesting research topics, and product manufacturers may benefit in the form of innovative R&D and testing of new ideas with universities' test facilities. This kind of cooperation has been successfully carried out between ABB and Lappeenranta University of Technology, Finland (LUT) in the field of electric motors and variable-speed drives (VSDs), which are an essential solution to improve the energy efficiency of rotating machinery.

Founded in 1969, LUT provides education and research in the areas of engineering and economics. The university's areas of strength include energy efficiency and the energy market, strategic management of business and technology, scientific computing and modeling of industrial processes, and expertise in Russian business and industry related to the above areas [2].

As the university has test facilities for pumping systems and electric motors, and strong expertise in the energy efficiency of these appliances, LUT has been able to carry out academic research, which has also helped with the R&D of new ABB products. Both direct torque control (DTC) of permanent magnet synchronous machines (PMSMs) and sensorless flow rate estimation for centrifugal pumps have been studied at LUT → 2 [3,4]. These research topics have resulted in several patent applications, scientific publications and also direct feedback to ABB's R&D team for drives.

Consequently, the research expertise of LUT has provided a good basis for cooperation with ABB on electric motors and variable-speed drives. In practice, the cooperation has been carried out at the Carelian Drives and Motor Center (CDMC), which is a part of the electrical engineering department of LUT. For ABB, this approach allows the development of innovative ideas with researchers in academia, and also the testing of upcoming products.

> Direct collaboration between industry and universities can be a fruitful source of innovation and new technology.

For CDMC, this cooperation has provided an excellent source of new research topics and the possibility of extending its expertise in the area of energy efficiency of electric motors, VSDs and rotating machinery. The cooperation has allowed CDMC research staff to be innovative participants in the research and development process of new products and services. Depending on the project, the results of the research can also be published as PhD theses and journal articles, or in the form of patent applications. The research projects have been related to the control methods of VSDs, efficiency improvements of electric motors, and the control and diagnostics of rotating machinery such as centrifugal pumps.

Cooperation with other companies and universities often brings new and innovative ideas. One example of this can be seen in the following article "Audit benefits." R&D collaboration therefore should not be overlooked, as more extensive research projects can be formed and expertise from different areas can be utilized in the research. Whether this is reached through consortium research with other companies and research institutes or through direct collaboration with universities or research institutes, there are benefits for all concerned.

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[4] Ahonen, T., Tamminen, J., Ahola, J., Viholainen, J., Aranto, N., Kestilä, J. 2010. Estimation of pump operational state with model-based methods. Energy Conversion and Management, 51, 1319–1325.

Audit benefits

ABB and Lappeenranta University of Technology are collaborating on an energy audit project for more efficient and durable pumping systems.

The energy audit project (EAP) at Lappeenranta University of Technology (LUT) was started in autumn 2008. An energy audit is an analysis of the energy consumption of a given process or a system → 1. The clients are energy consumers mainly in industrial fields. The auditing process concentrates on finding inefficiently operating applications with rotating electrical machinery and such cases usually involve pumps.

The EAP is funded by ABB and run by LUT's Institute of Energy [1]. This project is the result of a long-lasting cooperation between ABB and LUT, especially in the field of researching the efficiency of pumping systems. The project has provided special knowledge about the energy efficiency of pumping applications. In addition, specific simulation tools to determine the energy efficiency of pumping systems were developed during this project.

Auditing industrial energy usage

The main goal of this project was to create an easy-to-use method for auditing from which all participants could benefit. The aim of the audit is to obtain information about the energy consumption of the system in its present state and to identify the factors affecting it. The second step is to identify the economic opportunities for improving the efficiency of the system and achieving cost savings. The end product of the audit is an action plan on how to achieve improved energy efficiency.

Significant results in research and development for pumping applications

The advanced use of variable-speed drives (VSDs) in the diagnostics of centrifugal pumps has been studied at LUT since 2005, when accuracy of the sensorless flow calculation function available in ABB's industrial drives was tested in laboratory facilities. Test results were then published in World Pumps journals in 2005 and 2006.

As VSD are capable of estimating motor operation without sensors on the motor shaft, they can also be used to estimate the operation of a pump or other load of the motor. For instance, the sensorless flow calculation function available in ABB's industrial drives utilizes the internal rotational speed and shaft power estimates of the drive to inform the user about the pump flow rate without additional sensors on the pump. This function can be used in an application where the pump flow rate is required information, but it is not applied for revenue metering.

Research projects have also been carried out to find new ways of detecting cavitation [1] and for energy-efficient control of parallel-driven pumps. These studies permit the main causes of pump failures to be eliminated, and the total energy consumption of pumping systems to be substantially decreased.

More durable and energy-efficient pumping systems

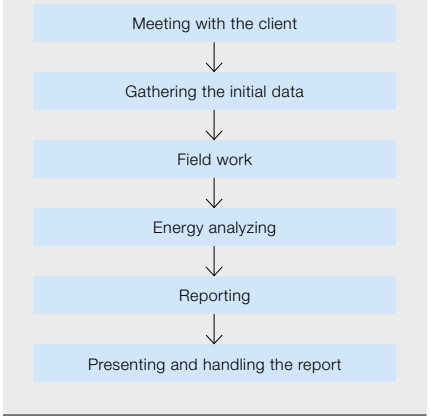
The sensorless detection of cavitation is based on the intelligent analysis of the converter estimates to determine

Significant energy savings could be achieved using advanced variable speed control with parallel-connected pumps.

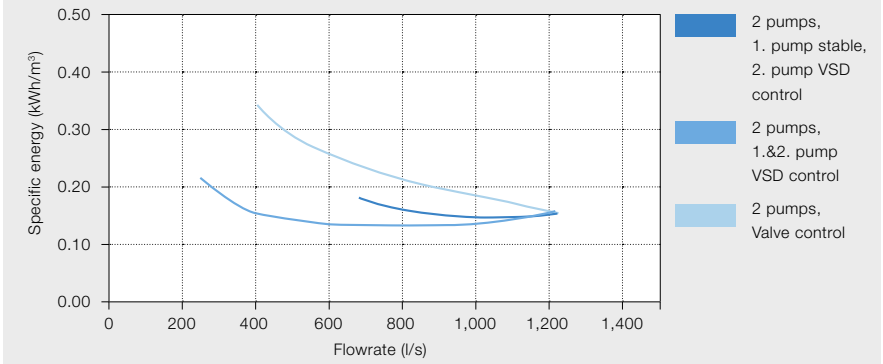
Footnote

1 Cavitation is the formation of gas bubbles in flowing liquid due to the pressure of the liquid falling below its vapor pressure. Shock waves caused by the rapid collapse of such bubbles can damage surfaces.

1 The LUT energy audit procedure



2 Specific energy consumption of different flow control methods for two parallel-connected centrifugal pumps



the abnormal operation of the pump. In the case of centrifugal pumps, cavitation is one of the widely known reasons for decreased pumping efficiency and pump failures. Because of this, several methods to detect cavitation have been developed. However, they are typically based on additional measurements that decrease their feasibility in several cases. The installation of sensors may be costly and the amount of pumps that should be monitored may be so high that it is reasonable to have a condition monitoring system for only a few pump drives. For this reason, sensorless cavitation detection can provide real benefits to the user, as there is no need for additional sensors and installations [2].

> As VSD are capable of estimating motor operation without sensors on the motor shaft, they can also be used to estimate the operation of a pump or other load of the motor.

In the case of parallel-connected pumps, their intelligent control by VSDs can provide substantial cost savings due to the lowered energy consumption. As parallel-connected pumps are often operated by applying the off/on control method, there is a huge savings potential by operating the required amount of centrifugal pumps at a lower rotational speed compared with the traditional off/on control method. This has been verified by test measurements carried out at LUT.

Several real-life research cases have also been conducted in industrial raw water pumping applications, power plants and municipal water stations. The results have shown that significant energy savings could be achieved using advanced variable speed control with parallel-connected pumps. One example of how the VSD can reduce specific energy consumption of two parallel operating centrifugal pumps is shown in ➔ 2. With the variable-speed control for both pumps, specific energy consumption can be minimized at lower flow rates [3].

Results of these research projects demonstrate the benefits of collaborative research and development: By combining the expertise of project participants, new solutions allowing efficiency improvements and cost savings can be more easily developed than by acting alone.

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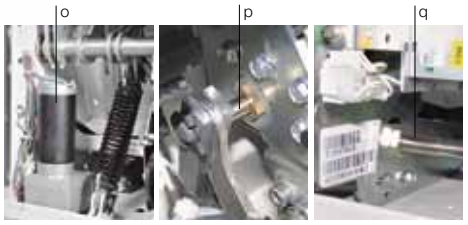
The smart eVolution

eVD4 brings simplicity and reliability to medium-voltage distribution networks

CALOGERO SAELI, CALLISTO GATTI, CARLO GEMME, EMILIA DANERI, CARLO CEREDA – Over the last decade, medium-voltage distribution networks have experienced significant changes thanks to the continuing evolution in technology. ABB is leading this evolution by providing customers with new products, such as Relion® protection and control devices, current and voltage sensors, and vacuum circuit breakers with embedded poles, all incorporating state-of-the-art ABB technologies. ABB has used these technologies to create an automatic circuit breaker that features onboard sensors and the RBX615 protection and control unit. Known as the eVD4, it enables simpler switchboard design and specification, faster installation, higher reliability and reduced maintenance needs and life-cycle costs, while increased standardization contributes to less complex switchgear and systems.

1 PCM600 is IEC 61850 compliant, which simplifies IED engineering and enables information exchange with other IEC 61850-compliant tools.

a Pole with vacuum interrupter
b Relay signals
c Sensor: Rogowski coil or combisensor
d Truck for the withdrawable circuit breaker
e RBX615 control and protection relay
f Opening push button
g Operating mechanism charging lever
h Open/closed mechanical signaling device
i Operating mechanism spring charging geared motor
j Plug for auxiliary circuits (withdrawable circuit-breaker only)
k Closing push button
l Charged /discharged spring mechanical signaling device
m Mechanical operation counter
n Mechanical operating mechanism



o Racking-in and racking-out geared motor (withdrawable circuit-breaker only)
p Circuit-breaker open-closed proximity sensor
q Charged /discharged spring proximity sensor

Recently, the medium-voltage (MV) world has seen a strong trend toward the evolution of new technologies that are enabling the development of new solutions to meet the present and future needs of distribution networks. The IEC 61850 standard, for example, is driving innovation in energy distribution devices, enabling new functionalities and new architectures for MV switchgear while increasing standardization. Products featuring a higher degree of integration, component standardization and greater overall versatility are now available on the market. Not only do they improve reliability, but they also reduce the time and effort needed for installation and maintenance.

ABB has pioneered many of these new technologies in its quest to develop new products and product series for the MV primary distribution environment.

One such product series, the innovative eVD4 automatic circuit breaker family (see title picture), has been specifically developed to enable easy, flexible and reliable MV switchgear projects, from the specification, tendering, engineering and production phases right through to the installation, commissioning, testing and maintenance phases.

The eVD4 series combines innovative ABB technologies in the field of mechanics, electronics and sensors. The result is a highly integrated device that combines measurement, protection and control capability with primary power disconnection, switching and interruption technology.

Innovation and a sound foundation of proven technology

The eVD4 is based on ABB's VD4 mechanically actuated vacuum MV circuit breaker and the new Relion® product and sensor technologies → 1. Since its introduction in 2003, the VD4 has a global installed base of over 250,000 units, and is characterized by its excellent reliability and versatility in a vast range of applications.

The RBX615 protection and control unit based on ABB's Relion technology is an intelligent electronic device (IED) dedicated to the protection, control, measurement and supervision of utility substations and industrial electrical systems. It is installed into the chassis of the eVD4 as a plug-in device via a docking unit.

The RBX615 unit guarantees the general protection of overhead and cable lines and distribution substation busbar systems, and it is suitable for any radial distribution network regardless of the grounding principle. The digital inputs and outputs (I/Os) and the communica-

> The innovative eVD4 automatic circuit breaker family has been developed specifically to enable easy, flexible and reliable MV switchgear projects.

2 Comparing a fully automatic eVD4 breaker with a standard MV circuit breaker in all stages of the product life cycle

Specification
The high level of flexibility of the eVD4 simplifies specification requirements.
In other words:
– There is no need to define any sensor parameters; the rating of the sensors is derived from the rating of the circuit breaker, whereas the type of sensors (only current or combined current and voltage version) is derived from the protection profile.
– All RBX615 preconfigurations can be customized to provide the best match to the network requirements.

Supply management
Rather than a number of separate orders, just one single order and one unique reference is required to ensure the delivery of a complete MV switchgear solution.

Fast delivery
The highly technical production line combined with component standardization enables ABB to guarantee the same delivery time for the eVD4 as for a standard circuit breaker.

Installation
The eVD4 is a ready-to-install solution. As the sensors are an integrated part of the complete unit, no wiring or additional work is needed; all the relay wiring is instantaneously connected by the circuit-breaker plug.

Reduced effort and time for engineering and wiring
As an integrated solution, a large proportion of the switchgear wiring is built into the circuit breaker, which results in a more standardized product. The amount of wiring destined for the low-voltage compartment is limited and the risk of wiring errors is significantly reduced. This in turn makes a complete switchgear solution faster and easier to engineer.

Reduced effort for factory acceptance test (FAT) with increased safety and reliability
A fully tested and integrated solution with fewer switchgear wires reduces the effort needed to complete compulsory FAT tests.

Easy maintenance, the optimization of spare part stocks and reduced mean time to repair (MTTR)
The eVD4 is built from standard components that can be used across a wide range of applications. In addition, with just a few variations, all circuit breaker models within the eVD4 family are covered and so only a small number of spare parts need to be kept in stock. All accessories are readily available and can be easily maintained. This integrated solution allows fast system recovery in case of failure, and all the core components of the switchgear will be replaced by simply replacing the eVD4.

The RBX615 protection and control unit is integrated into the eVD4 and performs the monitoring, control and diagnostic functions.

tion channels, which are available within switchgear's low-voltage (LV) compartment, can be accessed through the circuit-breaker plug that is connected to the LV compartment socket.

The sensors, mounted on the circuit-breaker poles, measure the currents and voltages needed for protection and control in MV power systems. The technology used to develop the sensors has resulted in a reduction in equipment size, improved equipment performance and an increased level of standardization. This combination of sensors and IED (the RBX615) enables the accurate and reliable monitoring and registering of network parameters while providing better protection for both operating personnel and the substation equipment.

The advantages of a fully automatic eVD4 breaker over a standard MV circuit breaker in all stages of the product life cycle are given in → 2.

The eVD4 covers most common MV circuit-breaker ratings: Nominal voltage up to 17.5 kV; nominal current up to 2,500 A; and breaking capacity up to 40 kA. The RBX615 relay can be ordered with five different protection profiles, each of which correspond to a particular set of protection functions that require both current and voltage measurements. Because it is integrated into the eVD4, the design of the relay has been optimized specifically so that it can perform the monitoring, control and diagnostic functions of the eVD4.

eVD4 structure overview

The design of the new eVD4 vacuum circuit breaker more than satisfies the requirements of simplicity (it is characterized by a small number of highly reliable components and can be customized with a wide range of easily and rapidly installed accessories) and safety (a sturdy metal frame fixes the poles and the operating mechanism are fixed).

Operating mechanism

The operating mechanism contains a spring to store the energy needed for the mechanical opening and closing releases and dedicated interlocks. Correct operation requires the immediate availability of stored energy, which can (in the case of the eVD4) be low because of lightweight interrupter contacts and reduced contact travel for switching. This limits the wear on the system and makes the circuit breaker practically maintenance-free. Up to 30,000 open/close operations are possible over the lifetime of the eVD4.

Proximity sensors

Proximity sensors allow the eVD4 to determine the status of its moving parts with high reliability. For example, these sensors detect the breaker's open/close status, the spring's charge/discharge state and the position of the truck. This information is then sent to the RBX615 relay via a dedicated wire link.

An enhanced auxiliary circuit plug

The eVD4 plug has to provide a reliable connection not only for the circuit breaker's auxiliary circuits but also for the relay connections, ie, the communication channels, the I/O signals and the residual current sensor connections → 3. This is achieved using an enhanced plug comprising 58 pins, plus separate communication channels (two electrical Ethernet ports are shown on the right of the plug).

3 The enhanced auxiliary circuit plug of the eVD4 circuit breaker

4 The RBX615 relay is based on ABB's Relion® technology

The eVD4 has been designed to fully exploit the potential of the IEC 61850 standard and generic object-oriented substation events (GOOSE) technology, including the horizontal high-speed relay-to-relay communication, by means of an inter-panel bus. However, when required, a traditional point-to-point hard-wired connection to the RBX615 relay is possible through 12 digital inputs and eight digital outputs in the plug.

To enable easy installation of the eVD4, a dedicated panel socket accessory has been designed.

The RBX615 and HMI

The RBX615 is a general purpose relay based on ABB's Relion® technology and is designed specifically for operation in the eVD4 ➔ 4. The shape and pin layout of the relay have been optimized to enable a straightforward plug-in interface to the breaker using a dedicated docking unit.

It is available with five different preconfigured protection profiles, three of which focus on feeder protection and the remaining two are mainly intended for motor protection ➔ 5. The preconfigurations can be fully customized by the protection and control IED manager tool, PCM600 [1], and the application configuration tool (ACT), a graphical tool that enables the easy and simple modification of application logic. Several logic blocks are available to meet every substation need. Modifying the parameters of the protection and control logic provided in the preconfigurations can also be carried out via a human machine interface (HMI) located on the relay front panel ➔ 6.

This interface shows the single-line diagram (SLD) on the left with the relay menu on the right. The SLD can be edited using the graphical display editor tool inside the PCM600. The symbols indicated are dynamically linked to the related object (eg, circuit breaker, circuit-breaker racking gear, earthing switch, line disconnector) and their status is shown in the display. Moreover, the status of these objects can be easily controlled from the HMI.

The Ethernet port on the HMI facilities a point-to-point connection between the relay and a PC. With such a connection, the HMI is automatically displayed in the Web browser, allowing the user to modify the parameters of the protection functions as well as download disturbance records and several other features. No additional software needs to be installed on the client PC to communicate with the protection and control device. Two communication channels allow the relay to communicate with the process system. Even though the RBX615 is IEC 61850 compliant it also implements Modbus® TCP/IP. Other communication protocols will be available in the future.

The eVD4 fully exploits the potential of the IEC 61850 standard and GOOSE technology, including the horizontal high-speed relay-to-relay communication.

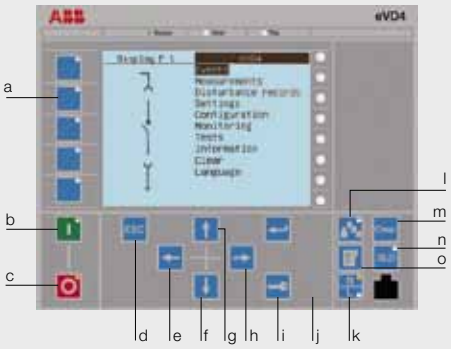
Footnote

1 PCM600 is IEC 61850 compliant, which simplifies IED engineering and enables information exchange with other IEC 61850-compliant tools.

5 The RBX615 relay can accommodate five different preconfigured protection profiles

Description	Configuration
Nondirectional overcurrent protection and nondirectional earth fault protection	Feeder 1 (F1)
Nondirectional overcurrent protection and directional earth fault protection based on measurement of the phase voltages	Feeder 2 (F2)
Directional overcurrent protection, directional earth fault protection based on measurement of the phase voltages, and undervoltage and overvoltage protection	Feeder 3 (F3)
Motor protection based on the current measurement	Motor 1 (M1)
Motor protection based on the current and voltage measurements	Motor 2 (M2)

6 The parameters of the protection and control logic provided in the preconfigurations are modified using the relay HMI



a Application function keys
b Closing
c Opening
d Escape
e Left
f Down
g Up
h Right
i Key
j Confirm
k Local/Remote
l LED page key
m Cancel
n Single-line diagram
o Menu

Two types of sensors are used in the eVD4: current sensors (based on the Rogowski coil principle) and a combined current and voltage sensor known as a combi-sensor.

Sensors

The latest and most advanced sensor technology is used in eVD4 automatic circuit breakers. Two types of sensors can be installed on board the eVD4 – current sensors (based on the Rogowski coil principle) and a combined current and voltage sensor known as a combi-sensor ➔ 7. The choice of sensor depends on the protection profile of the RBX615.

The sensors are used to:
- Convert large currents and voltages in the primary circuit of the network to an appropriate signal for secondary circuit equipment (ie, the protection relay RBX615)
- Insulate primary and secondary circuits from each other
- Protect secondary equipment from the harmful effects of the large currents and voltages that might occur on the primary side during a short circuit in the network

The entire range of currents and voltages is covered with just three sensor sizes, which extend up to the maximum rated current and voltage of the circuit breaker. A broken circuit or a short circuit in the signal cable is not dangerous and will cause no damage.

The current sensor consists of a Rogowski coil, a uniform winding on a closed circular support with a constant cross section and no ferromagnetic core ➔ 8. The voltage induced in the winding (the transmitted signal) is directly proportional to the variation in the let-through current. These sensors are characterized by the absence of saturation and hysteresis phenomena because there is no iron in the Rogowski coil and this guarantees excellent linearity. The current sensors for the eVD4 breaker output measurements are linear up to the maximum value set for the protection thresholds.

The voltage sensor uses a capacitive divider for voltage indication ➔ 9. In other words, a cylindrical metal electrode is molded into the sensor and faces the circuit-breaker bushing. The output signal is a voltage directly proportional to the primary voltage. As with the current sensors, the voltage sensors are characterized by the absence of ferroresonance phenomena and insensitivity to the effects of DC components.

The advantages of using integrated sensors in the eVD4 breaker include linear measurements and versatile protection; safety; small power comsumption; and that they are an environmentally friendly solution.

Linear measurements and versatile protection

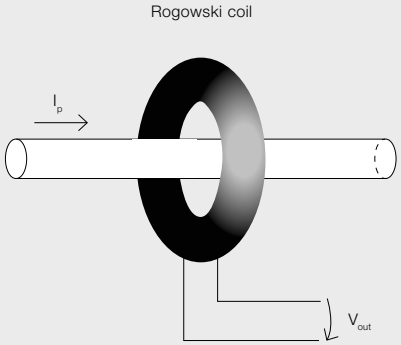
With no resonance and hysteresis phenomena the sensors exhibit good dynamic performance and are linear right up to the highest currents and voltages. As a result, they ensure high protection performance and enable multisided disturbance analysis.

Safety

The nominal value of the transmitted signal is low enough to be harmless to both people and secondary equipment, even when the highest currents and voltages occur on the primary side. A break or short circuit in the signal cable poses no danger and will cause no damage.

7 The choice of current or voltage sensors depends on the relay protection profile

8 The current sensors are based on the Rogowski coil principle



The transmitted signal is a voltage:

$$V_{out} = M\frac{di_p}{dt}$$

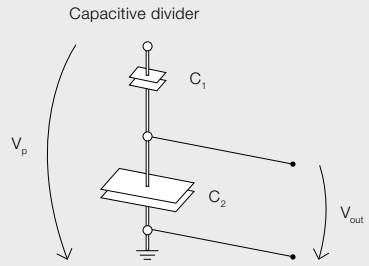
For a sinusoidal current under steady state conditions the voltage is:

$$V_{out} = M \cdot j \cdot \omega \cdot I_p$$

The signal is a sinusoidal voltage, proportional to the current, with 90° phase shift (lead).

In all cases, even if the primary current is non-sinusoidal, a signal reproducing the actual primary current waveform is obtained by integrating the transmitted signal.

9 The voltage sensors use a capacitive divider for voltage indication



Transmitted signal from a voltage divider:

The transmitted signal is:

$$V_{out} = \frac{C_1}{C_1 + C_2} V_p \quad \text{(capacitive divider)}$$

In all cases, the transmitted signal reproduces the actual primary voltage waveform.

Small power consumption

The efficiency of a sensor is high compared with that of instrument transformers. In addition, there are no losses in the secondary cabling. These savings contribute to increasing the life span of the equipment, and in a utility such savings are significant.

Environmentally friendly

In constructing the sensors, fewer raw materials are needed and power consumption is negligible.

The eVD4 is a major step forward in terms of performance, simplicity, reliability, safety and cost effectiveness.

Taking MV switchgear into the future

ABB's new eVD4 automatic circuit breaker is a key element for the creation of simple, reliable and safe MV switchgear. Full compliance with the new IEC 61850 standard and GOOSE functionality assure compatibility with new substation communication systems. The entire switchgear life cycle is optimized by the adoption of the eVD4. Starting from easier specification and ordering, to the drastically reduced complexity of the switchgear in terms of engineering, wiring and testing, to the commissioning and maintenance of the panel, the eVD4 is a major step forward in terms of performance, simplicity, reliability, safety and cost effectiveness.

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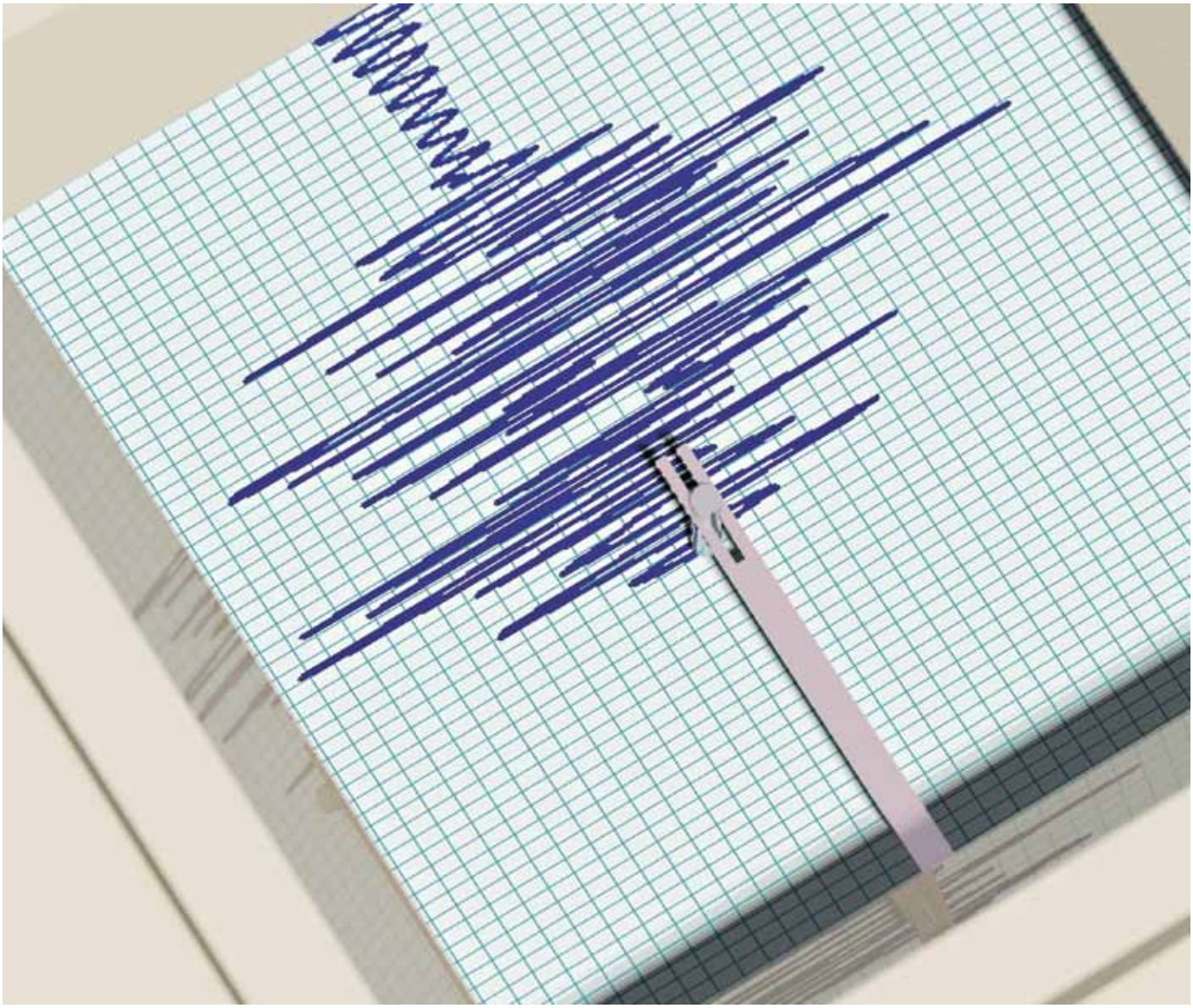
Title picture

The title picture shows ABB's eVD4 automatic circuit breaker with HMI for medium-voltage switchgear projects.

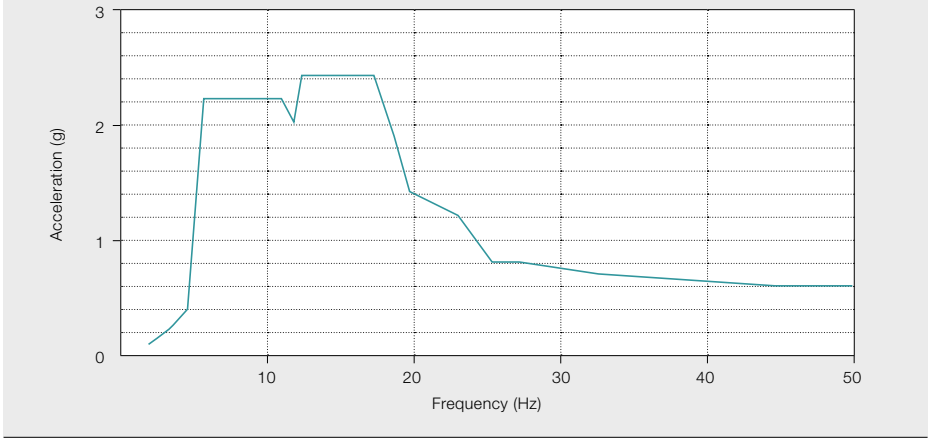


A seismic switch

Certified switchgear for nuclear power plants is providing a critical link in the chain

RENATO PICCARDO, ANNUNZIO REGANTINI, DAVIDE CATTANEO, LUCIANO DI MAIO – A nuclear power plant must be able to manage an enormous amount of energy in extremely safe conditions. All system functions must be controlled with absolute reliability and guaranteed operation. The equipment used must be able to withstand degradation over time caused by exposure to environmental extremes of temperature, pressure, humidity, radiation and vibration, including earthquakes. ABB has developed the UniGear ZS1 medium-voltage certified switchgear with the aim of satisfying all critical requirements.

1 Example of required response spectrum (RRS)



People working on nuclear projects know that attention to detail and only using equipment that has been certified is crucial: It is never acceptable to turn the key of a nuclear plant until it is certain that every component playing a safety function has been fully tested and certified. Detailed parameters for certification are specified in American IEEE[1] and European IEC[2] standards.

The qualification process

Every supplier of products for the safety chain of a nuclear power plant (NPP) must go through a specific qualification process, the purpose of which is to verify and certify complete reliability of system components.

Some of the equipment in a NPP may also be required to operate under very intense conditions. This is why the main purpose of a qualification process is to verify the ability to operate during various and well-defined environmental settings.

The critical scenario is the possibility of a seismic event: The system must be able to continue functioning during a so-called operating basic earthquake (OBE) or, in case of a very strong earthquake, it must be able to shut down the reactor, known as a safe shutdown earthquake (SSE). An additional requirement is verifying the functionality of each component under very intense environmental conditions in terms of temperature/humidity and after a thermal/radiation aging process.

According to both IEEE and IEC standards the following methods can be used to qualify system components (alone or in combination):

- Type testing: A type test subjects a representative sample of equipment, including interfaces, to a series of tests, simulating the effects of significant aging mechanisms during normal operation.
- Operating experience: Performance data from the equipment in question or from equipment of similar design that has successfully operated under known service conditions may be used in qualifying other equipment under equal or less severe conditions.
- Analysis: Qualification by analysis requires a logical assessment or a valid mathematical model of the equipment.

Degradation over time, along with exposure to environmental extremes of temperature, pressure, humidity, radiation and vibration, can hasten common-cause failures of qualified equipment. For this reason it is necessary to establish a "qualified life" for equipment with significant aging mechanisms. Qualified life is the period of time before the start of a design basis event for which equipment has demonstrated that it meets the design requirements for the specified service conditions [1].

Climatic qualification (cyclic damp heat)

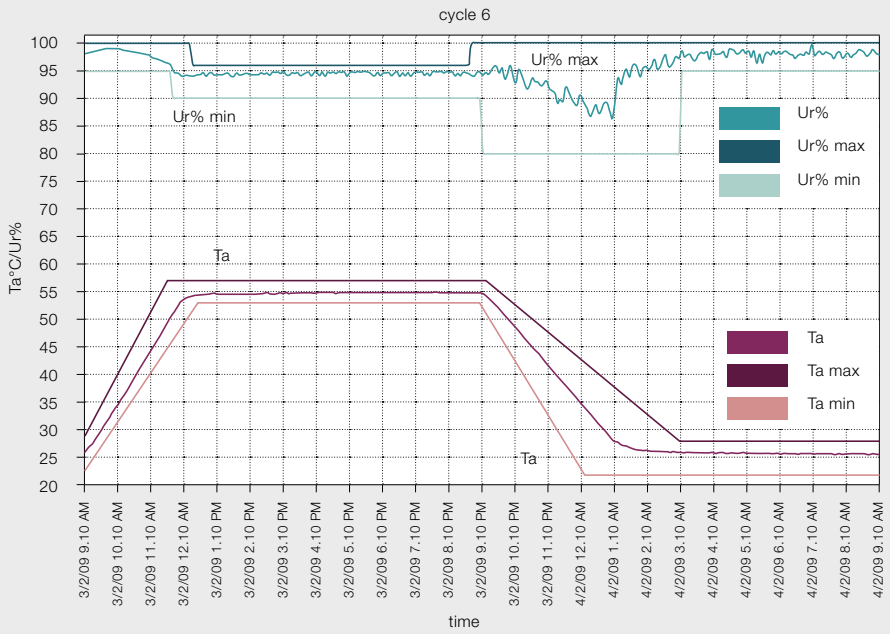
The purpose of climatic qualification is to prove that the switchgear will continue to perform its safety function before, during and after variation of the humidity and temperature levels in the environment where the equipment will be installed. The test determines the suitability of equipment under conditions of high humidity combined with cyclic temperature changes and production of condensation on the surface of the equipment being tested. In medium-voltage (MV) switchgear, condensation produced during humidity-temperature cycles can cause a reduction in the isolating properties.

The system must be able to continue functioning during a so-called operating basic earthquake (OBE) or, in case of a very strong earthquake, it must be able to shut down the reactor

Footnotes

1 Institute of Electrical and Electronics Engineers
2 International Electrotechnical Commission

2 The climatic testing cycle of the Doel NPP qualification



The ABB Competence Center located in Dalmine, Italy, has several recent references for medium voltage switchgear for nuclear plants in Europe: Tihange and Doel in Belgium, Cernavoda in Romania, Oskarsham in Sweden and Leibstadt in Switzerland.

Seismic and airplane impact test qualification

IEC 60980 [2] and IEEE 344 [3] standards represent the two main reference standards for the seismic qualification of safety electrical equipment for nuclear power stations. The response spectra are not defined in either standard, since they can vary depending on the geographic area and building structure. They are therefore normally defined in technical project specifications.

A time-history seismic test usually consists of a tri-axial independent multifrequency test performed on the basis of time histories (plots of the acceleration as a function of time) artificially synthesized from a given required response spectrum (RRS). The RRS takes into account the characteristics of the geographic location and of the supporting structure or building → 1. The time-history method is considered the best way to simulate seismic loads during the qualification of equipment.

During the seismic test the following earthquakes are simulated:

OBE/S1: an earthquake that produces accelerations where features for continued operation without risks to public safety are designed to remain functional.
SSE/S2: an earthquake that produces accelerations for which certain structures, systems and components necessary to ensure the integrity of the reactor coolant pressure boundary as well as the capability to shut down the reactor and maintain it in a safe shutdown condition, are designed to remain functional.

EMC qualification

The equipment must also be qualified to ensure full availability of the safety function in case of high electromagnetic stress, which may occur during accident conditions. Two types of testing, which reproduce the actual configuration of the instrumentation and control (I&C) devices installed in the primary equipment, including wiring, are performed on all of the equipment.

Immunity testing: Electromagnetic compatibility (EMC) qualification tests are performed in order to verify the level of immunity of the equipment from electromagnetic disturbance in a broad frequency range.

Emission testing: Electromagnetic emissions radiated and conducted on the wires by each piece of electrical equipment are measured over a broad spectrum.

Detailed functional tests are performed on all of the I&C functions, such as protection or control functions integrated into a single piece of equipment. The software qualification process follows IEC standards specifically developed for NPPs; these are described in IEC 60780 [4].

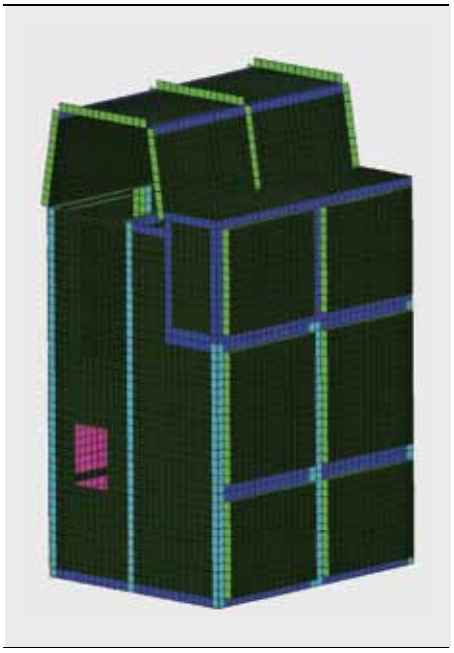
The ABB answer

ABB has the products, the expertise and the technical means to ensure that all NPP requirements are met. The ABB Competence Center located in Dalmine, Italy, has several recent references for MV NPP switchgear in Europe: Tihange and Doel in Belgium, Cernavoda in Romania, Oskarsham in Sweden and Leibstadt in Switzerland. For each of these projects, ABB's products underwent a rigorous qualification procedure. This process verified equipment functionality in the case of seismic events and severe environmental conditions.

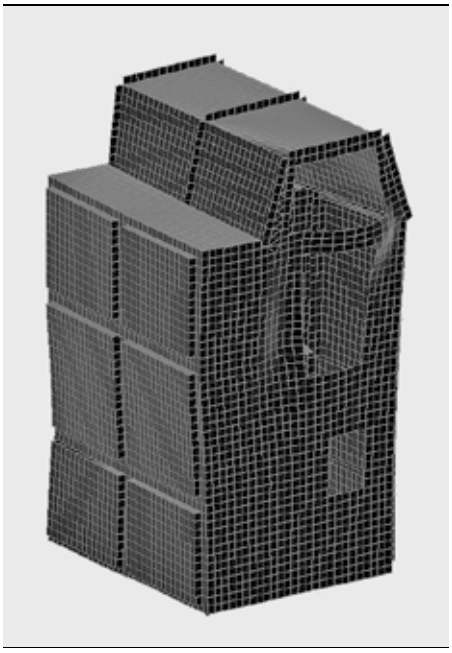
In addition to ABB's own products, laboratories and know-how, the company also can rely on a dedicated partnership with state-of-the-art laboratories located nearby containing, for example, a triaxial shake table; in addition, ABB can call on a team of experts on structures for seismic events. Software simulations of seismic events can provide many advantages for nuclear projects since no prototype is

3 Seismic test arrangement on UniGear ZS1 during Doel NPP qualification

4 Example of numerical evaluation of the structure used for analytical seismic qualification



5 Example of amplified deformation on UniGear ZS1 structure



needed, therefore achieving shorter scheduling times and a reduction in costs.

In 2009, Areva NP, an engineering, procurement and construction (EPC) leader in NPPs, certified that the ABB Competence Center satisfies the conditions for "planning and production of medium voltage switchgear for nuclear power plants."

MV Switchgear – UniGear ZS1

Medium-voltage switchgear is one of the most important links in the power distribution chain. ABB has developed the UniGear ZS1 switchgear with the aim of satisfying all users' requirements. UniGear ZS1 is a combination of consolidated solutions and innovative components from ABB. The MV switchgear is suitable for indoor installations. Metal partitions segregate the compartments from each other and the live parts are air-insulated. The range of apparatus for UniGear ZS1 switchgear is the most complete available on the market, and includes vacuum and gas circuit breakers and vacuum contactors with fuses.

Industry applications

Doel is one of two large-scale NPPs in Belgium. The Belgian energy corporation Electrabel, part of the GDF SUEZ group, is its largest stakeholder. In 2009 ABB supplied MV switchgear comprising 18 UniGear ZS1 panels with 12 kV / 1,600 A / 50 kA ratings and equipped with ABB HD4 SF_6 insulated circuit breakers. ABB equipment is used for distribution of energy supplied by diesel emergency generators.

The equipment supplied was qualified according to IEEE 323 and 344 standards and customer specifications, which included a request for climatic and seismic tests → 2. A specimen switchgear was identified so that all of the characteristics that were part of the supply were included. A qualification program was implemented on these prototypes → 3, achieving a successful outcome.

The Tihange Nuclear Plant is the other large-scale NPP in Belgium. The primary stakeholder in the plant is again the Belgian energy company Electrabel. The plant has three pressurized water reactors (PWRs), has a total capacity of 2,985 MWe and makes up 52 percent of the total Belgian nuclear generating capacity.

ABB has retrofitted 344 breakers made by CEM Gardy, with HD4 SF_6 breakers. On site there are 354 circuit breakers (including 35 spares) and 34 VT trucks (including seven spares). A VT truck is a piece of equipment that has voltage transformers fitted onto removable trucks. As required in the contract, the replacement of all circuit breakers and VT trucks took place within 2010; the site activity was performed along two years, during the annual routine maintenance shut-downs.

The qualification process was conceived in two different steps. Industrial and nuclear qualifications were based on IEC and IEEE standards for MV apparatus and switchgear, as well as on the customer's technical specifications. Seismic tests were performed according to IEEE standards at CESI-ISMES laboratories.

> Medium-voltage switchgear is one of the most important links in the power distribution chain. ABB's UniGear ZS1 switchgear is a combination of consolidated solutions and innovative components from ABB.

The Oskarshamn nuclear power station is one of ten active nuclear power stations in Sweden. With three reactors, the

ZS1 switchgear

In addition to ABB's own products, laboratories and know-how, the company also can rely on a dedicated partnership with state-of-the-art laboratories.

plant produces about 10 percent of the electricity needs of Sweden and its reactors use boiling water reactor (BWR) technology.

In 2009 ABB supplied four MV switchgear installations, each of them comprising seven UniGear ZS1 panels with a 12 kV / 1,600 A / 50 kA rating and equipped with ABB HD4 SF_6 breakers. As at Doel, ABB equipment is used for power distribution supplied by diesel generators for emergencies and the equipment supplied was qualified according to IEEE 323 and IEEE 344 standards, as well as the customer's specifications, which required seismic qualification.

Seismic qualification of the MV switchgear was performed by both analytical and testing methods. Both of these were carried out in collaboration with the CESI-ISMES laboratories located a few kilometers from the ABB MV switchgear factory → 4, → 5.

Modernization of existing NPPs

Retrofitting is the implementation of modern components (primary switching devices and digital protection/control technology) in existing MV installations. The aim of this modernization is to replace only those components that are planned for replacement according to their expected life cycle.

Because circuit breakers operate opening and closing currents, as opposed to other switchgear components that are static, in most cases breakers are the equipment most prone to aging. Therefore breakers are the components that are generally in the worst condition and replacing them with new ones is the best solution.

ABB has already performed retrofits on its own as well as competitors' breakers. The most extensive job was performed at the Tihange NPP where ABB retrofitted 344 CEM Gardy breakers with HD4 SF_6 breakers.

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[1] IEEE 323 IEEE standard for qualifying class 1E equipment for nuclear power generating stations.
[2] IEEE 344 Recommended practices for seismic qualification of class 1E equipment for nuclear power generating stations.
[3] IEC 60780 Nuclear power plants – Electrical equipment of the safety system – Qualification.
[4] IEC 60980 Recommended practices for seismic qualification of electrical equipment of the safety system for nuclear generating stations.

Further Reading

EN 61000-4 Series Electromagnetic compatibility – Testing and measurement techniques.

Title picture

Seismographs are used to record both real earthquakes and to monitor shake-table testing.

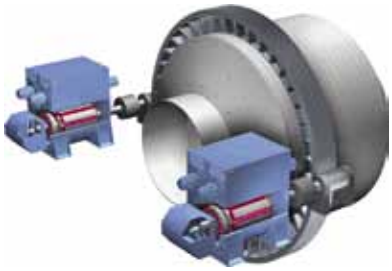
Driving value

Sophisticated ring-geared mill drives from ABB (Part 1)

MARCO RUFLI, MAARTEN VAN DE VIJFEIJKEN – The latest generation of ABB medium-voltage frequency converters provides excellent opportunities to improve the grinding process used in the minerals industry. Thanks to the development of several dedicated and advanced operational functions for the ring-geared grinding mills used in the industry, this generation of drives ensures smooth, safe and reliable operation with minimum stress on the mechanical equipment, as well as the highest possible availability of the mill. Part one of this two-part series will explains the operational benefits of implementing these functions, while part two will focus on the practical experiences gained with this kind of sophisticated ring-geared mill drive system.

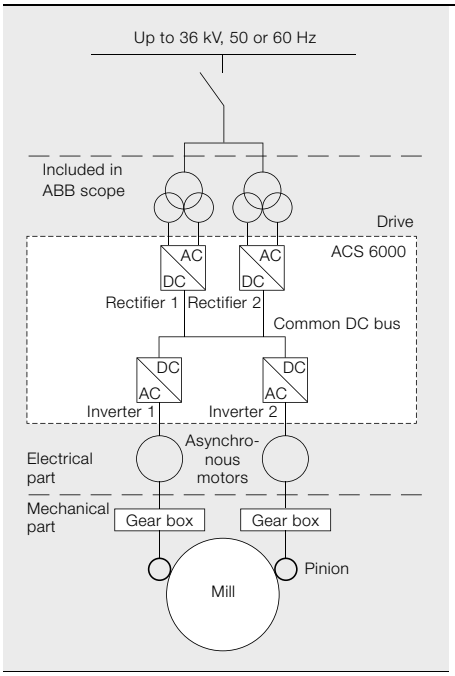
1 Dual-pinion high-speed mill drive and dual-pinion low-speed mill drive

With gearbox

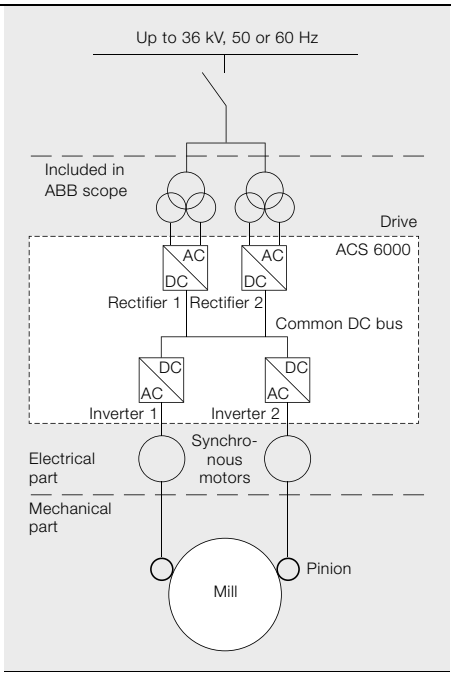


Without gearbox

2 A simplified overview of a dual-pinion high-speed mill drive and dual-pinion low-speed mill drive



With gearbox



Without gearbox

The demands of grinding mills can be split into operational, maintenance and protection: For smooth and safe operation, it is important that critical situations are avoided as much as possible; maintenance functionality must be quick and easy to execute; and protection of the system is important under all operating conditions.

In ring-geared mill drives (RMDs) and especially dual-pinion systems ➔ 1, the mechanical stress added by the motors can be significant. Therefore the control concept between the two motors must be fast and accurate to avoid any additional stress to the pinions and ring gear.

These demands can not only be reached but exceeded with ABB's latest generation of medium-voltage (MV) frequency-converter drives, which contain new and dedicated mill functions. The addition of an extra controller (ie, a mill controller) not only permits the inclusion of a lot of application related functionality and protection, but it also simplifies the interface between the mill drive system and the customer's distributed control system (DCS). The drives feature direct torque control (DTC) technology ➔ 2, which is known as the most advanced control method for AC drives in which the motor variables (torque and flux) are directly controlled by inverter switching. Operational- and maintenance-related functionality can only be added by using variable-speed drives and the accurate control that is part of the drive design. In addition, all inherent features of a frequency-converter drive benefit the system and provide greater flexibility in the control of the complete grinding process. These benefits include very accurate current and torque measurements, power-drop ride through and earth-fault and short-circuit protection.

On larger ring geared mills where the length of the pinion and ring-gear teeth is gradually increasing, the perfect alignment of the pinion and ring gear (and gearbox in some cases) is pivotal. However, experience has shown that it can be difficult to achieve and maintain perfect alignment; therefore, it is essential to avoid rough starts and torque spikes, in particular in larger mills. During all operation conditions (ie, starting, normal grinding operation, stopping) a mechanically friendly system is required.

The electric drive system configuration discussed in this article consists of a converter transformer, an ABB ACS 6000 multidrive MV frequency converter and two ABB AMI630 four-pole squirrel-cage asynchronous motors. The following sections explain the drive system performance during start, operation and stop sequences and how the sytem helps to improve overall mill operation.

Mill starting and stopping

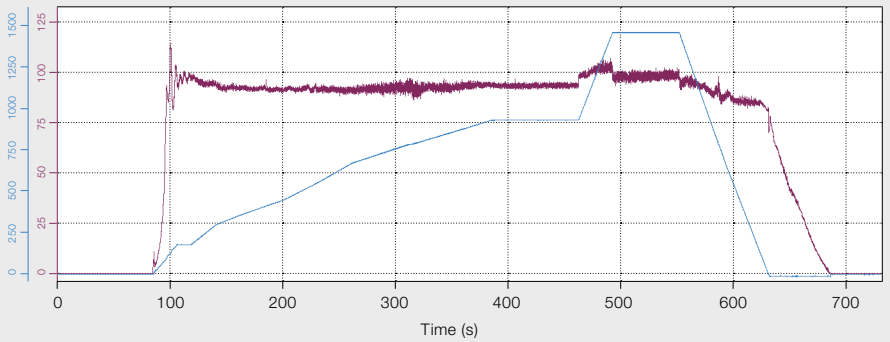
The mill start sequence is completely controlled by the electric drive system; the customer's DCS (or an operator-controlled local control panel close to the mill) only needs to send a simple start

command and the desired operation speed reference. To perform a smooth and safe start, the drive system first ramps up to the predefined starting speed (typically about 10 percent of nominal speed) where it is maintained and the torque and mill angle monitored. Normally the material in the mill cascades before the mill has turned 90 degrees. However, if the charge is locked or "frozen," it will drop from the top of the mill after it has turned 180 degrees. This could severely damage the mill and its bearings, resulting in an extensive and unscheduled shutdown. This situation can be avoided with ABB's sophisticated drive control technology which only releases the drive to follow the customer's DCS speed reference if the mill controller measures cascading of the material by a decreasing torque before the critical angle is reached ➔ 3. From then on the drive is under the customer's control, which means it will accurately follow any speed change requested by the DCS.

During startup there is a potential risk of a dropping frozen charge, which can seriously damage the mill shell, bearings and other equipment. ABB's mill controller completely eliminates this risk, and no further actions like creeping are required before giving a start command, even after a long downtime. If a frozen charge really does exist in the mill, the drive will trip and perform a coast stop before the critical angle is reached. In short, starting is extremely smooth for the mechanical components, such as the gearbox, pinion and ring gear as no huge torque spikes occur.

A section of the starting area shown in ➔ 3 is magnified in ➔ 4. The very first small torque peak (in maroon) demonstrates the breakaway torque after which the motor speed is ramped up slowly and gently while the torque increases with the mill rotating angle. At an angle of approximately 30 degrees (the first main torque peak is roughly 94 percent of rated torque, and the second and maximum torque peak is approximately 113 percent of rated torque), the material starts to cascade. Once the cascading charge has been detected, the mill is released to continue running at low speed until continuous cascade is reached, as illustrated by the constant torque measurements. At an angle of approximately 200 degrees the system is running stable, finally enabling the mill controller to release the drive so that it can follow the DCS speed reference.

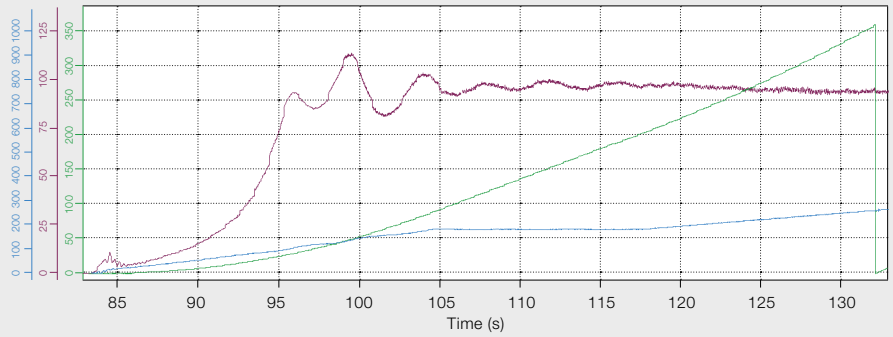
3 A complete start/stop sequence



Starting: Between 80 and 118 seconds
Operation: Between 118 and 550 seconds
Stopping: Between 550 and 690 seconds

Motor speed (rpm)
Motor torque (%)

4 Start sequence with frozen charge protection



Motor speed (rpm)
Motor torque (%)
Mill angle (deg)

The maximum possible motor torque can be limited in the drive with separate starting levels (higher torque limitation, such as 130 percent of rated torque) and for normal operation after starting (lower torque limitation, such as 110 percent of rated torque).

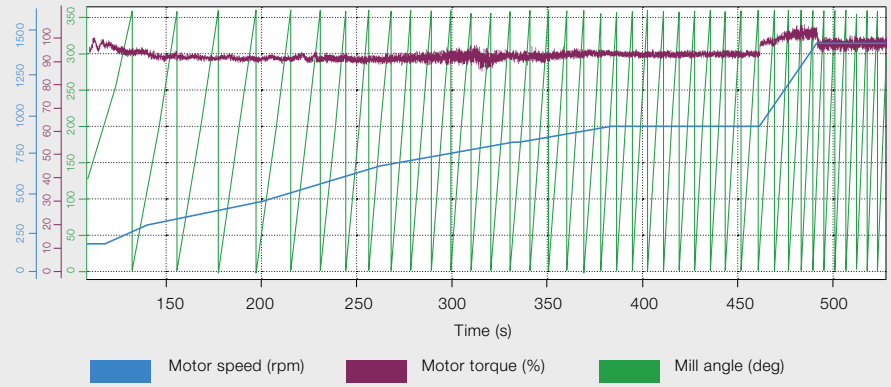
As well as being mechanically friendly, the starting process barely affects the electrical supply network because, as the motor is decoupled from the network via the ACS 6000 converter, there are no high starting currents as is typical with direct-online motors. Therefore, the current drawn from the network during starting is (at the maximum peak of 113 percent rated torque) only about 12 percent of the rated current.

Operation area

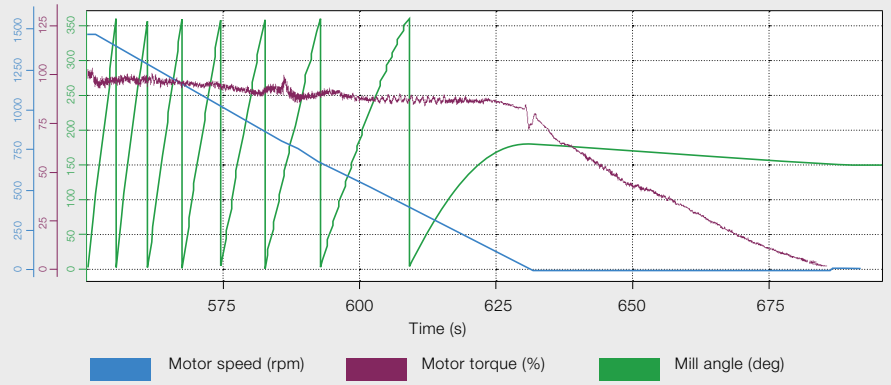
Once the mill controller releases the drive, the speed can be adapted by the operator according to the process

In ring-geared mill drives (RMDs), the mechanical stress added by the motors can be significant, and the control concept between them must be fast and accurate.

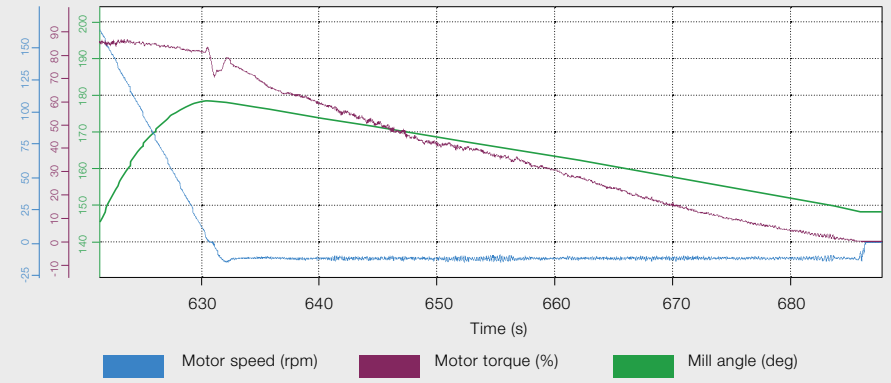
5 Normal operation



6 A complete stop sequence



7 A close-up view of controlled rollback



requirements. The electrical drive system can deliver constant torque over the entire speed range. It is also possible to run above nominal speed but with reduced torque (constant power operation area).

In ➔ 5, the operator slowly ramps up to the reference speed. After remaining at two-thirds of the nominal speed for more than a minute, the mill is ramped up to a top speed of almost 1,500 rpm (motor rated speed). Though it jumps slightly during the ramp-up (the acceleration torque is about 7 percent of nominal torque), the torque remains fairly constant over the entire speed range.

Stop sequence with controlled rollback

When a stop command has been issued by the DCS, the mill controller will assume full control of the stop sequence. To avoid the unnecessary and long backward and forward rocking of the mill caused by a coast stop, ABB has implemented a function called “controlled rollback,” which quickly brings the mill into a torque-free position in a controlled way.

For fast, easy and safe maintenance of the mill, ABB has implemented dedicated maintenance functions in the mill controller.

It works by ramping the speed down to zero. When it reaches zero, the drive system then proceeds slowly in the reverse direction in order to roll back the mill until no torque remains in the system ➔ 6. During this time the motor acts as a generator by reclaiming the potential energy left in the system due to the presence of material in the mill with a certain angle.

In this type of drive system – which includes a diode bridge rectifier that eliminates the possibility of feeding energy back into the network – the negative speed available to roll back the mill is relatively low. This is because the generative power is limited by the losses in the drive system (ie, the motor and in-

verter/DC link of the frequency converter). ABB also offers the option of a truly four-quadrant drive system with an active rectifier unit, which enables braking energy to be fed back into the network. This option significantly reduces the time required to roll back the mill.

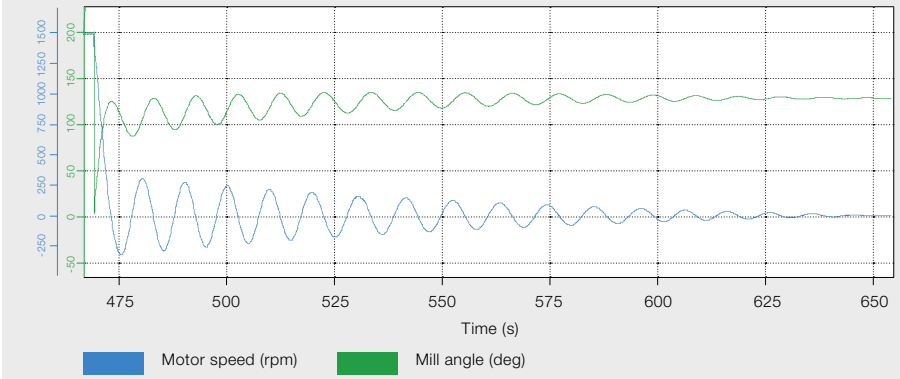
A close-up of the controlled rollback area (from ➔ 6) is shown in ➔ 7. When the mill speed has been ramped down and the mill is in an unbalanced position, the motor first creates a positive torque that just about holds the mill with the charge unbalanced. Slightly reducing the torque changes the direction of rotation, which then causes the mill to gently roll back until the charge is balanced. The data in ➔ 7 clearly show that the torque (applied to the pinion teeth) is always positive during the complete procedure, meaning there can be no backlash between the pinion and ring gear, and contact between the two is always maintained. If backlash were to happen, it would be shown by a drop in torque to zero or below.

In this particular configuration, the motor speed during controlled rollback is only 12.8 rpm, which is about 0.85 percent of nominal speed! In other words, the mill is smoothly rolled back in a controlled manner at a speed of about 0.1 rpm. Even at this very low speed, the system still runs stable thanks to ABB's advanced DTC technology. In addition, the time between reaching zero speed and zero torque (ie, mill stopped and no overshooting) takes about 55 seconds. While

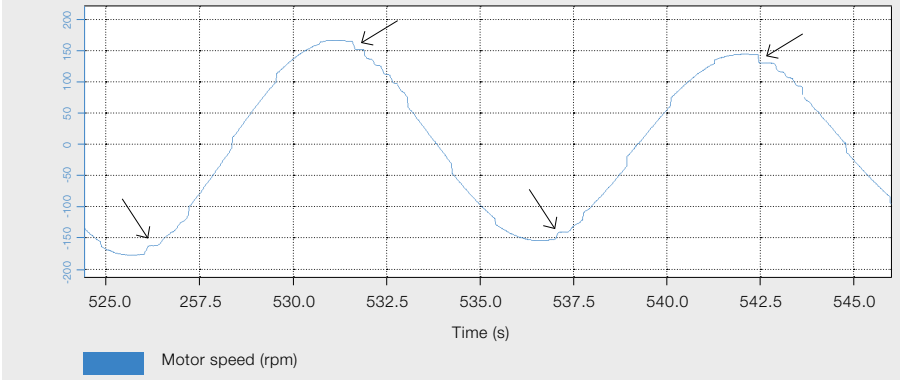
The latest generation of ABB MV frequency converters provides excellent opportunities to improve the grinding process used in the minerals industry.

this is significantly faster than a coast stop, the use of a converter setup with four quadrant capabilities would reduce this figure even further.

8 A coast stop (rocking mill)



9 Backlash during a coast stop



By looking at the angle curve (in ➔ 7), it can be observed that the mill was rolled back by 30 degrees, from about 178 degrees to approximately 148 degrees (ie, the angle curve decreases once the mill speed becomes negative at approximately 630 seconds). This matches perfectly with the measured cascading angle during the startup in ➔ 4.

Coast stop (rocking mill)

To fully appreciate the distinct benefits of variable-speed operation and therefore controlled rollback, a coast stop from nominal speed was tested on the same mill. The test showed that the time taken for the mill to reach a complete standstill, (ie, when the backward and forward rocking of the mill had ceased) after the "stop" command was received was about 180 seconds ➔ 8.

On closer inspection of the motor speed signal (measured by a tachometer on the motor) in ➔ 9, there is evidence of backlash (shown by the arrows) between the teeth of the pinion and the ring gear. The cause of this is as follows: The ring gear drives the motor, which has to be accelerated and decelerated due to its inertia. During the deceleration process, the tooth of the ring gear hits the tooth of the pinion several times to break the motor speed. Not only does this cause backlash, but it also severely stresses the gear teeth.

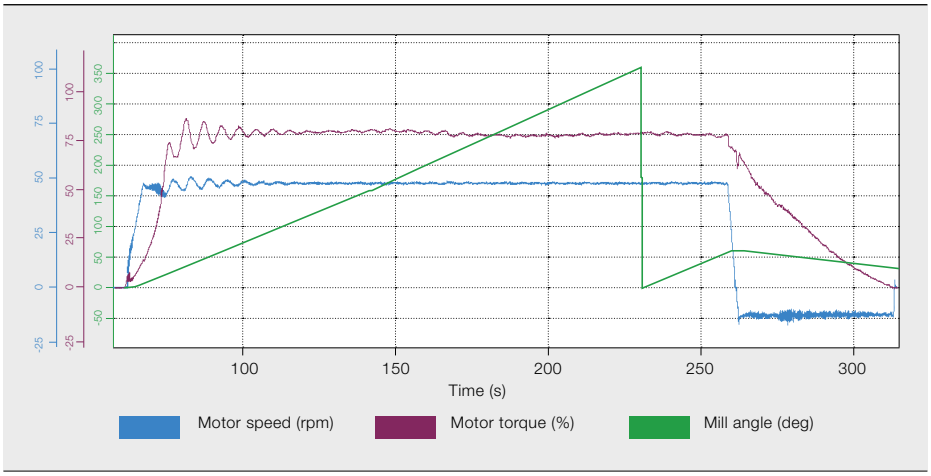
Maintenance functions

For fast, easy and safe maintenance of the mill, ABB has implemented dedicated maintenance functions in the mill controller.

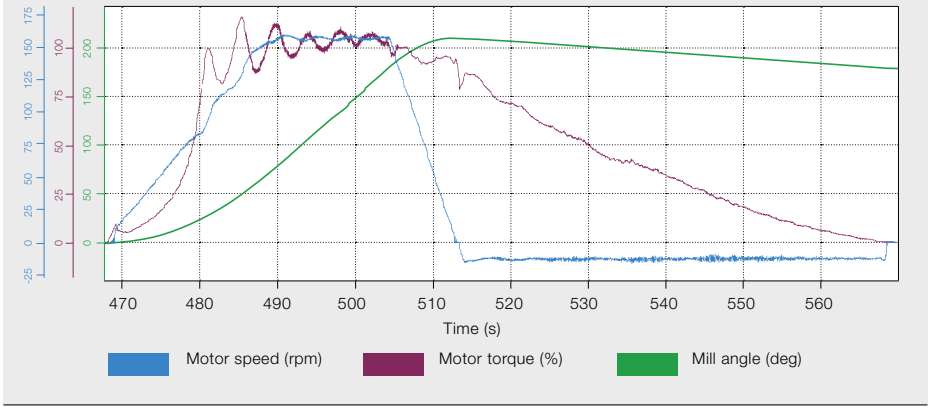
Creeping

Creeping, a common maintenance function for mills, is nothing more than turning the mill at very low speeds for maintenance purposes, such as the visual inspection of bearings or manual positioning for a liner change. In general mills using fixed-speed motors for the main drive system need an auxiliary motor with a reduction gearbox to perform creeping. ABB's mill drive systems can provide high torque at low speed, thereby ensuring creeping is possible with the main drive.

10 A creeping routine



11 Automatic positioning routine with 180 degree angle reference



The automatic positioning function allows operators to accurately turn the mill by any desired angle or number of liner rows.

Preferably, the creeping command should be initiated from a local control panel close to the mill, but it can also be activated remotely from the DCS. The start procedure is completely controlled by the mill controller and frozen charge protection is activated when creeping mode is selected. Creeping speed is typically 5 percent of nominal speed but can be adjusted to between 1 and 10 percent after a successful start.

A complete creeping sequence is shown in ➔ 10. The creeping speed is set at 48 rpm or 3.2 percent of nominal speed; cascading is detected at a mill angle of 23.5 degrees and a torque of 73 percent of nominal torque. The operator keeps the mill running at this speed for 420 degrees before initiating a stop command, causing the mill controller to ramp down the speed and perform a controlled rollback until there is no torque remaining in the system before stopping the drive.

Automatic positioning sequence

The automatic positioning function allows operators to accurately turn the mill by any desired angle or number of liner rows. In fact it is a very helpful function during liner replacement because it helps to reduce downtime and increase availability. Initiated by a local control panel or the DCS, the operator preselects the positioning mode, direction of rotation and desired angle or number of liners.

An automatic positioning function requesting a 180-degree turn is illustrated in ➔ 11: The material cascades at 27 degrees; the drive keeps running at low speed for a certain time before ramping down; at zero speed the mill has turned 209 degrees at which point the torque value is 94 percent of nominal torque (meaning the mill is fully loaded); and the drive then runs in reverse, slowly reducing the torque. By the time the drive stops (101.6 seconds later), the mill has turned 179.2 degrees, which translates into an inaccuracy of only 0.5 percent! The optimum positioning speed for this example was set at 158 rpm, which corresponds to 10.5 percent (10 percent is typical) of nominal speed. At this speed, the angle inaccuracies were below 1 percent for all tests.

Deformation protection

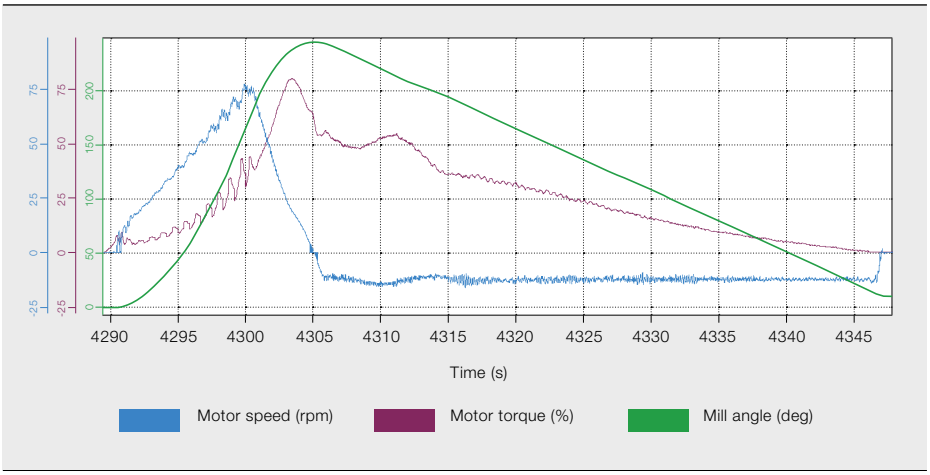
Deformation protection is an automatic positioning sequence with a fixed angle reference of 180 degrees. Even if deformation is not a real problem for grinding mills in the minerals industry, the function can still be used during longer mill stops (eg, maintenance) to prevent a frozen charge from occurring. Operators need only preselect a deformation protection mode and the preferred direction of rotation before issuing a start command. The mill controller then takes care of the 180 degree turn in exactly the same way as that illustrated in ➔ 11.

Frozen charge remover

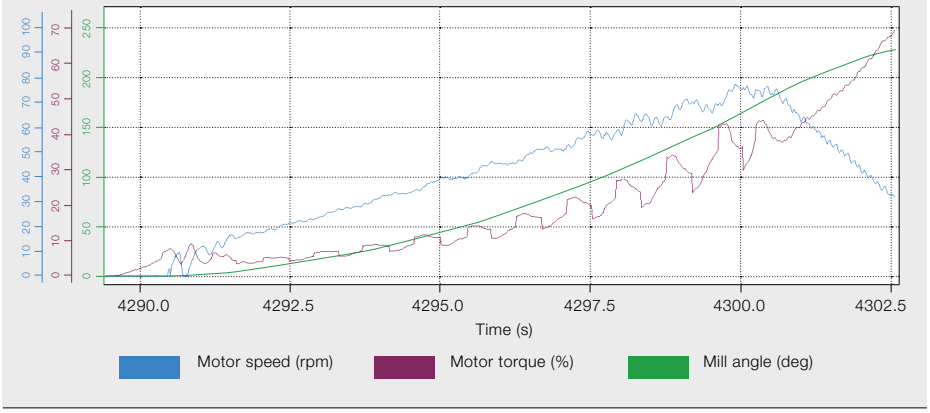
Frozen charges have been known to occur mostly on ball mills. After one has been detected, the frozen material needs to be removed; this is normally done manually and can result in significant downtime.

ABB's dedicated mill functionality not only protects the mill from a dropping frozen charge, but it also offers a patented function called frozen charge remover, which is available in the mill controller

12 Frozen charge remover with controlled rollback



13 Frozen charge remover torque steps



and can only be initiated manually from a local control panel or from the DCS. The frozen charge remover function tries to loosen the material by applying torque steps to the system. The optimal amplitude and duration of these steps are found and set during commissioning. The amplitude of the torque steps are defined in a way that adds a certain percentage of the actual torque to the system, while the protection functions, such as torque and current limits, operate as if the mill was performing under normal conditions. This means the mechanical equipment is never exposed to stress levels exceeding the values that can occur during normal operation. The frozen charge remover function can be applied in both positive and negative directions.

A complete frozen charge remover sequence with a positive direction of rotation and controlled rollback is shown in ➔ 12 and a close-up of the initial part of the sequence is given in ➔ 13. Torque steps, also reflected by speed changes, are applied to the system soon after a mill breakaway and are implemented by a sequence of accelerating and decelerating phases, which try to loosen the frozen charge. The amplitude of the steps is a fixed relative value of the actual torque added to the system and can be adjusted during commissioning.

With reference to ➔ 13 the maximum amplitude of the biggest torque step is 19.2 percent of nominal torque. Because torque and speed are always positive and operation takes place in the same (ie, first) quadrant, no backlash phenomenon can occur between the pinions and ring gear.

ABB's dedicated mill functions are capable of adding significant value to grinding mills in terms of efficient operation and maintenance.

To be continued …

ABB's dedicated mill functions are capable of adding significant value to grinding mills in terms of efficient operation and maintenance. But this drive system is also available for dual pinion mill drives, ie, when two motors are mechanically connected via the mill ring gear and operating together to turn the mill. This obviously requires accurate load sharing. Part two of this article will show, using field measurements, the amazing accuracy of a 2 × 5 MW dual pinion mill drive system.

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Further reading

[1] Ravani von Ow, T., Bomvisinho, L. (2010). *Use of the latest technology to overcome the demands of mill operation.* Paper presented at the 42nd Annual Canadian Mineral Processors Operators Conference, Ottawa, Canada.
[2] Ravani von Ow, T., Gerhard, B. (2010). *Ring-geared mills operated with frequency converter (much more than just variable speed).* Paper presented at the SME annual meeting, Phoenix, Arizona, United States.

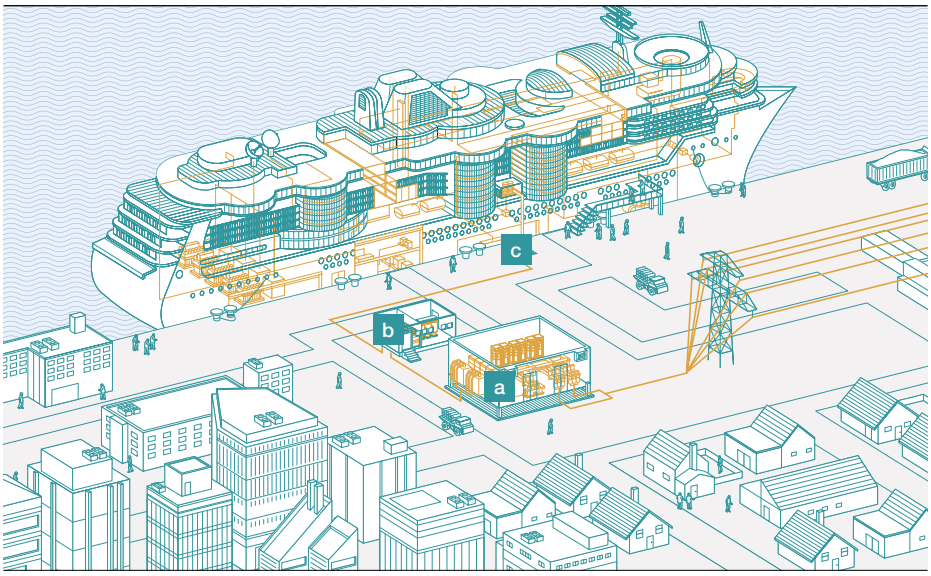
Title picture
The latest generation of ABB medium-voltage frequency converters are used in Boliden's Aitik copper concentrator plant in Sweden.

Onshore and onboard

Looking at the shore-side and shipside technologies and the case for standardization in shore-to-ship power

LUTZ THURM, ISMIR FAZLAGIC, THORSTEN HARDER, KNUT MARQUART –
The environmental footprint of port areas is under scrutiny. Governments, port authorities and shipowners have explored different solutions to reduce emissions from ships while they are engaged in port operations. One solution to this problem has been identified as connecting ships in port to an onshore power supply, where electricity from the shore-based grid is used to power ships' infrastructure used for hosting crew and passengers while docked, and for cargo-handling activities. With the impending standardization of shore-to-ship power, implementation of the solution is sure to expand, helping port authorities and shipowners to reduce portside emissions.

1 General overview of shore-to-ship power supply



1a Transformer and switchgear 1b Converter 1c Connector

A case has been made for shore-to-ship power supply → 1: The environmental profile of electricity generated by power plants on land versus ships' diesel engines running on bunker fuels is one of the main advantages of this technology. Through shore-based power [1], regulators can respond to a specific, local problem (pollution) with a specific, local solution (power connection from shore). For ports, the ability to supply power to ships at berth enables them to establish a more efficient and powerful overall electrical supply as a utility. In addition, the investment in infrastructure is sustainable over decades with long-term revenues. For the port area community, there is an additional benefit of reduced noise and vibration in harbor areas. And with standardization of shore-to-ship power supply, investment in the technology becomes more worthwhile.

Shoreside technology

The technology required to provide onshore power to ships at berth is not novel equipment. Engineers today can use proven technology in order to develop a reliable infrastructure to transfer the power, with rigorous technical attention to issues such as safe cable management. Costs for the equipment vary widely, depending on the specific needs of the port and the power it will provide. Additional investments stem from construction and installation at the quay and potential needs related to strengthening the port's electricity grid.

Power supply in ports is typically equivalent to that of a small factory, with electricity needed to power shoreside loading and unloading infrastructure such as cranes, belts and gantries, cooling, heating as well as incidentals. Most ports have access to enough power to run these consumers, with an additional 2 to 3 MW for secondary needs. Given that a vessel's power needs while in port may be as much as 10 MW depending on the type of vessel, the electrical infrastructure at many ports will be insufficient to handle significant shore-to-ship power connections without a major improvement to their grid. This may involve investing in a new substation or installing a new incoming power line with more power; both of these actions would involve negotiation with the port's power provider.

Power supply in ports is typically equivalent to that of a small factory, with electricity needed to power shoreside loading and unloading infrastructure.

Onshore power solutions often comprise the entire chain from the incoming substation and include transformers and frequency converters to match the grid power voltage and frequency to the ship's onboard power system. These allow several vessels to be connected simultaneously and enable the supply of 50 and 60 Hertz power regardless of the local grid frequency. They also comprise the connecting cables and berth terminals.

For each shore-based power connection point, the port or terminal must have a dedicated transformer, which serves two purposes. First, it provides the required galvanic separation (a nonmetallic direct connection between the onshore power supply grid and the ship's internal system), so that an earth fault in the ship's electrical system will not endanger the port grid or vice versa. Second, the transformer steps down the power supply from a voltage level optimized for distribution (eg, 20 kV) to one of the two voltage levels standardized for shore-to-

Footnote

1 Shore-to-ship power is also known as cold ironing, onshore power supply, alternative maritime power (AMP) or shore connection, among others.

2 ABB's static frequency converter portfolio for shore-to-ship power applications ranges from 120 kVA (PCS100) to multiple MVAs (PCS6000).

a ABB's PCS100 static frequency converter

b ABB's PCS6000 static frequency converter

ship power connections: 11 or 6.6 kV as required by the ship.

Each shore-based power connection point also requires medium-voltage (MV) switchgear with an automated earthing switch. In essence, the switchgear interrupts the power supply and the switch ensures that there is absolutely no power in the cables between the ship and shore while they are being handled and connected. As the highest risk associated with shore-based power connections is injury to personnel manipulating the cables and systems, this switchgear is critical.

A static frequency converter is required for most shore-based power connections ➔ 2. The majority of ships operate with a 60 Hz supply, whereas local power grids in many parts of the world use 50 Hz ➔ 3. As a result, most shore-based power connections will require a frequency conversion. Static frequency converters provide an economical solution to connect any ship to any grid independent of the required frequency. Depending on the port's layout, a centralized solution with one converter may serve multiple ships and berths. Thanks to their small footprint, the converters can fit into any substation building or container along with the compact switchgear and transformers. In addition, the frequency converters improve the overall power quality of the port grid by improving the power factor and stabilizing voltage and frequency. Depending on the project requirements, low-voltage PCS100 or medium-voltage PCS6000 converters are used ➔ 2.

Finally, the shoreside infrastructure for a shore-to-ship power connection must include an automation and communications system, which allows personnel to coordinate the connection of cables and synchronize the ship's electrical load to the shoreside supply. This is possible with two RTUs (remote terminal units) – one onboard and one onshore – that have Ethernet communication via a fiber-optic cable.

> Many of today's ships with shore connection equipment have been retrofitted rather than built with the equipment installed.

The shore-based power connection system need not occupy much precious quayside space. The incoming substation can be conveniently located as far as 10 km from the quayside transformer and MV panels that directly supply the vessel with electricity. At the quayside, there is only a small and secure room-sized container that houses the power transformer, the MV switchgear with an automated earthing switch, protection and control devices, and the operator interface. The major benefit of a compact shoreside infrastructure is that it ensures smooth dockside operations and can also be made mobile.

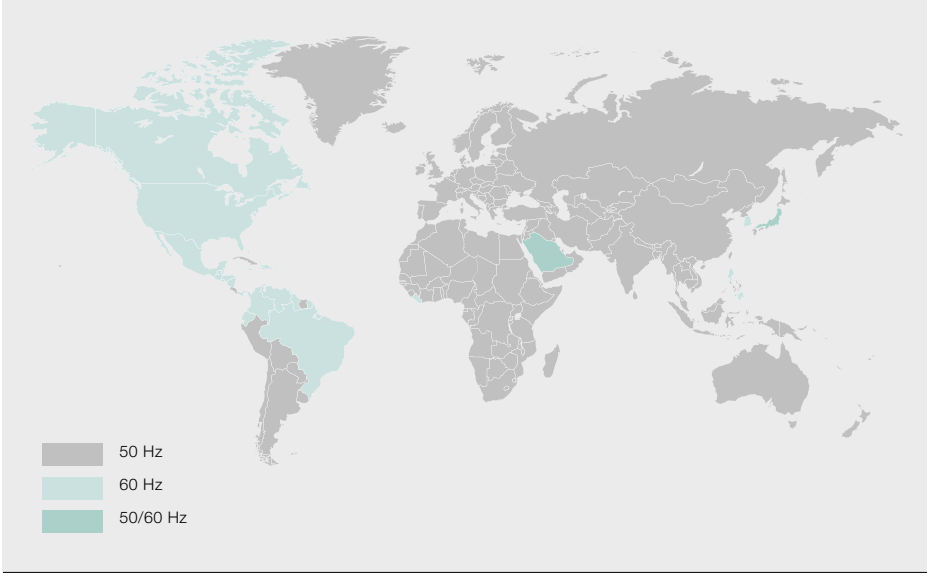
Shipside technology

To use power from the shore-based electricity grid, ships must be either built or retrofitted with equipment that enables the connection to shore, synchronizes the power changeover from shore to ship and connects the incoming power supply to the ship's auxiliary power system. Ships can be safely retrofitted in a relatively short time while in operation or dry docking, without major interruption of operations.

First, the shore-based power must get onboard via cables ➔ 4, 5. In some cases, particularly with container ships and roll-on/roll-off car carriers, the cable is installed on the ship and lowered via a spool or drum to the quay, where it is connected. On cruise ships, the cable is always shoreside, with a small integrated hydraulic arm to guide it.

When the cable-management system is onshore, the electrical connection is received shipside by a shore connection panel ➔ 6. This panel must generally be located close to the hull and in convenient reach of the heavy shoreside

3 Frequencies throughout the world. Such differences necessitate frequency converters for shore-to-ship power.



4 Connection cables on Holland America Line's Vista-class ms Oosterdam vessel

cables. The shore connection panel contains a circuit breaker, a protection relay, the physical electrical connection (plugs and grounding cable), and a control interface with the ship's integrated automation system, or power management system. These systems allow the incoming power to be synchronized with the ship's diesel auxiliary engines before the load is transferred. ABB shore connection panels include two cabinets, the dimensions of which vary depending on the power rating. This MV equipment must be installed in a dedicated room.

On ships that use conventional mechanical propulsion (in which the diesel engines directly power the ship's propellers, as opposed to diesel electric propulsion), the ship's low-voltage auxiliary power system – typically 400 to 690 V – requires a transformer to receive the 11 or 6.6 kV power supply from shore. This transformer is relatively large and bulky, but – unlike the shore connection panel – it can be installed in the engine room or any other suitable location onboard.

The process of connecting and disconnecting a ship to the shore-based power supply takes between five and 30 minutes. Onboard, the chief engineer or a trained staff member experienced with the ship's power management system handles the power transfer. Cable management can be done either by ship or shore personnel with adequate training in handling MV equipment. At least one company has begun investigating an automated system for plugging the cables into the ship to improve safety and save time.

Currently, the majority of ships equipped with the infrastructure to receive shore-based power are container vessels, and many ship designers are either including this infrastructure in their designs or are setting aside space for it. Many of today's ships with shore connection equipment have been retrofitted (ie, the equipment is added to an existing vessel), rather than built with the equipment installed.

While little of the technology installed onboard ships for onshore power supply is new, usually the entire system must be engineered on a case-by-case basis for each installation. Even if the connection is standardized, ship design is not, meaning that questions of space, accessibility, interfacing with the power management system and the diesel engines all need to be surveyed and assessed prior to installation. ABB has developed turnkey solutions covering the entire scope of delivery, with minimal interruption of ship operations.

Standardizing shore-to-ship power connection systems

In order for shore-to-ship power supply to make sense for ports and shipowners, the nature and arrangement of power connections must be standardized. Neither a port owner nor a shipowner can justify investment in expensive equipment to enable a shore connection system without assurance that such a system will be functional across many

The IEC, ISO and IEEE joined forces to create a standard that will enable onshore power connections to effectively have a water-tight global basis.

5 ABB shore-to-ship power connection in Gothenburg, Sweden

6 ABB shore connection panel

jurisdictions and for a defined period of time.

Work on a common standard for onshore power supply for ships at berth began early in 2005. Major players in this effort have included technology suppliers, governments, port authorities, shipowners (particularly cruise line, tanker and container ship companies), classification societies and others. The IEC, ISO and IEEE [2] joined forces to create a standard that will enable onshore power connections to effectively have a water-tight global basis.

Through shore-based power supply, regulators can respond to a specific, local problem (pollution) with a specific, local solution (power connection from shore).

The standard applies to the specification, installation and testing of onshore power systems and plants and addresses:
– The onshore distribution system
– The shore-to-ship connection
– Transformers/reactors
– Semiconductor converters and rotating converters
– Ship distribution systems
– Control, monitoring, interlocking and power management systems

The purpose of the standards work was to define requirements that "support, with the application of suitable operating practices, compliant ships to connect quickly to compliant high-voltage shore power supplies through a compatible shore-to-ship connection" [1]. This should eliminate the need for ships or port operators to adapt or adjust their infrastructure to enable connections.

The initial goal of creating a single, global connection standard for all ships at all ports was abandoned out of necessity. The power needs and capacities of ships differ so much that a single standard would be unfeasible. As a result, four separate, but linked, standards were created – one for ro-ro ships, one for container ships, one for cruise ships and another for tankers. In addition, there are two main standard voltages for connection – 11 kV and 6.6 kV.

With a global standard in place, investment in shore-to-ship power connection systems by ports and shipowners is due to take off. The final standard is on the verge of ratification.

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Further reading
– Marquart, K., Haasdijk, T., Ferrari, GB, Schmidhalter, R. Shore-to-ship power: ABB's turnkey solution is effectively reducing portside emissions. *ABB Review* 4/2010, 56–60.
– www.abb.com/ports

Reference
[1] IEC/PAS 60092-510. Edition 1.0 (2009, April). Electrical installations in ships – Part 510: Special features – High-voltage shore connection systems. Retrieved September 20, 2010 from http://webstore.iec.ch/preview/info_iecpas60092-510%7Bed1.0%7Den.pdf.

Footnote
2 IEC is the International Electrotechnical Commission; ISO is the International Organization for Standardization; IEEE is the Institute of Electrical and Electronics Engineers.

Title picture
The Holland America Line cruise ship ms Zuiderdam (page 36) is equipped with shore-to-ship power technology, helping to make residential life in harbors more liveable.

The five-level converter

ANPC-5L technology and the ACS 2000 drive

FREDERICK KIEFERNDORF, MICHAEL BASLER, LEONARDO SERPA, JAN-HENNING FABIAN, ANTONIO COCCIA, GERALD SCHEUER – Modern power electronics have revolutionized the delivery and usage of electrical power. In the area of drives, the ability to arbitrarily select and even continuously vary the output voltage frequency and amplitude of an inverter has permitted significant gains in energy efficiency and controllability. Inverters synthesize AC voltage by switching between different levels of DC voltage at a high frequency using semiconductors. The waveform created thus differs from an "ideal" sinusoidal waveform because of this rectangular switching pattern. The difference can be sufficient to bar the use of drives from many applications requiring a higher "quality" of AC voltage. One way to make the energy-efficient advantages of drives available to a broader range of applications is to increase the number of DC voltage levels available. ABB's ACS 2000 breaks beyond the commonly used three voltage levels and works with five. Furthermore, through its ingenious topology, it avoids many of the issues that otherwise make five-level converters complex.

An inverter (a circuit that converts DC to AC) works on the principle of switching between different levels of DC voltage. The output is thus not a sine-shaped AC wave but a pattern of high-frequency rectangular pulses that are made to resemble the sine wave as accurately as possible ➔ 1c. One analogy would be to consider a digital photograph taken at low resolution. The photograph does not accurately resemble the object it depicts because the low number of pixels limits the level of detail that can be represented. The ability to approximate an ideal sine wave with rectanglar pulses is similarly restricted by the number of available voltage levels. In contrast to the photograph, however, the differences are not just an aesthetic problem: The non-ideal sine shape causes harmonics (currents and voltages at higher frequencies) that can have repercussions ranging from stress on the insulation and bearings of motors to interference with other equipment. Harmonic filters can be used to smooth the output by absorbing problematic harmonics, but these are both a cost factor and a cause of additional losses. To deal with the effects of these harmonics, either motors must be designed to handle the extra stresses (which then excludes the use of many standard catalog motors) or such converters cannot be added to existing applications. There is therefore a strong case for a converter that can produce a more ideal sine output.

Inverter levels

The simplest inverter is the two-level converter. It is called two-level because it can apply only two voltage levels: the DC supply voltage and the reverse of that voltage. The three-level neutral-point clamped (NPC) converter is an extension of this concept that can additionally apply the neutral point voltage ➔ 1a and produce switching patterns of the type shown in ➔ 1c.

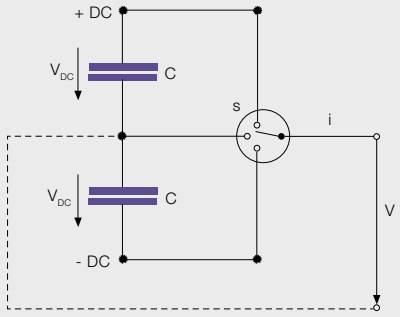
Converters have been designed that take a step beyond this and output five voltage levels. However, such circuits often come at the price of far higher complexity. For example, if the DC supply were to be built with five rather than three voltage levels, it would require additional clamping diodes and capacitors and the corresponding control and charging circuitry. An alternative approach is to connect converters in series. This again adds to the complexity of the DC supply circuit due to the need for galvanic separation of the supplies and thus costly transformers. Such solutions may be acceptable at high power levels, but the lower end of the medium-voltage drive range calls for simpler solutions.

ABB set out to address these issues, and found a solution that can output five power levels without adding complexity to the DC supply. A three-level DC supply alone cannot supply five voltage levels, and so the circuit does require an additional capacitor per output phase. But the solution ABB created ingeniously keeps this capacitor charged without the need for dedicated control circuitry.

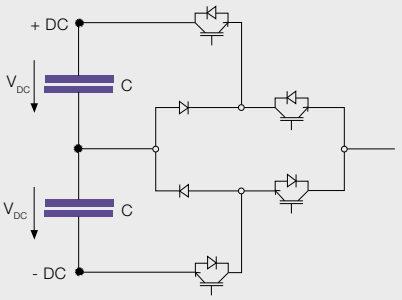
The ANPC-5L

The basics of the active neutral point clamped five-level (ANPC-5L) converter are shown in ➔ 2a. The phase capacitor C_{ph} is kept charged to half the voltage of the capacitors in the DC link, ie, one quarter of the total DC-link voltage. The overall principle of the circuit can be considered as a three-level NPC converter plus an additional capacitor. This phase capacitor is switched in series with the three-level converter as required and provides two additional intermediate output levels.

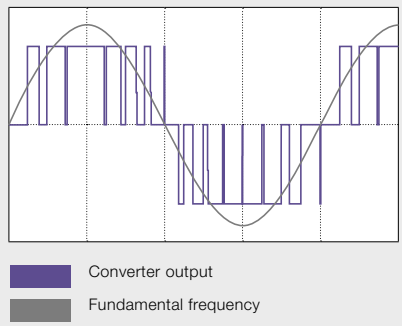
1 The basics of an NPC converter (only one phase shown)



1a Principle of operation



1b Circuit



1c Voltage waveform (sample)

The ANPC-5L requires only one more capacitor per phase than a NPC three-level converter.

The DC supply is identical to that of a three-level NPC converter. Cell 1 in ➔ 2b is clearly similar in its topology to a NPC three-level converter ➔ 1b. Similarly to such a circuit, the IGBT (insulated gate bipolar transistor) switching devices in cell 1 are rated for half the DC link voltage. Because the additional capacitor is charged to a quarter of the DC-link voltage, the IGBTs in cells 2 and 3 are rated for this lower voltage. This use of devices with lower ratings contributes to the simplicity of the converter. The elegance of the design becomes even more apparent when it is considered that it requires only one additional capacitor per phase than does an NPC three-level converter. The converter provides full four-quadrant functionality (power can be converted in both directions).

Operation of the ANPC-5L

The switching devices in cell 1 (of ➔ 2b) are operated in complementary fashion, with S1 and Snp2 being operated together (and likewise S4 and Snp1). The devices in cell 2 are operated in opposition as are those in cell 3. The total number of switching states per phase is shown in ➔ 3. In total, eight states are possible. As the converter has only five output levels, some states are redundant. However, rather than implying that certain converter states are never used, the study of ➔ 3 reveals that for two of the three redundant state pairs, ie, V1/V2 and V5/V6, opposite effects can be made on the charging of the phase capacitor. ➔ 4 compares V5 and V6, and shows how V6 subtracts $V_{DC}/2$ from the DC-link voltage whereas V5 adds it to the neutral point voltage. As a result the current through the phase capacitor is in the opposite direction. This feature can be used to maintain the required voltage in the phase capacitor without any further charging circuitry.

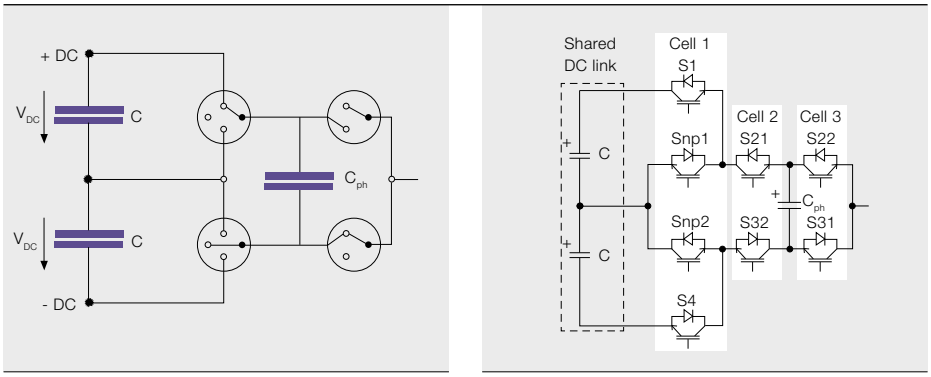
The ACS 2000

The ACS 2000 drive uses two five-level converters in a back-to-back (B2B) configuration. The basic layout of the ACS 2000 is presented in ➔ 5.

Mechanical design

The transformerless ACS 2000 ➔ 6, is designed to maximize uptime through its modular construction. Components are sized to fulfill the expected lifetime and easy front-side access is provided for all critical components. The drawer design

2 Principle of the ANPC-5L converter (only one phase shown)



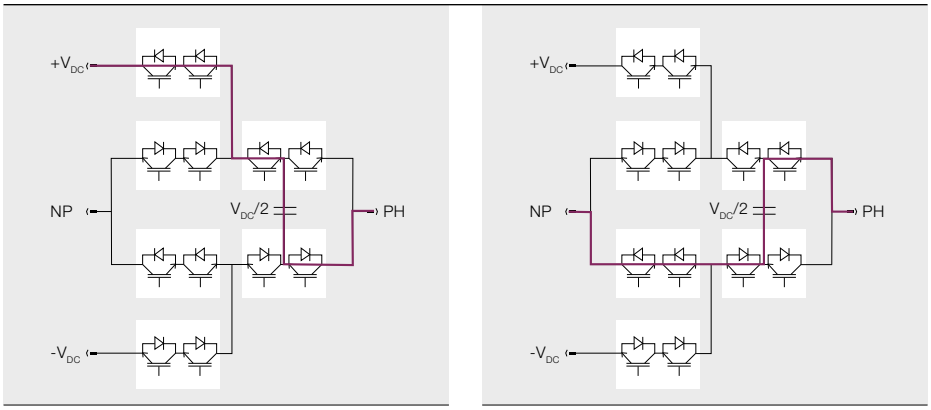
2a Principle of operation **2b Circuit**

The capacitor C_{ph} is kept charged to half the voltage of a DC-link capacitor.

3 Phase states of ANPC-5L converter

Cell 3				Cell 2		Cell 1		Output level	Phase output voltage	Effect on Cph		Effect on Vnp		Switching vector
S4	Snp2	Snp1	S1	S32	S21	S31	S22			i>0	i<0	i>0	i<0	
1	0	1	0	1	0	1	0	–2	–V	0	0	0	0	V0
1	0	1	0	1	0	0	1	–1	–V/2	–	+	0	0	V1
1	0	1	0	0	1	1	0	–1	–V/2	+	–	–	+	V2
1	0	1	0	0	1	0	1	0	0	0	0	–	+	V3
0	1	0	1	1	0	1	0	0	0	0	0	–	+	V4
0	1	0	1	1	0	0	1	+1	V/2	–	+	–	+	V5
0	1	0	1	0	1	1	0	+1	V/2	+	–	0	0	V6
0	1	0	1	0	1	0	1	+2	V	0	0	0	0	V7

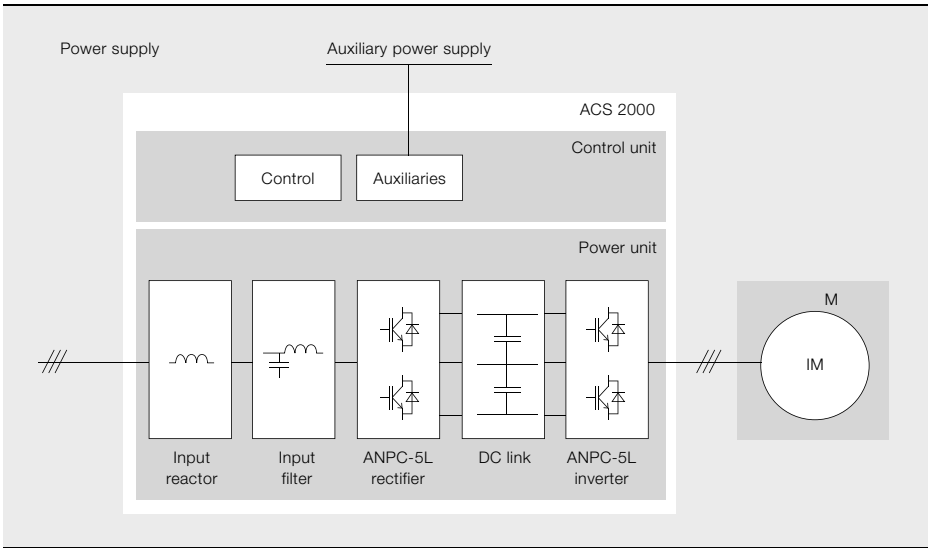
4 Two different current paths both producing the same output voltage.



4a Switching state V6 from ➔ 3 **4b Switching state V5 from ➔ 3**

The opposite direction of the current in C_{ph} permits the charge of this capacitor to be maintained.

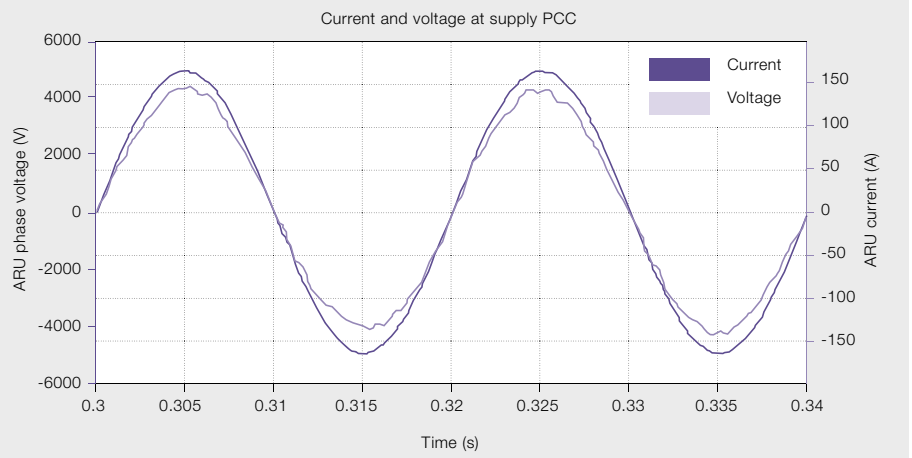
5 Basic configuration of ACS 2000 drive



6 800kW 6kV transformerless ACS 2000 drive

7 ACS 2000 phase module

8 Voltage and current of drive input showing unity power-factor operation



The transformerless ACS 2000 drive is designed to maximize uptime through its modular construction.

of the phase modules facilitates quick and safe replacement in case of faults.

A key component of the modular concept is the phase module ➔ 7. The module comprises the main components of one phase leg of the converter (as shown in ➔ 2b), including the power semiconductors, the gate unit and the phase capacitor. The module additionally contains an interface board to the upper-level control as well as current and voltage measurement equipment. This allows a simple interconnection as only a power connection and a fiber-optic link need to be established. The current-carrying connections are realized as contact plugs.

Thanks to this simplicity, the end user can replace a module within minutes.

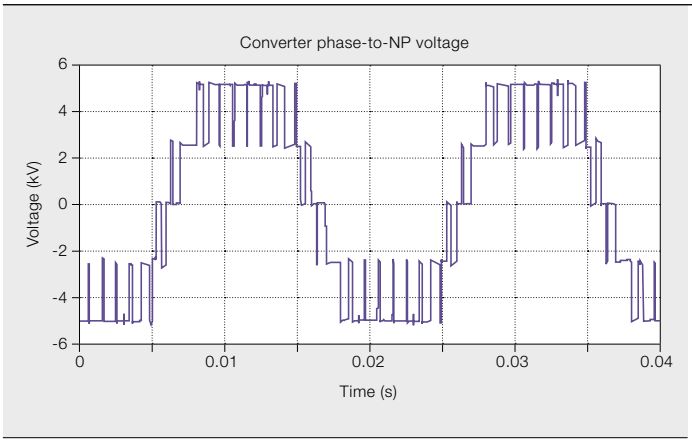
Testing

The ACS 2000 was tested in a B2B configuration. Two ACS 2000 drives were installed: the DUT (device under test) and a load inverter. Both drives were supplied from a common three-phase network connection and were connected to their respective electric machines (which were on a common shaft). One practical result of this interconnection is that only the losses in the drive system have to be covered by the supply. As both drives (DUT and loading inverter) were ACS 2000, it was possible to observe the motoring and regenerating modes simultaneously. Long-term B2B tests were also performed to verify the high reliability of the drives.

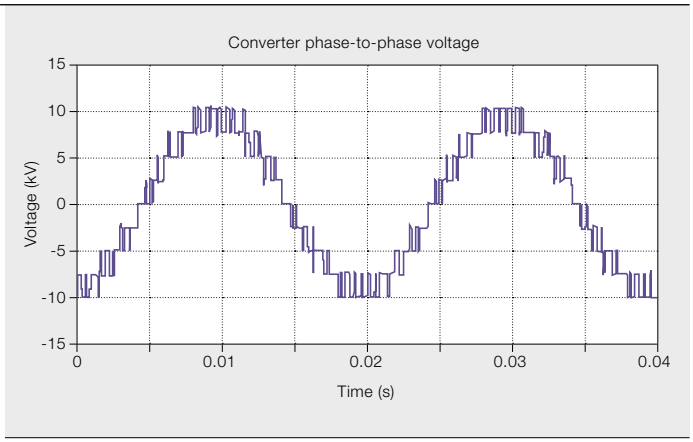
Input and output performance

The rectifier performance is illustrated in ➔ 8. The five-level inverter delivers a nine-level phase-to-phase voltage to the

9 Voltage waveforms from measurements



9a five-level waveform (phase to neutral point)



9b nine-level waveform (phase-to-phase)

motor. Typical voltage and current waveforms are shown in ➔ 9. The new five-level inverter produces an output that is pleasingly close to sinusoidal and meets the requirements for driving motors that were designed for direct-on-line (DOL) connection without needing to derate them.

Riding through outages

The combination of multilevel ANPC-5L technology and the dynamic performance of direct torque control can be used to prevent a trip of the drive, even in the case of a mains power outage lasting several seconds. Operation can also continue when certain auxiliary supplies fail for a limited time. The maximum sustainable duration of a power outage depends on the load, the machine and the operating point before the occurrence of the outage.

The combination of multilevel ANPC-5L topology and the dynamic performance of direct torque control can be used to prevent a trip of the drive, even in the case of a mains power outage lasting several seconds.

During ride-through operation, the voltage of the DC link is kept at a specified level to maintain the magnetization of the machine. For this purpose, energy from the rotating mass of the motor and the load is fed back through the inverter to compensate the losses and maintain the DC-link voltage. The ride-through mode can be maintained as long as the rotating mass has sufficient energy to supply these needs. When the main supply voltage is restored, the acceleration of the machine back to the desired speed commences immediately.

Field measurements made on an actual customer installation are illustrated in ➔ 10. The grid power outage lasted one second. ➔ 10a shows the grid voltage and input current dropping to zero. In ➔ 10c, the motor torque regenerates during the outage to maintain the DC-link voltage ➔ 10b. When the grid voltage returns, the torque quickly reverts to motoring mode.

Applications and success

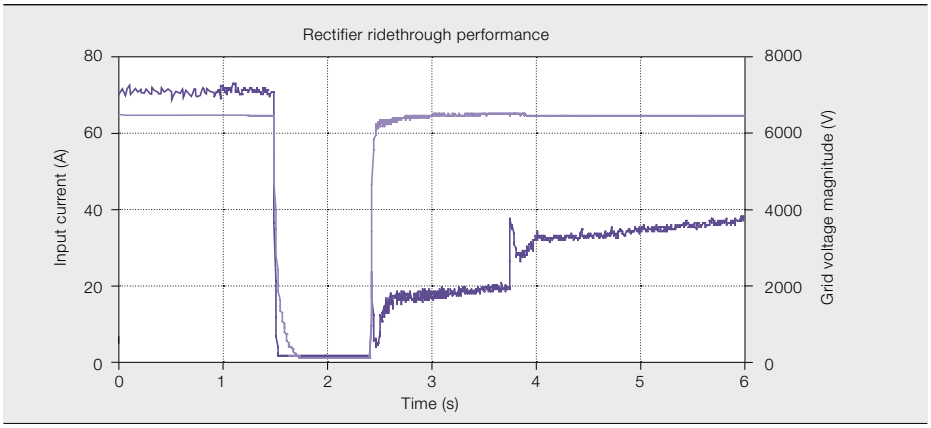
The ACS 2000 is designed for diverse fields of application in various industries within the general purpose drives market as shown in ➔ 11.

Award winning drive

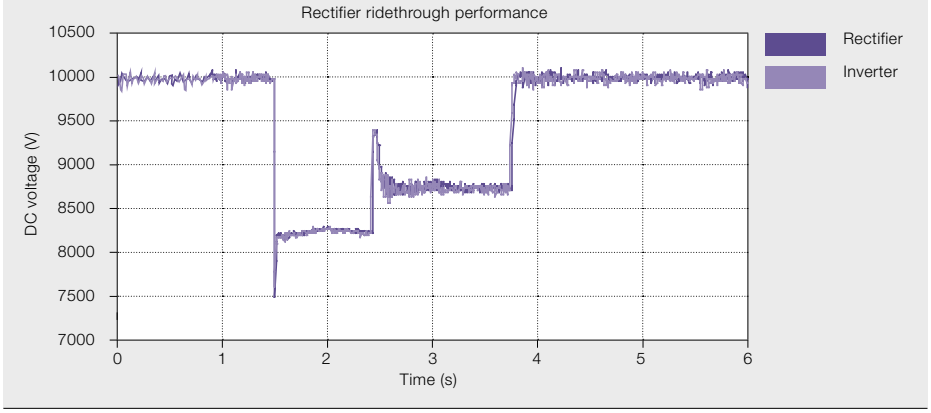
In December 2010, the consultancy company, Frost and Sullivan, recognized the ACS 2000 with the 2010 European Medium-Voltage Drives New Product Innovation Award. Frost and Sullivan said “the product offers benefits such as flexible line supply connections, lower harmonics, reduced energy consumption,

The new five-level inverter produces an output that meets the requirements for driving motors that were designed for direct-on-line (DOL) connection without needing to derate them.

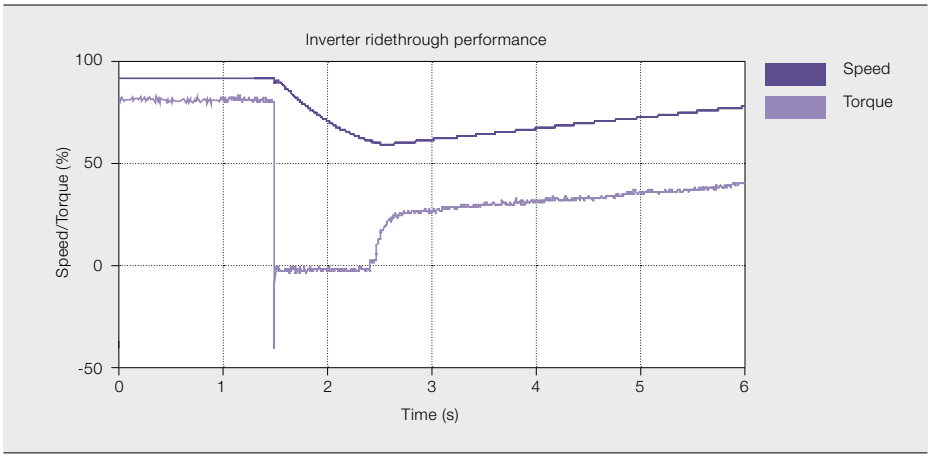
10 Surving a short power outage: measurement of ride-through mode



10a Supply



10b DC link voltage



10c Output performance

11 Target industries and applications of the ACS 2000

Industries	Applications
Cement, mining and minerals	Conveyors, crushers, mills, fans and pumps
Chemical, oil and gas	Pumps, compressors, extruders, mixers and blowers
Metals	Fans and pumps
Pulp and paper	Fans, pumps, refiners, vacuum pumps and chippers
Power generation	Fans, pumps, conveyors and coal mills
Water	Pumps
Other applications	Test stands and wind tunnels

ease of installation and commissioning, high reliability and lower cost of ownership. The only drive with voltage source inverter (VSI) topology, transformerless design and patented multi-level IGBT control, ACS 2000 marks a milestone in the medium-voltage (MV) drives segment [. . .] The product offers a range of value added features, including simple installation, commissioning and operation. Such attributes are critical from the end-user perspective."

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Further reading

The technical part of this article is based on a paper presented at a symposium in Pisa in June 2010. Due to space constraints, the present article was shortened considerably with respect to the original paper and readers interested in further details are recommended to read the original version [1].

The authors would like to acknowledge the contributions of current and former colleagues in the development of this technology: P. Barbosa, N. Celanovic, M. Winkelnkemper, F. Wildner, C. Haederli, P. Steimer, J. Steinke, and many others.

Reference

[1] Kieferndorf, F., Basler, M., Serpa, L. A., Fabian, J.-H., Coccia A., Scheuer, G.A. (2010, June). ANPC-5L technology applied to medium-voltage variable-speed drives applications. Paper presented at the International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Pisa, Italy. CD-ROM Proceedings.

Title picture

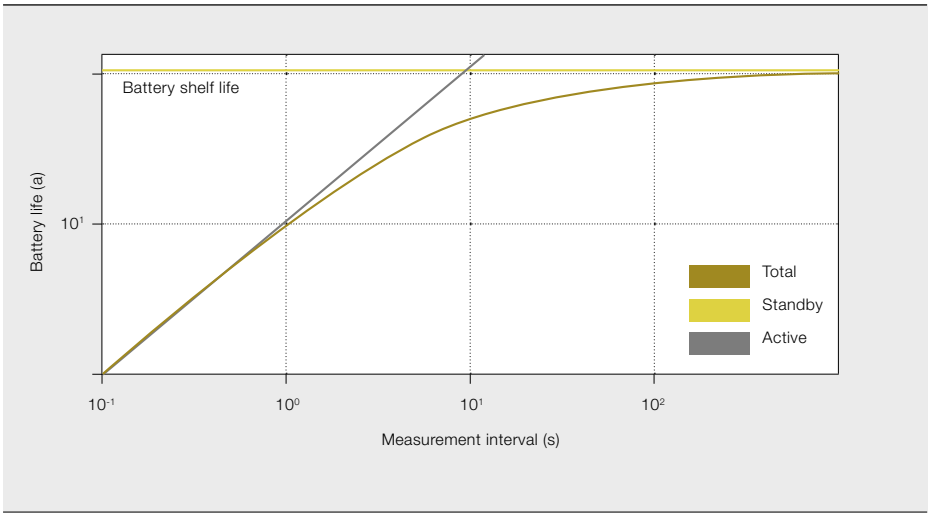
Drives are ubiquitous in plants and industries and come in all power classes ranging from small fans to large crushers. The cover picture shows the Torrevaldaliga Nord power plant in Italy.

Harvest time

Harvesting energy to create truly autonomous devices for industrial processes

PHILIPP NENNINGER, MARCO ULRICH – In an effort to further reduce downtime and maximize reliability, operators need to know more about the health of a plant's assets. This information is mostly supplied by sensors. Additional sensors mean extra wiring to power them and hence increased installation costs. Eliminating these wires would not only reduce costs but also the complexity of the entire process. Because the power consumption of many industrial sensors is quite modest, the use of batteries would seem like a suitable solution. However, exchanging batteries at regular intervals may very well offset the savings of having wireless sensors in the first place. Another solution is known as energy harvesting. Energy harvesting is the process by which energy (ambient, motion, wind, light), derived from external sources, is captured and stored to supply power for low-energy electronics. Ambient energy is available in abundance in the process industry and it is here that energy harvesting is beginning to make its mark.

1 Battery life over measurement interval of an idealized temperature transmitter



Wireless technology has had a significant impact on society over the past 15 years or so, and technological developments in the meantime mean it is gradually being accepted in the process industry, especially for asset monitoring.

Process automation plants usually have an operating lifetime of about 20 years, and to maximize return on investment during this time, plant utilization should be as high as possible. Since a plant can only be operational if all the necessary assets are functioning correctly, high component reliability is a must. This can be achieved through asset monitoring, an option to detect possible defects in equipment before they occur and to allow the root cause to be eliminated in a scheduled manner. In order to do this, additional sensor information is required. This information can come either from sensors already installed and capable of providing the required measurements, such as ABB's differential pressure transmitters used for plugged impulse line (PIL) detection or from additional sensors positioned in other locations of the process. If additional sensors are required, installation costs should be kept as low as possible in order to maximize the benefit of having them. But since wiring and installation can amount to almost 90 percent of the total cost of the device, it makes financial and technological sense to explore the possibility of using wireless devices.

Wireless technology

Wireless solutions are by no means a new concept in the process industry; In fact they first came to prominence in the 1960s. However, these solutions have been applied mainly in specialized products for certain markets such as ABB's AquaMaster, an electronic commercial water-flow meter, and flow totalizers in the oil and gas industry. ABB's Totalflow, a remote measurement and automation system, is one such example.

As is the case with fieldbus technology, any wireless protocol that aims at achieving critical mass requires a global standard, which is supported by all device manufacturers. One such standard does exist and is called WirelessHART. WirelessHART is the first international wireless standard which was developed specifically for the requirements of process field device networks.

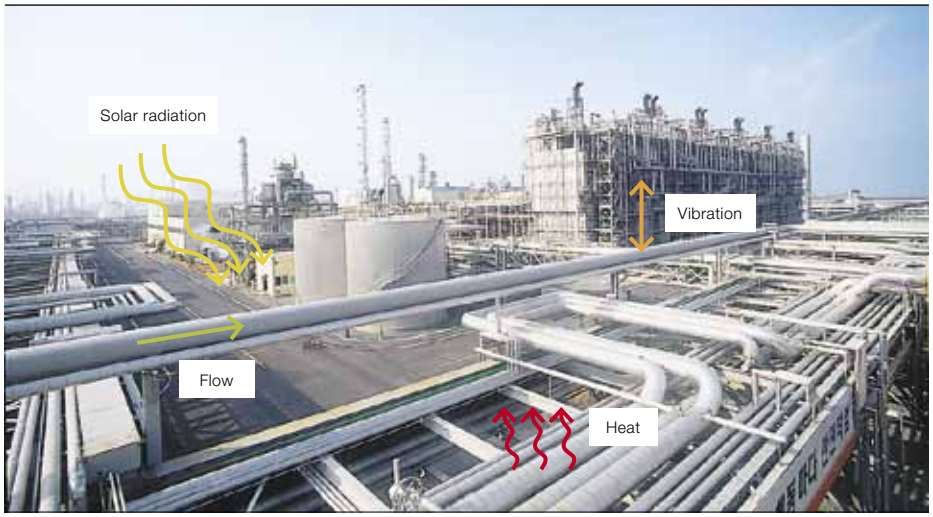
Network reliability is one of the main focus points in process automation An aspect of wireless networks that has influenced reliability is the area of meshed networking. Mesh networks provide spatially redundant channels between two nodes in the network by relaying messages over different routes. This in turn increases the fault tolerance of the communication and allows a well-designed network to become tolerant of both communication link and routing device failures. In addition, the spatial redundancy of mesh networking ensures reliable communication, even in industrial, scientific and medical (ISM) bands. Of course the relaying of messages (as a consequence of mesh networking) together with the requirement of constant security impacts the power budget, which has to be offset by achieving low-power optimization.

Low-power optimization

There are some major differences between wired and wireless devices when it comes to low-power optimization, and ABB's "wired" industrial temperature transmitter, the TTH300, will be used to illustrate this point. The TTH300 device is powered by the 4–20 mA current loop and measures, for example, the resistance of a 4-wire Pt100 (and thus the temperature at the sensor tip) at very short time intervals, which, depend-

Because wiring and installation can amount to almost 90 percent of the total cost of a device, it makes sense to explore the possibility of using wireless devices.

2 Energy harvesting allows the conversion of energy created by industrial processes into electrical energy



3 A fully autonomous temperature transmitter

ing on the sensor type and configuration, could be every 100 ms. Because the 4–20 mA loop continuously provides up to 40 mW of power, the device is limited by the power it can draw, while the energy consumed by the device is irrelevant.

A wireless sensor on the other hand does not have to measure temperature several times per second because most industrial wireless networks for the process industry do not usefully support such short update intervals. Between measurements the transmitter only has to fulfill its network duty of relaying messages for other nodes. The rest of the time the electronics can be in a so-called low-power mode during which no computations or measurements take place and only a fraction of the power is consumed.

In low-power mode, the power consumption of the device can be approximated by considering the power consumed in active and low-power mode and the duty cycle of the device. For the wireless device described above the duty cycle roughly correlates to the time needed for the sensor to update. If the self discharge of the battery is not considered, a rough estimate for the battery life of a battery-powered transmitter can be given. This estimate for an ideal device is shown in ➔ 1.

Energy harvesting

Exchanging batteries on a regular basis is not always an option since this could – depending on the plant setup – offset the savings of using wireless devices. Instead, energy harvesting (EH) is seen as a possible solution that overcomes this issue to create truly autonomous devices. EH converts the energy available in the process ➔ 2 into usable electrical energy, which in turn is used to power wireless devices. Typical energy sources include hot and cold processes, solar radiation, and vibration and kinetic energy from flowing media or moving parts. The most prominent mechanisms are solar radiation, thermoelectric and kinetic converters.

Solar radiation

Although photovoltaics is nowadays a robust and established technology, its application indoors is rather limited. While the outdoor intensity can reach approximately 1,000 W/m^2, typical indoor values lie in the region of 1 W/m^2 [1]. In other words, the amount of energy that can be harvested is restricted.

Thermoelectric

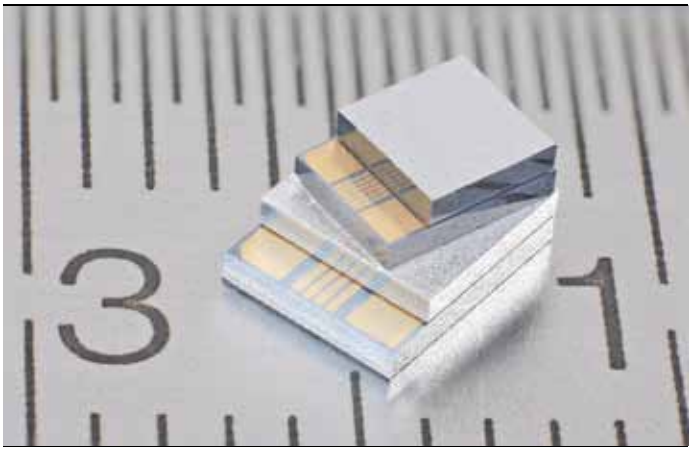
Thermoelectric generators (TEG) harvest electrical energy from thermal energy (ie, the temperature gradients between hot or cold processes and the ambient) using the Seebeck effect [1] [2]. While the efficiency of TEGs is rather low – typically below 1 percent – the technology is quite robust and stable. Often large temperature reservoirs are present especially in the process industry. Hence a lot of heat is available and the power that can be delivered by commercially available TEGs is sufficient to maintain a variety of wireless sensor nodes in different scenarios.

Energy harvesting converts the energy available in an industrial process into usable electrical energy.

Footnote

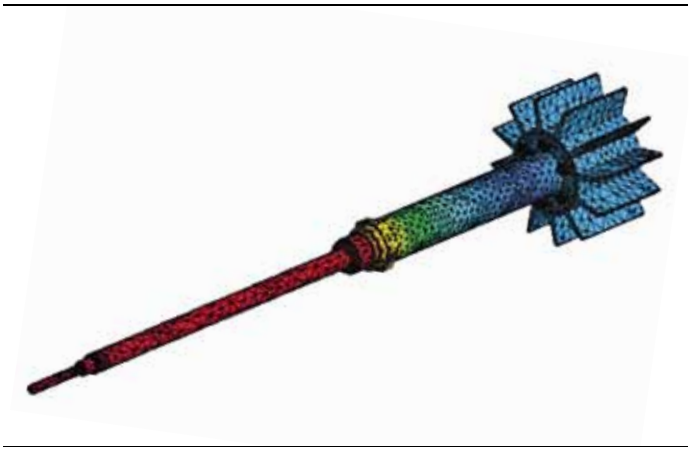
1 Discovered by Thomas Johann Seebeck in 1821, the Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

4 With a footprint of only 8 mm² the micro-TEG allows for high output voltages.



Source: Micropelt GmbH

5 Numerical thermal simulations



Process temperature distribution of 80°C (red)
An ambient temperature of 25°C (blue)

Kinetic converters

The direct conversion of mechanical movement, such as vibrations, into electrical energy can be achieved with different transducer mechanisms:

- Electromagnetic mechanisms use a flexible mounted coil, which moves inside the static magnetic field of a small permanent magnet. This induces a voltage as described by Faraday's law.
- Piezoelectric transducers are based on piezoelectric materials. By means of a proof mass supported by a suspension, kinetic movement results in a displacement of this mass, which induces a mechanical stress on the piezoelectric material.
- Electrostatic transducers are based on a charged variable capacitor. When mechanical forces are applied, work is done against the attraction of the oppositely charged capacitor plates. As a result, a change in capacity induces a current flow in a closed circuit.

In short, all kinetic converter principles are based on a mechanical resonator, and the systems can only deliver a reasonable power output if the resonance frequency of the harvesting device matches the external excitation frequency. The use of variable-frequency drives in the process actually limits the application of vibration harvesting systems.

System components and architecture

Energy harvesting can be a discontinuous process: For example, in the case of outdoor photovoltaic applications, day-night cycles will lead to unstable power sources; plant downtimes can lead to different process temperatures, which may influence the energy delivered by TEGs; and variable-frequency drives can lead to varying power yields of vibration harvesters. In contrast there may be times when the energy harvesting system supplies more energy than is actually needed.

The power consumption profile of typical wireless sensor nodes is also discontinuous: Depending on the duty cycle and update rate of the sensor, peak loads may occur which have to be buffered because EH systems are not able to support these high short-term currents. Essentially every EH system needs a buffer to overcome times when the harvesting device is unable to supply enough energy for the sensor node. Typical buffers include:

- Special super or hybrid-layer capacitors. These capacitors tolerate high peak currents.
- Rechargeable secondary cells.
- Conventional primary cells. These cannot store an excessive amount of energy coming from the EH system but they can be used to provide power at times when the system cannot.
- Typical industrial primary cells. These cells have a very long shelf life with low self-discharge rates and are a very reliable buffer alternative.

ABB has developed a complete autonomous temperature transmitter using a fully integrated EH system.

Conventional lithium-ion based secondary cells suffer from a limited amount of discharge/charge cycles.

Harvesting devices and buffers need an appropriate power management (PM) system for a truly autonomous power supply. The PM has two major functions:

- To adjust the characteristics of the output voltage and current of the EH system to the input requirements of the electrical consumer.
- To switch smoothly between energy buffers and the different EH sources.

ABB's autonomous temperature transmitter

Research in ABB has developed a complete autonomous temperature transmitter → 3 using a fully integrated EH system. Thermoelectric generators have been integrated into the device in a way that the handling, stability and form factor of the transmitter stays the same while its lifetime and functionality are considerably enhanced. The device also includes a smart energy buffer solution for occasions when the process temperature is insufficient to generate enough energy.

The overall size of the selected temperature transmitter prevented the integration of conventional TEGs, which normally have macroscopic dimensions around

10 to 20 cm^2. Instead novel micro-thermoelectric generators (micro-TEGs), produced with a wafer-based manufacturing process [4], were used → 4. The major challenge of integrating these two devices was ensuring that the stability and robustness of the transmitter was maintained.

Fully autonomous devices can help to better understand and control industrial processes and therefore make them more profitable.

In most cases the process is warmer than the ambient air temperature and so the hot side of the TEGs needs to be coupled to the process with the most optimal thermal conductivity. Extensive numerical simulations were carried out to maximize the heat flow through the TEGs → 5. The other (or cold) side must be cooled and is therefore coupled to the ambient air with a heat sink. The heat sink needs to be positioned at a sufficient distance to allow for applications where the process pipe is covered with a thick insulation layer.

With a minimum difference of about 30 K between the process and ambient temperatures, the system is able to generate sufficient energy to supply both the measurement and wireless communication electronics. At temperature gradients greater than 30 K, more energy is generated than is needed, which could be used to allow for faster update rates, for example.

Future outlook

The EH-powered temperature transmitter solves a central issue of wireless sensor nodes: The regular exchange of primary cells is no longer necessary, and this in turn can help reduce the total cost of ownership. While EH is not possible for all sensors in every circumstance, it is a viable energy supply for a wide range of devices. Fully autonomous devices can help to better understand and control industrial processes and therefore make them more profitable.

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Title picture
Just as grains are harvested to produce food, energy can be harvested to produce power.

Spark-free safety

Synchronous and induction motors and generators with guaranteed spark-free operation

GÖRAN PAULSSON, JOHAN KARLSSON, JUSSI RAUTEE – Electrical motors and generators are the backbone of our industrial society, driving compressors and pumps and generating electricity. But because these appliances are electrical, they pose enormous risks when used in situations where explosive gases are present. The oil and gas extraction industries are one example. A spark, a hot surface or a high electrical field such as a corona (the buzzing sound that sometimes can be heard under a high-voltage power line) are all potential threats to safety in an explosive gas-rich environment. ABB's large synchronous and induction motors and generators are certified according to the latest and most stringent of safety requirements – the IEC international standards – guaranteeing spark-free operation.

The design and certification of ABB's large high-voltage synchronous and induction motors brings faster startup times and reduced maintenance requirements.

For years, ABB has taken design and manufacturing steps to exceed official standards of quality and safety, both of which are paramount for its customers. In 2010, all of its large synchronous motors and generators were certified according to the most stringent international standards (IEC 60079-15:2010 and IEC 60079-7:2006); now, the company's complete range of low- and high-voltage motors and generators are certified for operation in hazardous areas ➔ 1.

Customers using equipment that is not tested or certified usually equip the motor with a pressurizing system. This means investing in high-capacity air compressors, piping and a ventilation control unit. By testing and certifying its motors, ABB helps customers streamline their risk assessment processes.

Benefits of the ABB approach include reduced initial capital expenditure, lower operating costs and faster motor starting. Reliability also improves, as no additional components are required. Certification can greatly impact costs. For example, in a refinery, ventilating a motor for even 30 minutes costs enormous amounts of money in downtime and lost production. Using ABB's certified equipment makes it possible for customers to avoid such expenses.

The development of IEC 60079 standards began after several serious explosive incidents, which were related to motors operating in hazardous areas in and around North Sea oil and gas fields, occurred in the 1980s and 1990s ➔ 2. Together with the German national institute; Physikalisch-Technischen Bundesanstalt (PTB) and Shell, ABB presented a paper [1] at a large IEEE PCIC [1] Europe conference in 2008. The standards they presented in the paper were developed by the International Electrotechnical Commission (IEC), an over 100-year-old organization that focuses on international regulations and standards ➔ 3. Over the years, the organization's standards and tests have become something like a license for the electrical motor manufacturing industry to produce and sell electrical motors that are safe and efficient to use.

Despite great advances in automation, making an electric motor that weighs up to 80 tons is still a manually intensive job.

Footnote

1 IEEE PCIC are the Institute of Electrical and Electronics Engineers and the Petroleum and Chemical Industry Committee

1 Principles of explosion protection

The atmospheres in which operations in the chemical, oil and gas industries are carried out are categorized as either hazardous or nonhazardous. Hazardous environments contain potentially explosive constituents such as gases, vapors, mists or dust. These atmospheres are classified into risk categories, based on the presence and concentration of explosive substances:

- Zone 0 – An explosive atmosphere is present continuously.
- Zone 1 – An explosive atmosphere is present less than 1,000 hours/year.
- Zone 2 – An explosive atmosphere is present less than 10 hours/year.

For a machine placed in a hazardous area, a different kind of protection is needed to prevent ignition of any explosive gas that may be present. International standards define the types of protection that make industrial operations possible in two zones – zones 1 and 2. The aim of all protection is to avoid potentially explosive sources, which are typically hot surfaces and sparks.

One of the most important considerations when placing the coils inside the stator is to allow enough space between them to avoid corona discharges.

2 Protection types “n” and “e”

IEC 60079–15:2010 specifies requirements for the construction, testing and marking for Group II electrical equipment with protection type “n” (nonsparking), intended for use in explosive gas atmospheres in zone 2. This standard applies to electrical equipment where the rated voltage does not exceed 15 kV rms AC or DC.

IEC 60079–7:2006 specifies the requirements for the design, construction, testing and marking of an electrical apparatus with protection type “e” (enhanced safety), intended for use in explosive gas atmospheres in zones 1 and 2. This standard applies to electrical apparatus where the rated voltage does not exceed 11 kV rms AC or DC.

3 IEC standards

On September 15, 1904, delegates to the International Electrical Congress in St. Louis, Missouri, USA, adopted a report that included the following sentence: “Steps should be taken to secure the cooperation of the technical societies of the world by the appointment of a representative commission to consider the question of the standardization of the nomenclature and ratings of electrical apparatus and machinery.”

Accordingly, the IEC was officially founded in June 1906 in London. Since then, the IEC has been involved in developing standards, safety guidelines, testing and specification of components for the world’s electrotechnical industries. The group’s mission includes everything from capacitors, resistors, semiconductors, radio communication and electrical equipment to electric motors.

In 1930, the IEC was instrumental in establishing the Hertz (Hz) as a unit of frequency, the gauss (G) as a unit of magnetic flux density and the gilbert (Gi) as a unit of magnetomotive force, among other units.

In 2005, the IEC published a multilingual dictionary of more than 20,000 electrotechnical terms in 13 languages.

4 Cross section of an insulated high-voltage coil

5 Wound and impregnated stator ready for further assembly

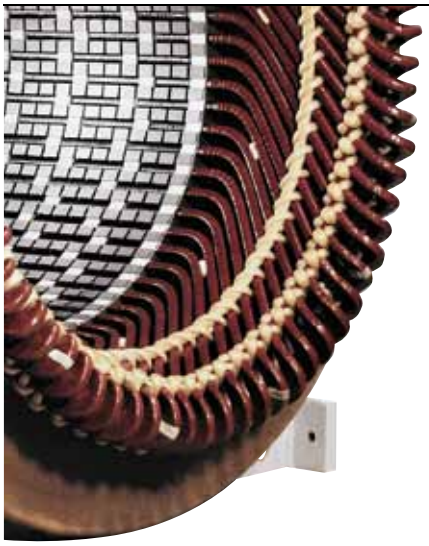

ABB and standards

ABB produces two types of high-voltage electrical motors – synchronous and induction – at factories in Sweden, Finland, Italy, South Africa, China and India. A synchronous electric motor is an AC motor distinguished by a rotational speed proportional to the frequency of the AC-voltage power supply; ie, the motor is running synchronously. The magnetization of the rotor is normally done by an external unit. These motors can be designed to run continuously in zone-2-rated atmospheres, classified as “Ex nA, non-sparking machines.”

An induction or asynchronous motor is an AC motor in which the rotor is magnetized by means of electromagnetic induction, but its rotational speed is slightly below the synchronous speed; ie, the motor is running asynchronously. These motors can be designed to run in zone 1, also known as “Ex e, increased safety machines.”

On January 28, 2010, new IEC standards, for equipment placed in an explosive atmosphere, came into effect. Based on previous development and testing, the majority of ABB’s product range of synchronous and induction HV motors and generators were compliant with these standards. The rest were made fully compliant during 2010.

6 The test

Compliance with the IEC 60079–15: 2010 standard for nonsparking motors and generators requires a three-minute test of the stator in an explosive gas environment. The test is mandatory for motors with a rated voltage of more than 1 kV operating in environments where there is a presence of, for example, hydrogen, ethylene or acetylene, and above 6.6 kV for motors working in environments where there are traces of propane, diesel fuel, acetone, ethane, ammonia or any of a dozen other explosive gases and vapors.

During the test, a stator winding is covered with a layer of plastic, which is then filled with an explosive gas such as hydrogen mixed with air, as shown in the picture on the right. The stator is then subjected to varying and increasing voltages (sinusoidal) up to the specified test level. If a gas explosion happens, caused by a small spark in the stator winding, the plastic will break and let the pressure wave escape. The specified test voltage is 1.5 times the rated voltage. To pass the test, ignition of the explosive gas mixture must not occur.

According to the test performed in Germany at the Physikalisch-Technischen Bundesanstalt (PTB) in 2004 and 2009, ABB's stators are spark-free up to and including 13.8 kV for hydrogen (representative for gas group IIC) and 15 kV for both ethylene and propane (representative for gas groups IIB and IIA).

For an induction motor with a cage rotor, the rotor is also tested in an explosive gas environment for possible sparking from the rotor bars. Such a rotor ignition test is not needed for a synchronous rotor, due to its different construction.

The same standard, IEC 60079, also specifies the respective test for induction motors of the enhanced safety protection type.

Despite great advances in automation, making an electric motor that weighs up to 80 tons is still a manually intensive job. At the ABB factory in Västerås, Sweden, for example, about 200 motors and generators are tailor-made each year to customers' precise specifications. There, workers use a machine to painstakingly bend index-finger-sized strands of mica-insulated copper into the required exact shape ➔ 4. In the next step, the ready-formed coils are insulated with an additional layer of mica before being placed in the stator.

The physics of electrical motors are relatively basic and are well understood by many; where it gets tricky, however, is in the insulation of the copper coils that are wound into the stator and tied together with fiberglass rope. The whole stator is subsequently impregnated with an epoxy resin, called a vacuum pressure impregnation, or VPI. After impregnation, the stator is cured in an oven to get its final electrical and mechanical properties ➔ 5.

This Micadur®-Compact Industry (MCI) insulation system ensures sealed and homogenous insulation, resulting in low dielectric losses, high electrical and mechanical strength and excellent heat transfer inside the stator. While this insulation is a tried and proven system, one of the most important considerations when placing the coils inside the stator is to allow enough space between them to avoid corona discharges. If the coils are too near each other, there is risk of a corona buildup. Having enough air between the coils and optimizing the way they are laid out enables maximum use of the machine. The use of corona-suppressing materials is also essential.

The design and certification of ABB's large high-voltage synchronous and induction motors brings faster startup times and reduced maintenance requirements. While faster payback time and reduced maintenance costs are certainly beneficial, what is essential is that ABB's certified motors also offer proven safety, as testing represents the only way to verify that equipment really is safe ➔ 6.

> On January 28, 2010, new IEC standards came into effect. Based on previous development and testing, the majority of ABB's product range of HV motors and generators were compliant.

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Title picture
An oil and gas platform is an environment with strict spark prevention requirements. The motors used must pass a demanding certification.

Motoring ahead

Synchronous motors controlled by variable-speed drives are bringing higher efficiencies to industrial applications

HEINZ LENDENMANN, REZA R. MOGHADDAM, ARI TAMMI, LARS-ERIK THAND – Electric motors in industrial applications account for approximately 60 – 65 percent of consumed industrial electricity. Using energy effectively by increasing motor efficiency is at the center of continued motor optimization. Major energy savings are also gained through the use of variable speed drive systems and today this technology is adopted in as many as 30 – 40 percent of all newly installed motors. Sustainable use and investment also demands increased reliability and lifetime of a motor. The streamlined rotor structure of ABB's synchronous reluctance motors eliminates rotor cage losses therefore increasing efficiency and compactness. The possibility of achieving standard power and torque levels at merely a low class-A temperature rise (60 K) improves the lifetime of the motor insulation, and lengthens the bearing lifetime or greasing intervals.

The possibility of high speed operation helps to eliminate mechanical power transmission elements such as gearboxes.

Electric motors are used in a wide range of industrial applications. What most applications have in common is the need for their motor to be as efficient as possible and to have the longest possible lifetime while simultaneously not increasing maintenance demands or failures. ABB's synchronous reluctance motors are physically smaller in size, helping machine builders to design smaller, lighter, and more efficient equipment. Additionally, the possibility of high speed operation helps to eliminate mechanical power transmission elements such as gearboxes. This eventually enables the integration of the motor and the load equipment which is an increasingly common request.

To answer the need for a motor that is more efficient, smaller, with a long lifetime and low maintenance needs with a new motor type, which would also be perfectly adapted to variable speed drive (VSD) operation, ABB radically rethought all technology options. Starting a VSD motor is very different compared to the direct line connection start. This, and other changes in boundary conditions, highlighted potential opportunities to simplify the motor design and improve efficiency. One well known approach is the utilization of synchronous motors (SM). SMs with a 4-pole rotor operated at 50 Hz rotate in synchronism with the supply at exactly 1500 rpm. The corresponding induction motor (IM) however, has slip losses and rotates only at 1475 rpm for a chosen 30 kW example. In modern IMs with a short circuit rotor cage, the losses associated with the rotor amount to 20 – 35 percent of the total motor losses. Synchronous rotation eliminates most of these associated losses.

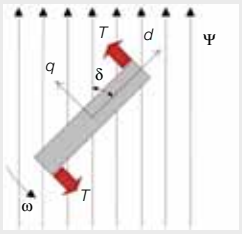
The elimination of these slip losses leads to an efficiency increase of about ~0.6 percent (220 kW motor) to 8 percent (3 kW), as well as a 20 – 40 percent increase in power and torque density for the same insulation temperature class.

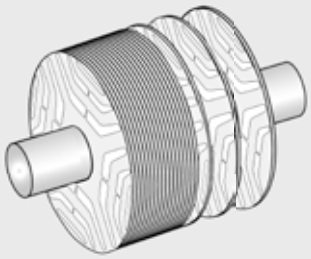
Synchronous motors come in different variants: as field wound with brushless exciters; as permanent magnet (PM) motors; or as motors based on the principle of magnetic reluctance (often called a synchronous reluctance motor or SynRM). A SynRM rotor has neither a conducting short circuit cage as with the IM, nor permanent magnets, nor a field excitation winding. Instead, the magnetic principle of reluctance is utilized.

The synchronous reluctance motor

Magnetic reluctance is the magnetic equivalent of the resistance in electrical circuits. The rotor consists of one direction of least possible magnetic resistance (d) and a perpendicular direction (q) with a high magnetic reluctance or good magnetic "insulation" → 1. Torque is produced, as the rotor attempts to align the

1 Synchronous reluctance rotor and torque principle

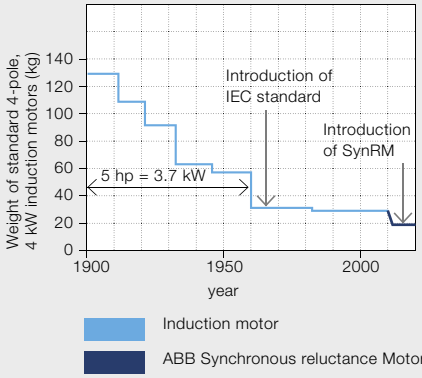




$$T = \frac{3}{2} P_p \left(\frac{1}{L_q} - \frac{1}{L_d}\right) \Psi^2 \sin(2\delta)$$

P_p = Pole pairs of the motor

2 Innovation timeline in LV motors



size	Induction motor	SynRM	Output
100	3.3kW η=83%	4.3kW η=90%	+30-45%
160	22kW	29kW	+32%
280	90kW	110kW	+22%

Technology comparison measured ratings

magnetically conducting direction to the stator field. The strength of the produced torque is directly related to the saliency ratio, ie the inductance ratio between the two magnetic directions of the rotor.

The invention of the synchronous reluctance motor concept dates back to 1923. However, the motor type was not industrially adapted primarily due to the lack of a direct online starting capability. Now, with the use of variable speed controllers, this obstacle has been removed ➔ 2.

In 1982 NdFeB based permanent magnet materials were discovered. The resulting new permanent magnet (PM) motor technology was adapted for servomotors and is now emerging in many industrial specialty applications, such as gearless low-speed torque motors [1]. Again, less attention was paid to the unpretentious SynRM.

In addition, not all earlier published work on SynRM succeeded in demonstrating superior torque performance or reaching higher efficiency than the IM, as was expected from the calculations: a fact cited by experts and academics as to why the SynRM is not used more often today. Presumably these early results were due to less optimized converter control. Indeed some publications show very promising results, and have addressed the electromagnetic design aspects in great depth [2], [3]. It is important to note the contrast of the SynRM to the switched reluctance, or stepper motor, with an entirely different stator, winding concept, and non-sinusoidal current waves; a motor often considered unsuitable for industrial use, due to high noise. A cited disadvantage of the SynRM is a higher current need for the same torque compared to the PM motor, since the rotor must be magnetized through the stator. However, the power factor as seen from the network is determined by the power converter and is near unity in all operating modes, even for the SynRM.

The industrial motor for VSD systems

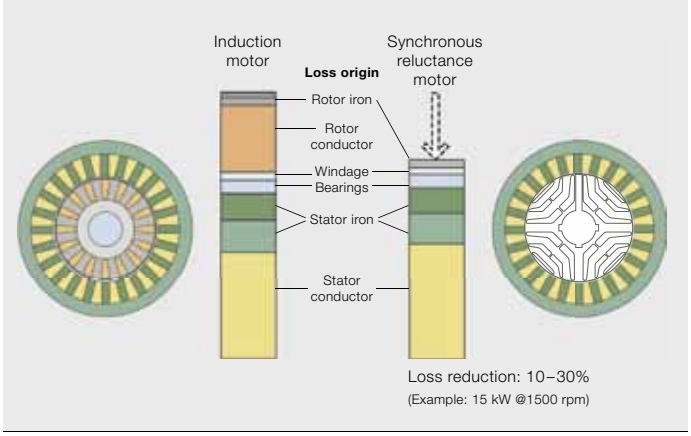
In ABB's SynRM rotor designs and drive control, the motor current, proportional to the inverse of power factor and efficiency, ($\propto 1/(\eta^*\cos(\rho))$ is actually lower than for a small size induction machine at the same torque and speed. This is primarily due to the significant gain in efficiency. Only for large motors is the converter current higher than with an IM at the same torque. In general, the ABB SynRM operates with the same frame size for the drive (e.g. ACS850) as the IM at the same power and torque level, albeit at the increased power density and higher efficiency than the IM. The motor efficiency increase translates to a nearly identical energy saving at the drive system level.

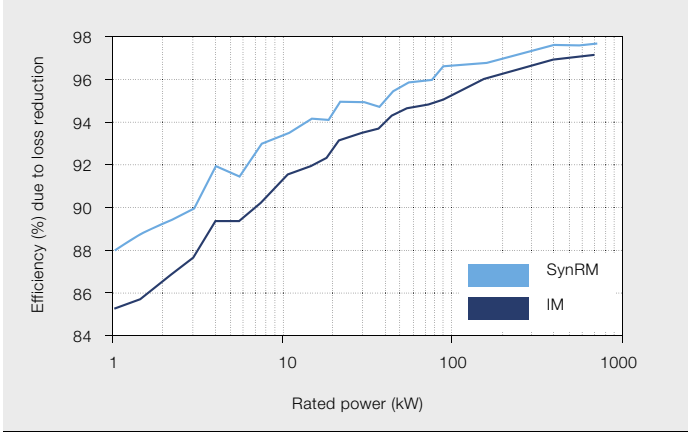
One other key advantage of ABB's SynRM is the plain rotor structure. Without magnets and without cage, the rotor construction is more robust than either IM or PM machines. In addition, no risk of permanent loss of performance exists due to potential demagnetization in case of failure or overheating situations. The motor is inherently safe in operation since, without magnets, no back-EMF voltage is induced, and over-voltage protection of the converter becomes superfluous. Finally, rare earth materials for permanent magnets are relatively expensive and may be in limited supply for some markets, due to geographic concentration of the common raw materials suppliers.

Elimination of most of the rotor losses, and the streamlined rotor structure, results in a number of benefits for this motor and its connected load equipment ➔ 3. A motor with this technology can be operated at the IEC standardized power level for the given frame size. In this case, the VSD efficiency gain ranges from more than 5 percent units for single kW machines to about 0.5 percent for the largest motors (frame 315). Consequently, where an IM would have run at class-F temperature rise (105 K), the ABB SynRM operates merely at class-A temperature rise (60 K) ➔ 4. In comparison for a specific compressor at 4500 rpm, the associated ABB SynRM features still lower bearing temperatures when run at true class-H rise (125 K), than the larger IM run at class-F rise (105 K). The motor was thus also called a "CoolMotor" ➔ 5. This low temperature operation improves the lifetime of the motor insulation, and lengthens the bearing lifetime or greasing intervals. Motor bearings in particular require regular servicing and according to some

For small motors at 3 or 4 kW level, as much as 60 percent more power can be obtained for the same temperature rise.

3 Loss distribution and efficiency





studies bearing failure is the root cause of approximately 70 percent of all unplanned motor outages. The lower bearing temperature directly translates into longer greasing intervals, reduced maintenance and higher reliability. Even if a bearing eventually needs replacing, having no magnetic forces, unlike a PM motor, the bearing change is as easy as for an IM.

The technology enables good torque utilization at higher speeds. In another utilization of this technology, the operation is maintained at the conventional temperature often B- or F-class. Since losses on the rotor are arduous to cool, compared to stator losses, its near elimination has a particularly high impact on the torque performance. For small motors at 3 or 4kW level, as much as 60 percent more power can be obtained for the same temperature rise. For a 60 kW motor the gain is in the 40 percent range and for a 220 kW motor in the 20 percent range compared to an IM. In most cases, the same power can be obtained from a motor by one, or sometimes two, frame sizes smaller than an IM. The reduction of the footprint is appreciable for all applications that can utilize lower frame heights and smaller motors. An additional gain is the reduced heat load on nearby parts, particularly in closed cabinets. Even at this vastly increased power density, a further important advantage results from the removal of the losses on the rotor side: since much of the heat conduction through the shaft is eliminated, the bearing temperature, particularly on the drive-end, is reduced. Comparing an ABB SynRM with an IM at 6 kW, this can be as much as a 30 K reduction, with an approximately 15 to 20 K reduction typical over the entire range. This effect is particularly pronounced at higher speeds, as well as for operation at higher temperature classes. The generally high efficiency is maintained even at this high output. Furthermore, the ABB SynRM has the excellent partial load efficiency curve which is typical of synchronous machines, ie the efficiency remains high even at partial load, a feature particularly appreciated in VSD drives for fans and pumps.

Finally, these rotors feature about 30 – 50 % percent reduced inertia due to the lack of cage and magnets. In highly dynamic applications such as cranes, this reduction implies further benefits in energy efficiency as well as faster lift cycles due to higher speed ramp rates.

Rotor construction and reliability

Most technical aspects of drive systems with ABB's SynRMs are directly based on existing technology. The housing, connection box, stator, winding design and technology, and bearing options are identical to IMs. As the 3-phase currents are sinusoidal, the same drive products can control this motor type, provided the firmware is optimized and includes this motor type. Only the rotor is different.

The rotor is less complex than in both IM and PM. Laminated electrical steel sheets are fitted to the shaft. Instead, the complexity, is in the design. Extensive finite element simulations (FEM) were used to design the cross-section carefully, in terms of electrical and mechanical properties. Important design choices are the number of magnetic segments and the exact shape of the air barriers. This determines the torque production and the magnetization current of the motor. Minimizing this reactive current was

The low temperature operation improves the lifetime of the motor insulation, and extends the bearing lifetime or greasing intervals.

4 Temperature classes

Ambient temperature is the temperature of the air surrounding the motor. This is the threshold point or temperature the motor assumes when shut off and completely cool.

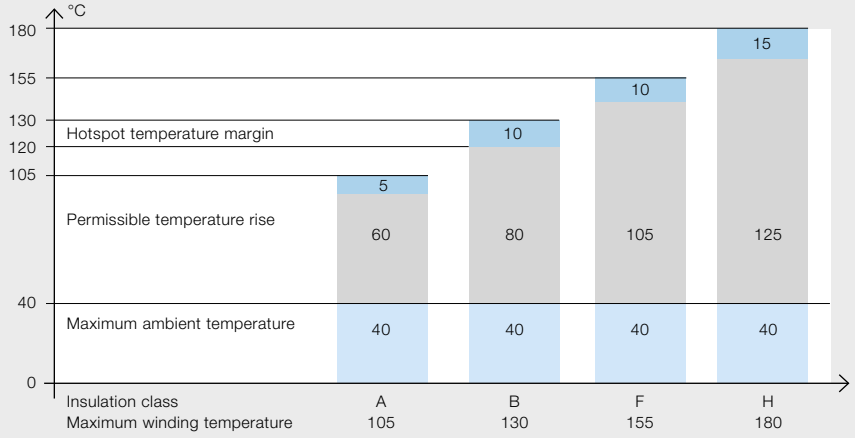
Temperature rise is the change within a motor when operating at full load. The difference between the motor's starting temperature and its final elevated temperature is the motor's temperature rise.

The standard method of measuring temperature rise involves taking the difference between the cold and hot ohmic resistance of the winding. This averages the temperature change of the whole winding, including the motor leads, end turns, and wire deep inside the stator slots. Since some of these spots are hotter than others, an allowance factor uses the average temperature to indicate what the temperature probably is at the hottest spot. This is known as the "hot spot" allowance.

Insulation classes group insulations by their resistance to thermal aging and failure. The four common insulation classes are designated as A, B, F, or H. The temperature capability of each class is the maximum temperature at which the insulation can operate to give an average life of 20,000 hr.

Operating a motor at a lower temperature rise than allowed by the insulation class can change the motor's thermal capacity, allowing it to handle higher than normal ambient temperatures. In doing so, the motor's life is extended.

The graph below shows the temperature ratings, temperature rise allowances and hot spot allowances for various enclosures of standard motors.



Drive conditions of pumps, fans, compressors, and mining and crane applications were emulated using methods for highly accelerated stress testing (HAST).

crucial to maintain a favorable drive rating. The exact placement of the segments along the periphery is essential to create smooth torque during rotation, keeping the motor noise as low as in conventional motors. One result of this complex optimization using FEM, analytical and genetic algorithms, was that a 4-pole configuration is most suitable for the entire speed range up to 6000 rpm.

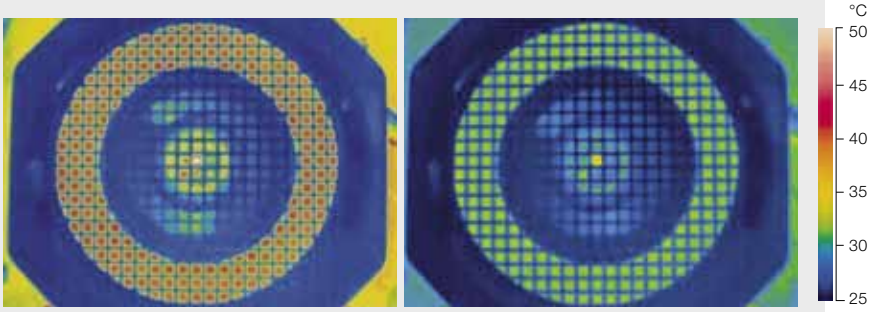
To verify the reliability of this new rotor, extensive motor and drive system testing was conducted throughout development (see title picture, pages 56–57). Drive conditions of pumps, fans, compressors, and mining and crane applications were emulated using methods for highly accelerated stress testing (HAST). HAST cycles were developed specifically for this motor to ensure robust lifetime performance. For example, one successful experiment conducted at high repetition rate motor starts and stops into speeds above catalog permitted values. The cycle count and overload conditions were dimensioned to correspond to more than a 20 year lifetime of rated operation.

Drive converter and control

Conventional ABB drive technology used for IM and PM motors, with standard direct torque control (DTC), was adapted to include the SynRM as a new motor type. Despite sharing many similarities with the PM motor, except for zero rotor flux, strong development focus was given to optimizing the torque production through maximum torque per Ampere (MTPA) control. This ensures that the drive current is kept minimal in each operating point. The control also includes capabilities for the field weakening range, ie the speed range above the nominal rated speed. A maximal rated speed of as much as 1.5x nominal can be reached for much of the motor range. This drive control is a particularly important ABB result which enables this SynRM to reach appreciably higher torque densities than IMs.

The installation and operation of the power electronic drive for this motor is indistinguishable from driving VSDs with IM or PM motors. Standard features include automatic parameter identification based on name plate values and sensorless operation. The motor does not need any speed sensors but nevertheless can maintain perfect speed

5 Temperature scans from a thermal imaging camera



Induction rotor

Synchronous reluctance rotor

6 Performance of motor drive system for piloting

The performances of the new motor drive system are given for three IEC motor frame sizes.

Motor, temperature rise class F								Drive, 400 V				
Size mm	PN kW	nN r/min	PN kW	nmax r/min	Eff %(1/1)	TN Nm	MM kg	Type code ACS-850-04	IN A	Noise dBA	Frame size	MD kg
100	4	1500	4	2250	84.3	25	22	010A-5	10.5	39	B	5
100	7.5	3000	7.5	4500	88.7	23	22	018A-5	18	39	B	5
100	13	4500	13	6000	90.5	27	22	030A-5	30	63	C	16
100	17.5	6000	17.5	6000	91.3	27	22	044A-5	44	71	C	16
160	26	1500	26	2250	91.7	165	180	061A-5	61	70	D	23
160	50	3000	50	4500	94.0	159	180	144A-5	144	65	E0	35
160	70	4500	70	5300	94.6	148	180	166A-5	166	65	E	67
280	110	1500	110	1800	96.0	700	640	260A-5	260	65	E	67
280	130	1800	130	2200	95.9	689	640	290A-5	290	65	E	67

For full specifications check ABB web pages at www.abb.com/motors&generators

accuracy, as well as a high torque dynamic. The drive can even be dimensioned for specially requested overload and cycle load capability.

An additional gain is the reduced heat load on nearby parts, particularly in closed cabinets.

Performance preview

Since this motor, like the PM motor, always requires a VSD drive, matched pairs of motor and ACS drives are given as the standard recommendation for a range of power and speed levels → 6.

As a response to the key market trends of higher output, higher efficiency, longer service intervals, and footprint reduction, a radical new motor uniquely suited for VSD systems is now available. Increased power density by 20 – 40 percent when compared to an IM, with a rotor construction without short circuit cage nor permanent magnets, featuring smaller motors, with less heat generation, and highest efficiency for VSD systems is being achieved. A standard IM fitted with a new rotor, combined with a standard drive with new software, results in a high output, high efficiency VSD system. The output and efficiency performance is comparable to a PM motor drive, but using technologies associated with the robust induction motor, bring the best of both worlds to users, and with additional benefits as a bonus.

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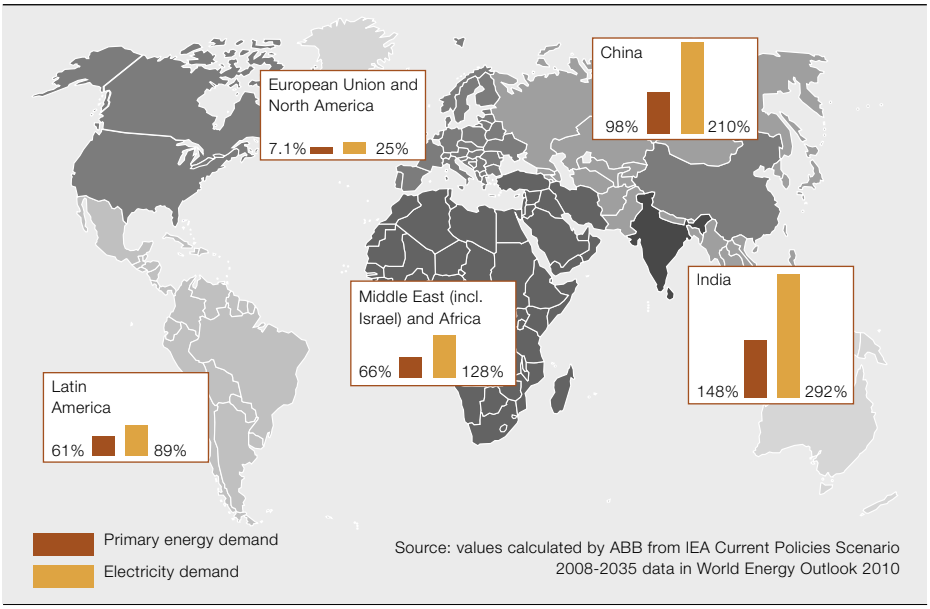
Title picture
The motor and drive system undergoing highly accelerated stress testing (HAST)

The other alternative fuel

Energy efficiency is a critical part of a sustainable energy policy for many power plants

WERNER JANIK, JOSEPH LAUER – As the global population continues to grow, so too does its hunger for energy. The long-term consequence of this will be a diminished supply of fossil fuels, currently the world's primary energy source. However, fossil fuels are also responsible for much of the CO_2 emissions produced today which severely impact the world's climate. Therefore as long as there is a continued reliance on fossil-based energy production this "catch 22" situation will remain. Of course it has long been known that renewable energy sources are the solution to this predicament. However, although rapid progress is being made to substitute thermal power plants with renewable energy sources, many issues still need to be resolved before renewable sources can effectively contribute to the overall energy mix. Unfortunately time is running out for planet Earth as it waits for further developments in renewable energy sources or the long expected break-through in nuclear fusion. In parallel to this work, action needs to be taken to protect the planet and to preserve its assets and biosphere for future generations; this can be achieved by the application of already developed energy efficiency methods and technologies.

1 A demand growth comparison of primary and electrical energy



The majority of the electrical energy produced today is based on the combustion of fossil fuels. In fact coal fuels more than 40 percent of the world's electricity supply, making electricity generation the single largest and fastest growing contributor to CO_2 emissions. The growth rate of renewable energy generation is high, and the correlation between energy use and emissions could effectively be reduced by the application of renewable energy sources. Unfortunately the contribution of renewable energy in the overall energy mix is still quite small and research is ongoing to efficiently integrate greater amounts of renewable energy.

Planet earth does not have the luxury of time on its side and therefore other improvements need to be made in parallel if the pattern of global energy use and the correlated carbon footprint is to be improved.

Projections by the International Energy Agency (IEA) show that using energy more efficiently has a greater potential to curb CO_2 emissions over the next 20 years than all the other options put together. The application of energy efficiency technology, methods and behaviors can immediately affect (ie, lower) the correlation between economic growth and energy use. In the field of power generation, in thermal power plants in particular, technology and methods required to achieve this are already available from ABB.

Today's energy challenges

In all regions of the world the demand for electrical energy is rising twice as fast as the demand for primary energy → 1. This trend is particularly noticeable in the expanding economies of the Middle East, India and China where demand is expected to be between 140 and 261 percent compared with between 89 and 116 percent for primary energy.

However, satisfying demand is really about striking the correct balance between the production and consumption of electrical energy. Hence the global target for energy efficiency will be to generate as much electrical energy as is possible out of the available fossil fuels, and at the same time consume as little of this energy as possible. By doing this every barrel-equivalent of saved electrical energy can be considered as "additional alternative fuel" which is available for other purposes.

Energy efficiency – the other alternative fuel

The chain of electrical energy production and energy consumption usually contains losses, the biggest of which are illustrated in → 2. It shows that from primary energy sources, such as gas or oil right down to the industrial user or private households, about 80 percent of energy is being lost. The majority of these losses occur during the generation process in power plants mainly because of the thermodynamic fundamentals of the process itself. For example, a conventional coal-fired power plant that can produce 500 MW of gross electrical energy is considered. The plant is around 25 years old with a typical thermal plant efficiency of 34 percent at a net heat rate of 10.2 BTU/kWh [1]. Even though the plant was originally designed for base load operation, this philosophy has changed to ensure the plant is capable of meeting the more fluctuating demands of today's grids, ie, the annual capacity factor has been reduced to about 70 percent with lots of part-load operation

In the chain of electrical energy production and consumption, up to 80 percent of energy can be lost, the majority of which occurs during generation.

between 50 and 90 percent. This practice has become more or less standard in many of today's power generation facilities, and it inherently has the potential to generate an "alternative fuel," ie, energy efficiency.

But before any power plant invests in energy efficiency improvements, three fundamental questions must be considered:
- Who has the know-how and technology to implement cost-effective energy efficient methods?
- What kind of savings can be generated?
- How can it be achieved?

The first two questions can be answered in one sentence: Methods and technologies developed by ABB enable an improvement in energy efficiency of between 8 and 10 percent. Looking at it another way, the amount of additional fuel available and savings possible (per annum) from the reference coal-fired 500 MW power plant example presented above are:
- Original fuel consumption: 1.4 billion kg (3 billion pounds)
- Additional energy to grid: 21.25 MWh
- Energy saved: 22.5 million kWh
- Reduction in CO_2 emissions: 260,000 tons
- Equivalent additional alternative fuel: 340 million pounds (enough to run approximately 850 cars for one year!)

In terms of the economic feasibility of implementing energy efficiency methods and technologies, ABB's experience has shown that an average payback period of between two and three years is all that is required to achieve these targets.

ABB's energy efficiency improvement methodology

ABB's approach to energy efficiency improvement consists of a three-phase methodology:
- Phase 1: Opportunity identification
- Phase 2: Master plan
- Phase 3: Implementation

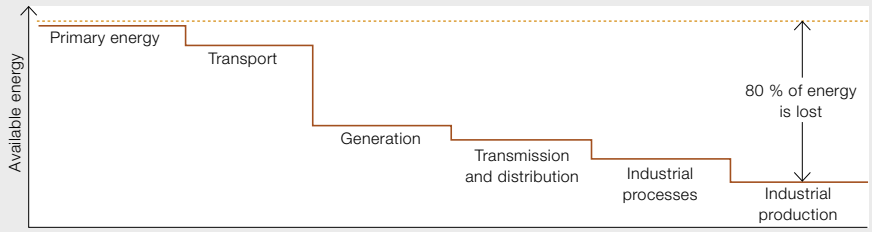
The accompanying tools and techniques used in this methodology have been developed through the experiences gained from working on a wide and varying range of energy generating and consuming processes at many customer sites over several years. Each step of the energy efficiency improvement methodology aims to deliver precisely the information needed to enable power plant operators to move forward with confidence and eventually complete a program of improvements that will deliver real and sustainable energy savings.

Opportunity identification

The first phase is concerned with an energy efficiency assessment, which aims to: identify specific opportunities to deliver improvements by confirming how, where and why energy is used; identify areas of inefficiency; and compare current performance with established industry best practices. A wide range of energy management aspects are outlined in → 3.

Within a typical coal-fired power plant similar to the 25-year old one described previously (ie, 500 MW gross electrical energy, production, plant efficiency of 34 percent, net heat rate of 10.2 BTU/kWh, annual capacity factor of about 70 percent) the aspects that would form components of the opportunity identification study are given in → 4.

2 Losses of up to 80 percent can occur along the entire energy value chain



3 ABB's opportunity identification study provides a comprehensive assessment of a wide range of energy management aspects

Technology and control

Identification of improvements through process control, equipment modification or alternative energy efficient technologies, typically covering the following energy systems:
- Fired equipment (gas turbines, furnaces, heaters, etc.)
- Steam boilers, turbines and systems
- Electricity generation and equipment
- Major pump, fan and motor systems
- Electrical systems – high-voltage and site medium-voltage/low-voltage users
- Compressed air and industrial gases
- Heating, ventilation and air conditioning (HVAC)
- Industrial refrigeration and chilling systems

Behaviors and practices

Assessment of behaviors and practices relating to energy efficiency across site processes and utility operations through a comprehensive review versus best practice including:
- Energy strategy and policy
- Energy management methods
- Capital investment
- Information technology
- Operational management
- Operational planning and performance
- Training and development
- Maintenance practices and strategies
- Staff motivations

Projections by the IEA show that using energy more efficiently has a greater potential to curb CO_2 emissions over the next 20 years than all the other options put together.

Footnote

1 The British thermal unit (BTU) is a traditional unit of energy equal to about 1.055 kilojoules. It is approximately the amount of energy needed to heat 0.454 kg of water 0.556°C.

4 Components of an opportunity identification study for a 25-year old 500 MW gross electrical energy coal fired power plant with an efficiency of 34 percent

Steam turbine performance and control
- Thermodynamic performance
- Condenser performance (where applicable)
- Optimization of extraction/back-pressure steam control
- Turbine control – as individual units and global control of fleet for optimum heat rates

Gas turbine (GT) performance and control
- Thermodynamic performance
- GT predictive maintenance
- Performance degradation
- GT control – as individual units and global control of fleet for optimum heat rates

Boiler performance and control
- Thermodynamic performance
- Feed-water conditions
- Boiler control – as individual units and global control of boilers for optimum heat rates
- Steam distribution systems

Electrical balance of plant
- Motors and drives (pumps and fans)
- Transformers
- Switchgear
- Field devices
- Compressed air system

Energy management system(s)
- Energy metering, monitoring and recording
- Extent of KPI analysis and ongoing performance assessment
- Integration within energy management policy

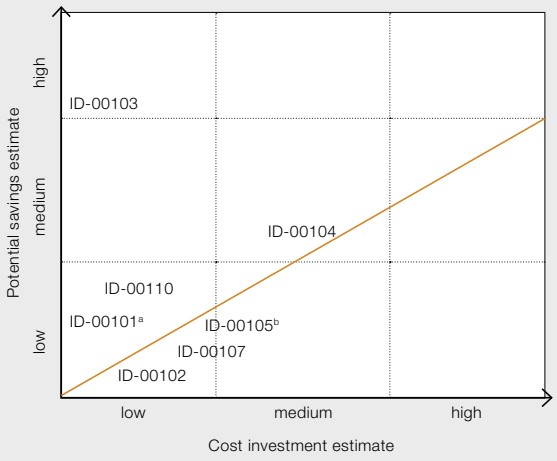
Panel board equipment
- Data acquisition system
- Alarm systems
- Auxiliaries

Overall plant heat rate
- Opportunities to further optimize

6 Measures identified for energy efficiency improvements in a coal-fired power plant

- Optimization of coal handling
- Improvement of ID and FD fan flow control
- Improvement of boiler feed water pump control
- Implementation of high efficiency motors and drives
- Optimized turbine controls
- Advanced steam temperature control
- Stabilization of firing rate and combustion optimization
- Excess oxygen reduction for boiler combustion
- Improved feed water pressure and level control
- Electric power system improvement (gsu's and auxiliary transformers)
- Reduction of leakages
- Reduction of thermal losses
- Thermal optimization of chiller operations

5 An opportunity identification payback chart



Plant Area A1
Project Considered

ID101 PXXQ (Dys Chassess)
3.2.1 VSD Installation on 1 x pump

ID102 PXXW (Dys Agitation)
3.2.1 VSD Installation on 1 x pump

ID103 PXX Pressure control
3.2.1 Pumping system pressure

ID104 PXX Pumping system
3.2.1 VSD Installation on 1 x pump

ID105 PXX, PXY, PXZ pumps
ID106 VSD Installation on 1 x pump
ID108 VSD in each above pumping system
3.2.1

ID107 PXX Pumping system
3.2.1 VSD Installation on 1 x pump

ID109 SX Cooling tower
3.2.1 Reduce 'overcooling' – elevate CW temperature

ID110 SX Cooling tower
3.2.1 VSD Installation on fans

By assessing each of these aspects, ABB would be able to describe the nature and scale of the energy saving opportunities and make clear recommendations about what further steps to take to realize additional potential benefits. After finalization of the energy efficiency assessment out of a comprehensive portfolio of identified project opportunities, the most promising ones are executed.

Another way of determining which individual measures should be realized is by using a generated payback chart which presents a qualitative overview of the identified energy saving opportunities with respect to the expected energy savings and likely investment costs → 5. Or to put it another way, the payback chart visually presents a basic interpretation of opportunity payback. This graphical evaluation helps to quickly identify which measures (normally those above the orange line) have the potential to give a good return on investment.

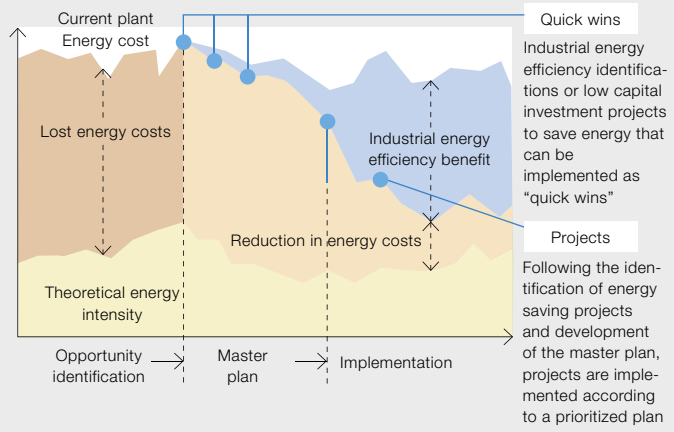
For the coal-fired power plant example, the measures finally identified as worth the investment for energy efficiency improvements and which are very typical for such examples are given in → 6.

It is not only technical measures that will improve the energy efficiency of power plants; improving operational practices both on the plant management and operator levels also has a significant impact. Examples for improvement potential can be found in lots of power plant operations:
- The manual shutdown of devices that are not needed
- The increased isolation of walk downs frequency
- The development of an effective lighting-replacement policy
- The establishment of a device-replacement policy based on a life-cycle cost assessment (LCA)
- The development of a policy for predictive maintenance
- The establishment of an energy efficiency targeting program

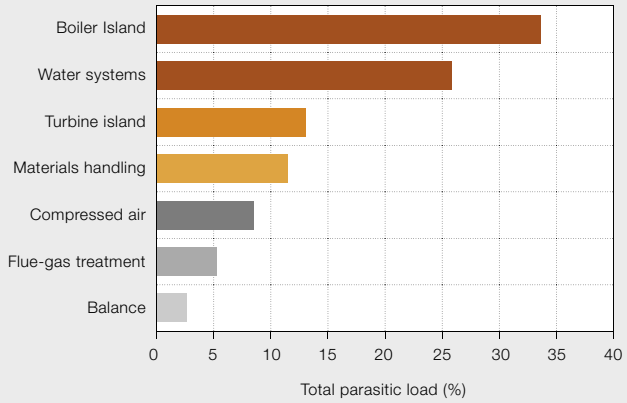
Master plan

In this phase the opportunities identified in the assessment phase are developed into a detailed implementation plan. The master plan takes the form of a suite of improvement projects, each with well understood and calculable benefits. The master plan is generally developed by ABB together with the client, and at the end of the phase a clear roadmap, including detailed project specifications, are developed to allow the most economic implementation of the energy saving opportunities. Some of the quick and easy measures can already be imple-

7 Energy cost assessment using ABB's three-phase methodology



8 Certain areas of a power plant contribute more to the overall plant energy consumption



mented by the client during this phase without the assistance of ABB. While many opportunities can be implemented with ABB's core technologies, those that are not based on these technologies may be implemented by third parties.

Implementation

The implementation phase covers the execution of the implementation projects and is generally carried out by ABB and the client together, or depending on what is needed to achieve the defined targets, by ABB with the appropriate technology partners or other original equipment manufacturers.

Measuring success

All implemented methods for energy efficiency improvement are effectively useless if the benefits cannot be seen on a daily basis. Therefore it is essential to implement proper tools to record and show the achieved improvement in all relevant areas of the plant. This information is needed for all implemented measures either in plant technology and control, monitoring and targeting or in behaviors and practices.

Success, especially for coal-fired power plants strongly depends on the operational mode of the plant; plants operated in steady-state mode have little potential for optimization while those with significant part-load operational modes are ideally suited to energy efficiency improvement identification exercises → 7.

In the 500 MW example mentioned in this article, a heat-rate improvement of about 8 percent can be achieved. Greenhouse gas emissions can also be reduced by 8 percent relative to the increased plant power output. This value is more or less distributed between the different plant areas, depending on the influence of each area to the plant parasitic load → 8.

These results can be achieved thanks to ABB's strength and flexibility in finding the best possible solution to improve energy efficiency in power plants.

In all regions of the world the demand for electrical energy is rising twice as fast as the demand for primary energy, a trend that is particularly noticeable in the expanding economies of the Middle East, India and China.

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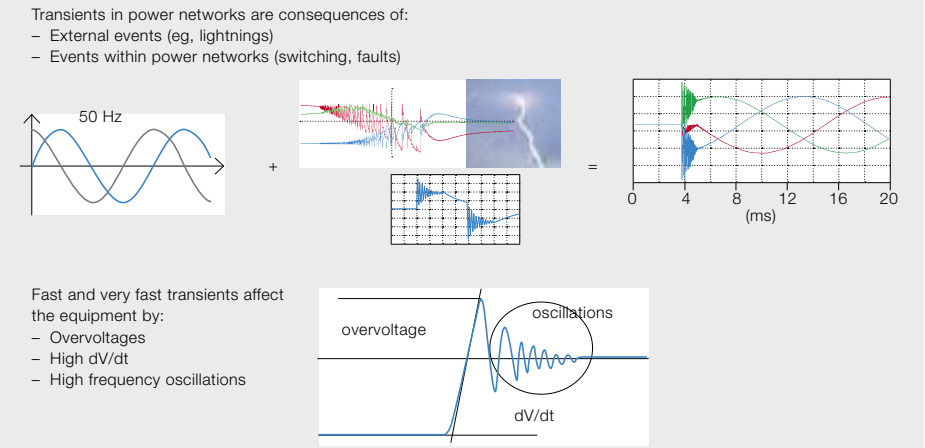
Title picture
Even though the growth rate of renewable energy generation is high, research is ongoing to efficiently integrate greater amounts of renewable energy.

Surviving a strike

ABB helps distribution transformers survive rapid voltage transients

WOJCIECH PIASECKI, MAREK FLORKOWSKI, MAREK FULCZYK, PAWEŁ KŁYS, EGIL STRYKEN, PIOTR GAWĄD – A lightning strike is not a pleasant experience under any circumstances. For electrical equipment it is not just the voltage peak that can cause damage, but also the sudden and rapid voltage rise. In some cases the voltage transients are far steeper than those that occur in typical situations covered by common standards – they can surge by megavolts in the space of microseconds. The insulation covering the windings of transformers and motors is not normally designed for such transients and can suffer permanent damage if no additional protection is used. Studies show that despite each piece of equipment being designed to withstand typical surges, as many as 35 percent of total dielectric failures in power equipment may be caused by such surges [1]. One solution is to totally redesign equipment to better cope with such transients. A simpler approach involves adding a component that protects the equipment from surges without affecting normal everyday operation. ABB has developed precisely such a component.

1 Transients in power networks



Transients in power networks result in overvoltages and oscillations superimposed on the phase voltages and currents.

The high-frequency components in the spectrum of a voltage surge ➔ 1 result in a highly nonuniform voltage distribution. This causes local stresses on the insulation system, going far beyond those encountered during normal operating conditions. Furthermore, the complicated internal structures of electric apparatus can act as multiresonant circuits. High frequencies can therefore additionally cause local amplification. The resulting stresses on the insulation system can significantly compromise the equipment's lifetime, and often leads to internal short circuits.

The voltage impulse the insulation material can withstand strongly depends on the impulse rise time. This is normally taken into account when choosing insulation for electric motors. Of special concern is dry type insulation on rotating electric machines when these machines are fed by drives that use solid-state switching devices at high frequency. Manufacturers of such machines often provide guidelines regarding the limits of surge voltage amplitudes and corresponding front times. Of special concern are surges whose rise time is typically below 1µs [2], resulting in a nonlinear initial voltage distribution along the winding. This initial uneven voltage distribution produces high-voltage insulation stress and can lead to breakdowns, corona and partial discharges ➔ 2.

The increasing demand for a higher withstand level is also observed in distribution transformers. This is being met by nonconventional designs of windings that are increasing both design and manufacturing costs. Of special concern are transformers exposed to frequent atmospheric discharges. Operators of such networks often request compliance with a highly demanding norm, requiring the testing of transformers with a steep-fronted impulse. The Finnish standard SFS 2646 prescribes a voltage rise (dV/dt) of 2 MV/µs [3]. This norm requires that the transformer should be protected against overvoltages by a spark gap in its proximity. As a spark gap is relatively slow to react, the voltage at the transformer terminals may (under test conditions) rise to levels largely in excess of the basic insulation level (BIL) determined by the operating voltage of the equipment. In addition, the high dV/dt of the waveform results in a highly nonlinear initial voltage distribution in a conventional winding, leading to local overstressing of the insulation system ➔ 3. Experimental results confirm this and indicate that a spark gap may not provide sufficient protection for distribution transformers [4] of standard design.

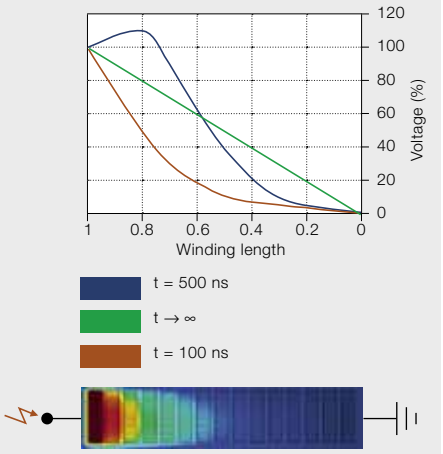
The common solution is to apply a special winding design comprising additional elements (electrostatic screens) equalizing the initial potential distribution. Such a solution helps avoid local overstressing of the insulation by high dV/dt values, but it adds complexity to both the design and the manufacturing process of the transformer. Furthermore, the peak overvoltage nevertheless reaches the transformer winding and thus the insulation must be dimensioned to withstand overvoltages in excess of the standard BIL.

SmartChoke – series-impedance-based protection

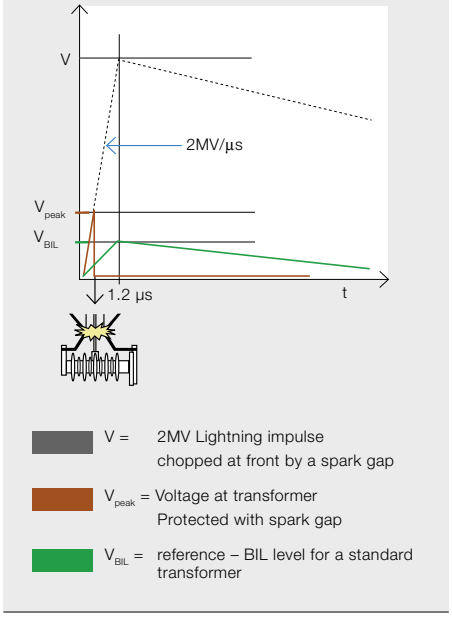
ABB has developed an alternative to such a special transformer design by providing a series-connected filtering element (referred to as a choke) upstream of the protected equipment. The basic principle of the series element is to provide an appropriate impedance-frequency characteristic ➔ 4. This makes the device practically transparent at 50 or 60 Hz while suppressing very high frequency components.

Of special concern are surges, whose rise time is typically below 1µs, resulting in the initial voltage distribution along the winding being nonlinear.

2 Initial, nonlinear distributions of electrical potential along the transformer winding

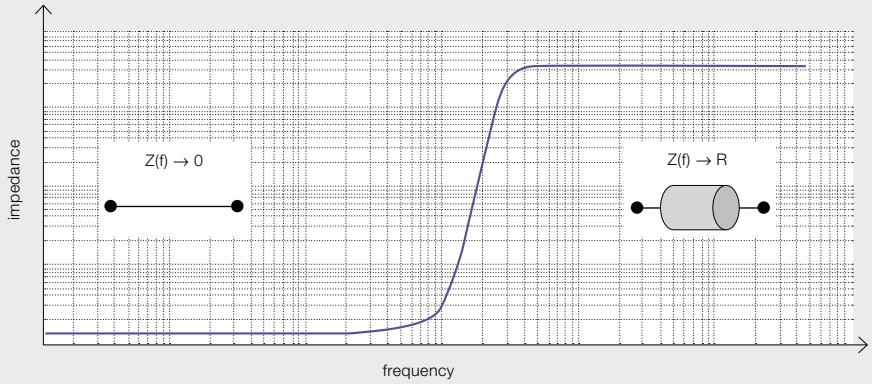


3 Impact of a front-chopped lightning surge on a transformer



The standard BIL waveform (green line) is a reference.

4 Idealized representation of the frequency characteristic of the impedance of the series choke



Experiments have demonstrated the effectiveness of this method in reducing the dV/dt resulting from transients associated with reignitions and prestrikes in a circuit breaker. The externally installed series choke element combined with a small shunt capacitor reduced dV/dt to a safe level and also eliminated the high-frequency oscillations that would otherwise have followed such a transient [5].

The successful mitigation of switching-induced dV/dt transients raised the question of whether a similar approach could be used to mitigate the lightning-induced chopped dV/dt transients to which pole-mounted distribution transformers are frequently exposed. Furthermore, ABB sought to integrate the device within the transformer itself.

The series choke element can be regarded as an alternative to specially designed winding described above that uses electrostatic screens for the equalization of potential distribution at high frequencies. The series choke element forms a low-pass filter when combined with the self capacitance of a transformer (at high frequency the transformer winding's characteristic can be represented by its surge capacitance). This capacitance varies depending on the type and size of the device. For oil-filled transformers it can be between a single and a few nanofarads per phase.

The frequency response of such a filter can then be optimized by appropriate selection of the R and L parameters. It must furthermore be ensured that the choke behaves correctly under normal operating conditions and is able to withstand the short-circuit test.

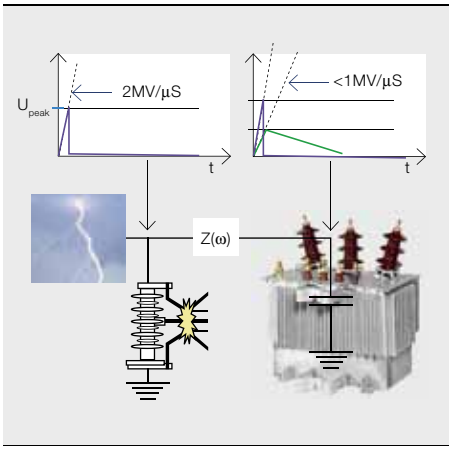
Depending on the relation between the R, L, and C values, the circuit response can be either aperiodic, or it can additionally contain oscillatory components. If the resistance value is lower than the critical value Rc, the periodic terms are equal to zero and the output voltage is a combination of exponential functions.

Therefore, selecting an appropriate value for the damping resistance is extremely important in order to achieve the highest possible reduction in dV/dt, while still preventing overshoots and oscillations of the voltage downstream of the choke element ➔ 5.

In this approach, the capacitance C is the equivalent phase-to-ground capacitance of the transformer. Since, as mentioned above, the limits of this capacitance are known for a given class of transformer, the optimization of the R

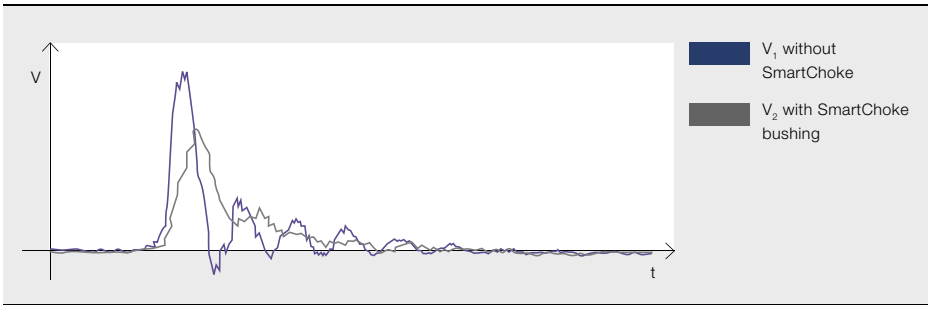
The choke is series-connected upstream of the protected equipment. Its basic principle is to provide an appropriate impedance-frequency characteristic

5 Concept of series device protecting the distribution transformer against high dV/dt



6 Transformer bushing with integrated SmartChoke filter

7 Experimentally measured reduction in the overvoltage and dV/dt



8 SmartChoke-protected, high dV/dt resistant transformer by ABB

and L values can be achieved to cover all typical transformers of a certain category. Considering the idealized situation of ➔ 3, in which a 2 MV lightning impulse is chopped with a spark gap, the unprotected equipment (eg, pole-mounted transformer) would experience the phase-to-ground voltage at a peak above 270 kV (characterized by a dV/dt of 2 MV/µs). With the series choke element installed upstream of the protected device, the dV/dt is not only lower, but the peak value of the voltage surge reaching the transformer is also reduced.

SmartChoke-protected transformer

The described series choke element concept has been implemented in new ABB distribution transformers, giving them a superior protection against high dV/dt transients. The SmartChoke element is integrated within the transformer bushing ➔ 6 and thus the filtering of the high dV/dt transient takes place before it reaches the winding.

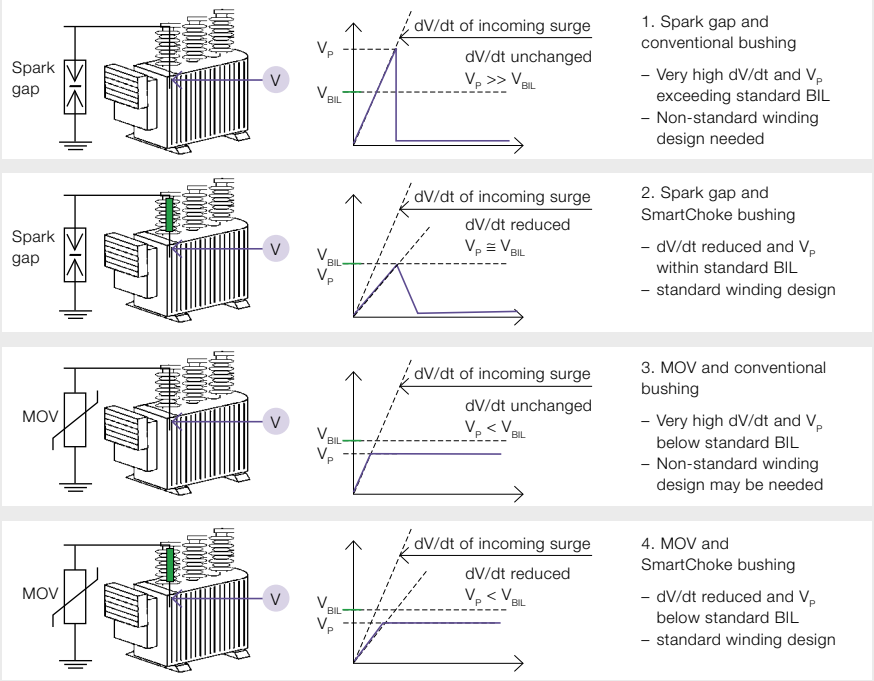
Selecting an appropriate value for the damping resistance is extremely important in order to achieve the highest possible reduction in dV/dt.

The parameters of the choke element embedded within the epoxy-cast transformer bushing are selected so that the same bushing can be used to protect all typical sizes of distribution transformers working in pole-mounted substations in distribution networks.

Experiments performed have shown that a reduction in dV/dt exceeds a factor of two with respect to the standard transformer bushing. A significant reduction in peak overvoltage was also observed ➔ 7.

A transformer featuring the SmartChoke bushing ➔ 8 has been certified according to the SFS 2646 standard at the HV

9 Comparison of different protection scenarios



Experiments have shown that reduction in dV/dt exceeds a factor of two with respect to the standard transformer bushing.

laboratory of the Helsinki University of Technology in Espoo, Finland. It was demonstrated that the transformer using a standard winding design and that has protective chokes embedded in the bushings as well as a 2 × 40 mm spark gap could be safely exposed to a 2 MV/µs lightning impulse.

Successful protection

The use of a choke upstream of the equipment to be protected has been shown to represent an attractive alternative to complex redesigning of the equipment itself. Although chokes reduce dV/dt and consequentially also the peak value of the front-chopped wave, it should be pointed out that the primary function of the protective device is the reduction in dV/dt of a transient caused by a lightning surge. It is therefore complementary to the standard overvoltage protection provided, for example, by protective spark gaps or metal oxide arresters ➔ 9.

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[5] Glinkowski, M., Piasecki, W., Florkowski, M., Fulczyk, M., Arauzo, F. (2008, May). SmartChoke-protecting power equipment from fast transients. Paper presented at IEEE PES Transmission and Distribution Conference, Chicago, IL, United States.

Title picture
Lightning strikes are a cause of steep voltage transients that can damage electrical equipment.

Sharing values

ABB is implementing the first commercial installation of IEC 61850-9-2 LE process-bus technology

STEFAN MEIER – The introduction of the IEC 61850 standard represents a great step forward in substation automation – and the process is continuing. One example is the application of the standard's subsection, IEC 61850-9-2, for the sharing of sampled analog values using Ethernet. By integrating this technology into its substation automation systems, ABB has combined over 10 years of experience in producing non-conventional instrument transformers for current and voltage measurement with the latest communications technologies. It is now possible to connect primary (high-voltage) equipment to ABB's field-proven substation protection and control devices more effectively, improving the reliability and availability of optimized substations. Combining these vital technologies in the world's first commercial implementation of IEC 61850-9-2 LE, ABB is refurbishing a substation it first commissioned in 1999.

As a pioneer in the fields of NCIT [1] and process bus technology, ABB began commissioning a series of six outdoor substations with process bus and NCIT technology in 1999. The mixed technology, or "hybrid" substations supplied to the Australian utility, Powerlink Queensland, were based on ABB's intelligent plug-and-switch system (iPASS). Electronic modules integrated into the drives of the circuit breaker, disconnector and earthing switch of the iPASS modules could communicate using a proprietary optical process bus. Furthermore, the iPASS modules were equipped with ABB's ELK-CP sensor for voltage and current measurement, also connected to the process bus.

> The publication of IEC 61850, began a new chapter in describing substation functionality and communications.

A process bus is the communication network between primary equipment (such as instrument transformers) and secondary equipment (such as protection and control IEDs [2]) of a substation automation system. This optical communication network is used to transmit analog data (such as current and voltage measurements). The network can also be used to transmit binary data (such as the switchgear's position indications) and trip-and-close commands (to operate the circuit breakers and disconnectors), but this is not part of current process bus implementations. In today's conventional substations, this information is exchanged through extensive parallel copper cabling. The use of fiber-optic networks not only eliminates vast parts of the copper cabling, it also increases operational safety by isolating the primary from the secondary process ➔ 1.

The ELK-CP sensor families are based on redundant sets of Rogowsky coils [3] for current measurement and two independent capacitive dividers for voltage measurement. As it contains no oil, this equipment is both environmentally friendly and extremely safe. The fully redundant design of the sensors (including the associated electronics) permits application of two completely independent and parallel protection systems, boosting the availability of the secondary system. As sensor electronics can be replaced independently and without requiring a shutdown of the entire protection system, repair activities require less time and, because no live parts need to be handled, thee activities are also much safer ➔ 2.

ABB installed more than 300 such electronic sensors in Powerlink's substations. Notably, in more than 10 years of service, none of the primary converters ever failed. Based on experience values, the mean time between failures (MTBF) of the sensor electronics is almost 300 years. This demonstrates the extreme reliability and high availability of the sensors, even under the very demanding environmental conditions of the Australian climate.

The upgrade

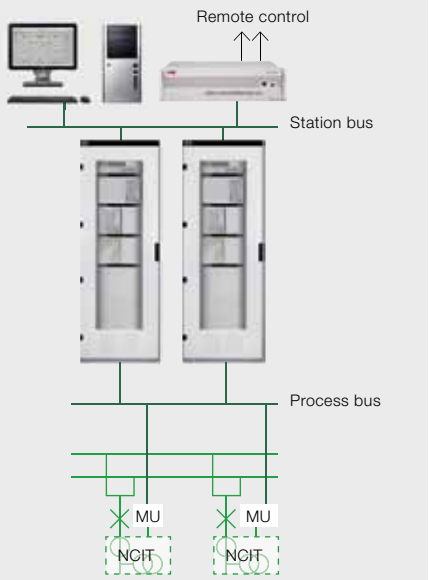
Powerlink launched an upgrade project that involved replacing secondary equipment in the hybrid substations, including the process-oriented electronics that connect to the process bus. A central requirement of this upgrade is its full compliance with international standards, especially the implementation of the process bus for sampled analog values, which has to comply with IEC 61850-9-2 LE ➔ 3.

Powerlink awarded the contract for upgrading the first iPASS substation to ABB. This project represents the world's first commercial implementation of a process bus according to IEC 61850-9-2 LE. Its implementation is now well under way.

Process bus according to IEC 61850-9-2 LE

The publication of the international standard for communication networks and systems in substations, IEC 61850, began a new chapter in describing substation functionality and communications. For the first time, there is now a standard supporting true interoperability between devices from different vendors, along with a future-proof design. The standard has rapidly gained market acceptance [4].

1 Station and process bus in substations



Footnotes

1 NCIT: non-conventional instrument transformer
2 IED: intelligent electronic device
3 The Rogowski coil is a device used to measure alternating current. It comprises a toroidal winding. The current-carrying conductor is arranged to pass through the center of the toroid. The output of the sensor is a voltage, which is proportional to the derivative of the current.
4 See also *ABB Review Special Report IEC 61850*

ABB played an important part in the creation of the standard and continues to be a driving force in its maintenance and further development. Since installing the world's first multivendor project in 2004, ABB has gone on to deliver more than 1,000 systems with an IEC 61850-compliant station bus to sites in about 70 countries.

Following the successful introduction of IEC 61850 at the station level, its importance in process-oriented communication using process bus is increasing rapidly. Completing the standard's ability to define all necessary time-critical signal exchanges between the process and bay levels, the standard's part 9-2 focuses on the exchange of sampled analog values through an Ethernet network.

IEC 61850-9-2 requires that analog samples are transmitted by so-called merging units (MUs). The MU time correlates and merges analog data from individual phases or measuring points in the substation before transmitting them via the Ethernet network, from where the data can be accessed by protection and control devices. With the introduction of the CP-MUP, ABB is the first company to offer a conformance-tested, UCA-certified [5] merging unit.

IEC 61850-9-2 has made it possible to exchange signals from NCITs in a standardized way, supporting the eminent advantages of NCIT technology. These include the highest levels of accuracy throughout the complete measuring range, a space-saving design and dramatically improved safety compared to conventional equipment.

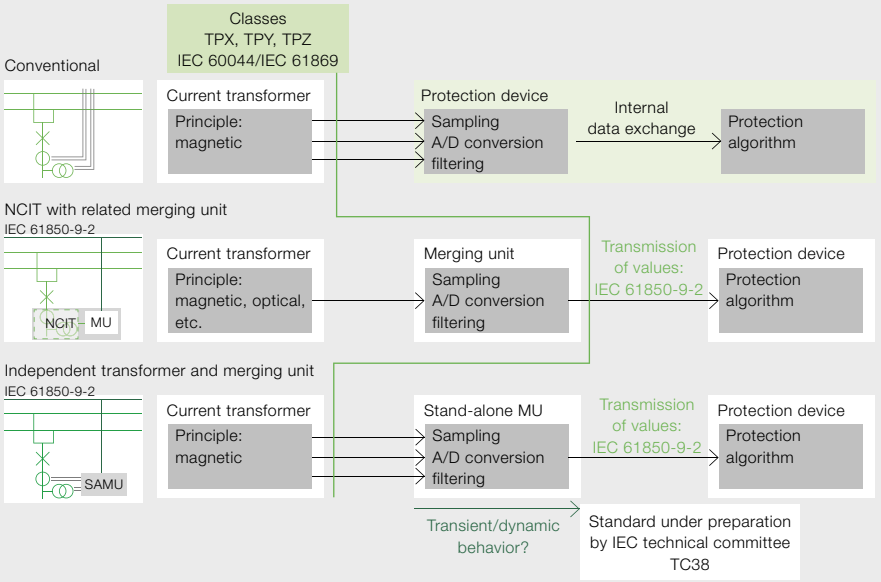
To facilitate implementation of part 9-2 of the standard, and to simplify its application, the UCA International Users Group has developed an implementation guideline for IEC 61850-9-2. The guideline provides additional information on how to implement the standard and defines a subset of the same. This document is referred to as IEC 61850-9-2 LE (for light edition) and is predominant among today's 9-2 implementations.

Because the NCIT merging units are tailor-made for a specific type of NCIT, they form a single entity that can be jointly developed and type tested, permitting the behavior of the complete measuring chain at the IEC 61850 port to be defined.

This is in contrast to stand-alone merging units (SAMUs), which interface to conventional CTs [6] and VTs [7]. SAMUs sample the analog signals and supply them to the process bus. Inevitably the conversion of analog values to digital samples influences the transient response of the measuring chain. This dynamic behavior of the SAMU is not covered by the IEC 61850 standard. Activities to address this are ongoing in the relevant IEC and Cigré technical committees and working groups. The definition will be incorporated in a future release of IEC 61869, the international standard for instrument transformers → 3.

2 ELK-CP3 combined current and voltage NCITs with IEC 61850-9-2 LE merging unit

3 Standardization of transient performance and communication interfaces



Using fiber optic networks not only eliminates vast parts of the copper cabling, it also increases operational safety.

Footnotes

5 The UCA International Users Group is a not-for-profit corporation focused on assisting users and vendors in the deployment of standards for real-time applications for several industries with related requirements.

6 CT: current transformer

7 VT: voltage transformer

4 Substation automation system for a 1½ breaker switchgear with one of two redundant protection systems

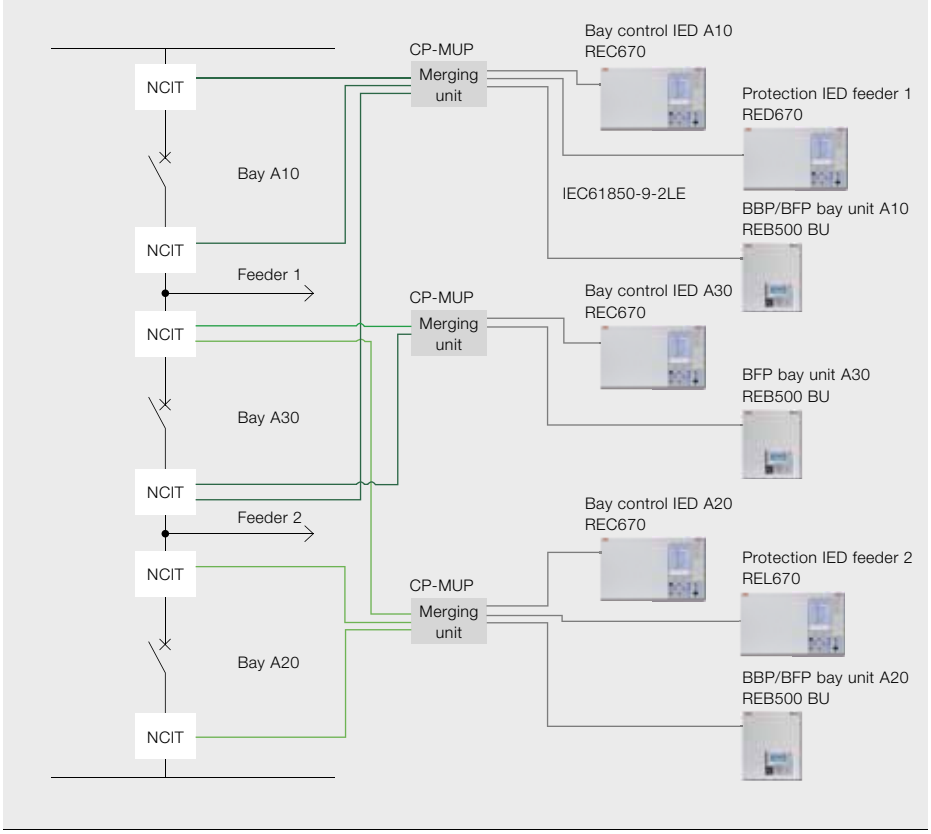


ABB played an important part in the creation of the IEC 61850 standard and continues to be a driving force in its maintenance and further development.

Extension of proven sensor technology with state-of-the-art process bus

In the upgrade project for Powerlink, ABB is building on its extensive experience with NCITs and will replace the originally installed proprietary process bus with IEC 61850 technology. The new IEC 61850-compliant system will handle communications at both the station and process levels.

In the Powerlink Queensland project, ABB will use its SAS600 substation automation system, protection and control IEDs from its Relion® 670 series and its REB500 decentralized busbar and breaker-failure protection system. All protection and control devices in the system will connect to the IEC 61850-9-2 LE process bus and receive sampled analog values from ABB's CP-MUP merging units. The MUs will interface with the existing combined current and voltage sensors through new sensor electronics. In this way, modifications to the primary apparatus can be kept to a minimum ➔ 5.

A substation automation system for a 1½ breaker arrangement, similar to that used for the secondary system upgrade in Australia, is shown in ➔ 4. Using the embedded redundant design of ABB's NCITs, a second fully independent system of merging units and protection IEDs is used to meet the customer's redundancy requirements.

To demonstrate the suitability of components and prove the concepts to be used in the Powerlink project, additional measures to verify the new technology were taken.

A series of pilot installations featuring NCITs and IEDs connected to the process bus were commissioned to gain experience with the new technology in real-life substation environments. Among these was the upgrade of a feeder at one of Powerlink's 275 kV substations with new sensor electronics, merging units and protection IEDs from ABB's Relion® range. Besides helping customers to gain important experience and confidence, the pilot installations are also delivering vital information on the long-term stability and behavior of the pilot equipment compared with conventional or non-conventional devices.

All ABB protection and control equipment undergoes rigorous product and system verification testing in ABB's own UCA-certified system verification center[8]. In addition, a concept test was performed for the Powerlink secondary system upgrade project in ABB's test field with experts from both companies. Special attention was paid to the behavior of the system under various fault conditions.

The system behaved reliably, as specified, and under no condition did it overreact or issue incorrect tripping signals. Such erroneous signals could, in a real-life situation, lead to blackouts in the power network.

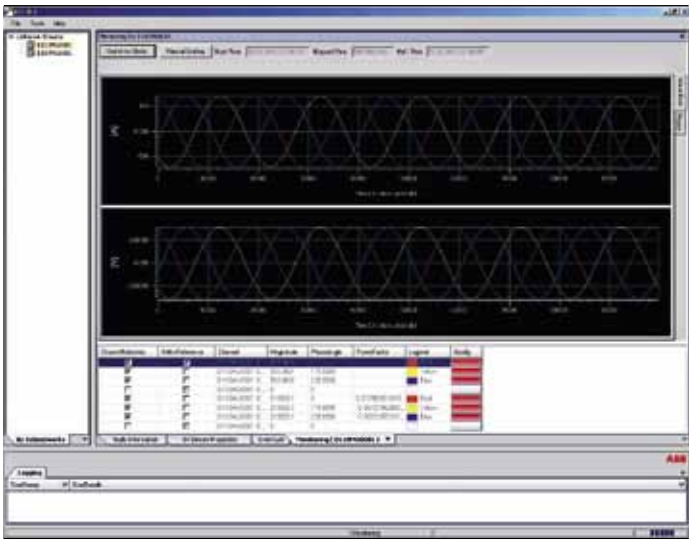
During the simulation of the various potential failure conditions, permanent and detailed supervision of all system components proved its importance in enabling the fast and accurate identification of faults. Continuous system supervision drastically reduces the need for periodic maintenance activities and tremendously simplifies maintenance by guiding substation personnel to the precise location of faults.

Footnote

8 See also "Verified and validated: ABB has its own verification and validation center" on pages 23–28 of *ABB Review Special Report IEC 61850*.

5 One of Powerlink's iPASS substations with NCITs

6 ABB IEC 61850-9-2 analyzer



Testing and maintenance of process bus installations

The replacement of copper wires by fiber optic cables and the description of the transferred information according to IEC 61850 open new opportunities for intelligent testing tools that support the commissioning and maintenance of substation automation systems.

ABB was quick to release the integrated testing toolbox, ITT600[9], containing a comprehensive suite of tools to help users fully benefit from the advantages of IEC 61850.

ITT600 masks the underlying complexity of the IEC 61850 standard and provides testing and maintenance personnel with a clear view of the data available in the system. For example, it facilitates the verification of consistency of the installation with the station configuration description (SCD), and helps to analyze communication between IEDs and the station-level system.

Since the introduction of the process bus for sampled analog values, the corresponding tools have been added to the toolbox. This is particularly important in a scenario where measurements are provided by NCITs using an optical connection to the merging units. In such a situation, all conventional CT and VT terminals are rendered obsolete and all analysis is done on the IEC 61850-9-2 network. Drawing on its extensive experience with the integration of IEC 61850 and the development of testing tools, ABB is developing a feature-rich analyzer for sampled analog values ➔ 6.

The advantage of analyzing values on the process bus versus conventional current and voltage measurement begins when the measurement points need to be accessed. With the values available on the process bus network, it is no longer necessary to access live components and no CT terminals need to be short-circuited and opened. By connecting the Ethernet port of the analysis tool to the process bus network, or directly to the merging unit, the maintenance engineer can easily access all sampled value streams. In contrast to analysis by amp- or volt-meter, the 9-2 analyzer readily displays data that were previously not directly available. These include views of current and voltages of all phases at once, phasor diagrams and in-depth information on the transmitted telegrams. This last information gives vital insights into the system's health and can, for example, indicate that parts of the system are undergoing testing.

> All ABB protection and control equipment undergoes rigorous product as well as system verification testing in ABB's own UCA-certified system verification center.

Future trends

Using the full potential of the process bus concept and its definition in IEC 61850, binary data can also be transmitted through the optical communication network between primary process and protection and control IEDs. By placing binary input and output modules close to the primary process, virtually all copper cabling can be avoided, resulting in additional advantages such as the ability to electrically isolate process- and bay-level systems, and the continuous supervision of all signals.

By combining its cutting-edge application of IEC 61850 technologies on the station as well as the process level with vast experience in the field of NCIT technology, ABB is building intelligent, future-proof offerings to meet customer demands for more reliable, efficient and safe solutions, maximizing the benefits and value of their assets.

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Footnote

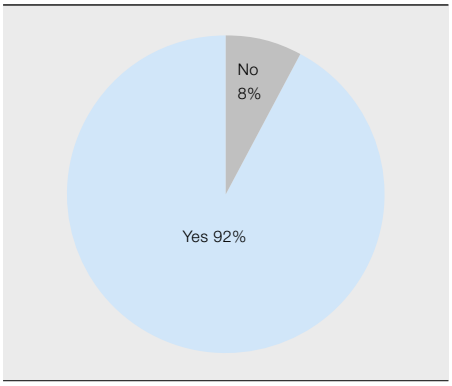
9 See also "A testing environment: ABB's comprehensive suite of software testing and commissioning tools for substation automation systems" on pages 29–32 of *ABB Review Special Report IEC 61850*.

The results are in

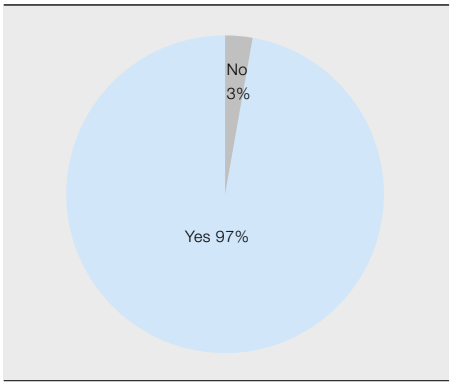
ABB Review readership survey

The *ABB Review* team and everyone at ABB Group R&D and Technology would like to thank you for taking the time to complete the *ABB Review* readership survey this past fall. Your feedback is helping to steer the direction of the journal. We are particularly glad to see that most readers read articles that are outside their area of expertise and have multiple uses for the journal – this shows the applicability of *ABB Review* across many different technology areas. Although the survey was published in five languages and was available worldwide, all five of our raffle winners were nevertheless from the Far East and Southeast Asia! Congratulations and thank you to Gary-Hua Guan (China), Barton-XingPing Liu (China), Giridhar Sharma (India), Sheng Zhang (China) and Feni-Nurdiana Masrani (Malaysia)! They will each receive a solar-powered flashlight and a 4 GB USB stick.

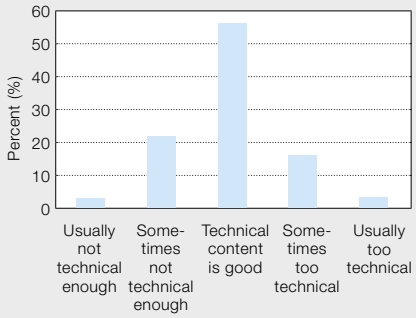
1 Do you read *ABB Review* articles that are outside your area(s) of expertise?



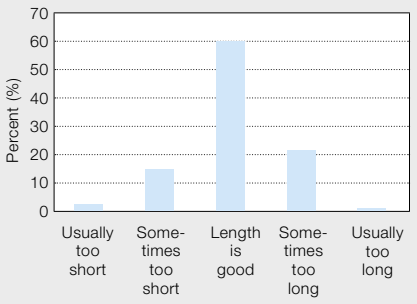
2 Would you recommend *ABB Review* to a colleague?



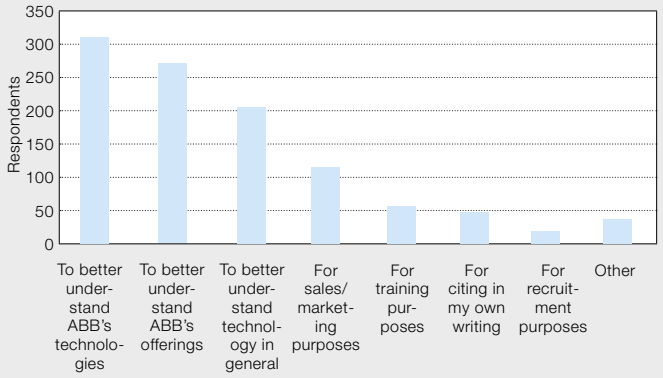
3 How satisfied are you with the level of technical content in *ABB Review* articles?



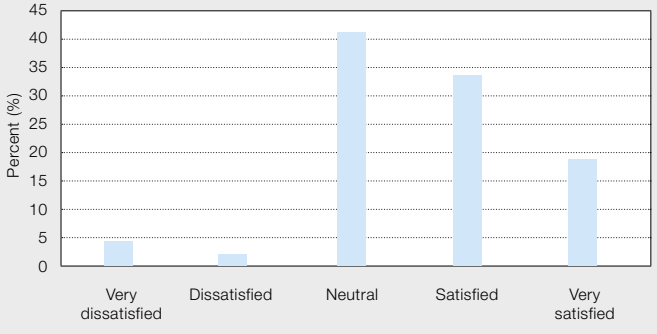
4 How satisfied are you with the length of the articles?



5 How do you use *ABB Review*? (multiple responses permitted)



6 Beginning with issue 1/2010, *ABB Review* was redesigned to reflect ABB's new brand strategy. How satisfied are you with this new look?



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Oil and gas

According to estimates by the US Energy Information Administration (EIA), oil accounts for about 36 percent of primary energy consumed on the planet and is the single largest source of primary energy. Natural gas takes third place (behind coal) and accounts for about 23 percent. Between them these energy sources cover almost 60 percent of mankind's energy needs, or the equivalent of over 100 million barrels a day. The continuity of the oil and gas supply is of prime importance for the economy, for industry and for countless aspects of human activity. Despite growth in the fields of alternative energies and nuclear power, and progress with energy efficiency, the volume of oil and gas required will in all likelihood continue to increase for many years to come.

ABB provides numerous technologies that strengthen the value chain of oil and gas. These support the industry in almost all its activities, ranging from exploration and extraction to processing and transportation. Issue 2/2011 of *ABB Review* will take a closer look at some of the contributions the company is making to this fascinating industry.

Connect renewable power to the grid?

Electricity generated by water, sun and wind is most abundant in remote areas like mountains, deserts or far out at sea. ABB's leading power and automation technologies help renewable power reach about 70 million people by integrating it into electrical grids, sometimes over vast distances. Our effort to harness renewable energy is making power networks smarter, and helping to protect the environment and fight climate change. **www.abb.com/betterworld**

Naturally.

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