ABB review

4|10

The corporate technical journal

Focus on productivity

Power and productivity for a better world™

ABB

It is often said that the whole can be more than the sum of its parts. This is true in almost all aspects of industrial activity. The objective of minimizing waste, variability and unplanned downtime must be met not only by optimizing individual aspects and components but also by considering how different resources and components interact. This edition of *ABB Review*, Focus on productivity, looks at both specific technologies and their broader interaction, all of them serving the goal of greater productivity.

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Productivity

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

Dear Reader,

Production is the transformation of raw materials, capital, labor and energy into products and services. Producers continuously strive to minimize their resource footprint while maximizing output while taking into account safety, environmental, regulatory and other concerns. The quest for higher productivity has shifted from optimizing individual components in isolation and increasingly looks at the broader process. In this it is supported by technological progress in such domains as monitoring, communications, integration and real-time analysis.

Our opening article looks at the exchange of information between a plant and its operating staff. The design of human machine interfaces has great influence on an operator's ability to detect abnormal situations and react to them before they become critical. Apparent details in interface design can favor early detection and hence have a real effect on plant productivity.

Not all abnormal situations can be avoided by operator vigilance alone. It is the task of safety systems to continuously monitor equipment and processes and react when given parameters are exceeded. Safety systems have traditionally been separate from control systems and have required dedicated wiring and hardware. Increasingly however, safety functions can be integrated into control systems. We discuss this with the example of AC drives.

Avoiding abnormal situations through good operating practices and a strong safety culture is the best way to avoid downtime and lost productivity. There are situations, however, where disturbances are caused by exceptional external influences such as earthquakes. Equipment should be sufficiently robust to survive such incidents and to be able to resume normal operations as soon as possible. We dedicate an article to the seismic resilience of large transformers.

Despite all precautions, situations will occur that see the unexpected failure of large components. Due to lead times in their manufacture and transportation, large power transformers cannot easily be replaced at short notice. One solution lies in the use of mobile transformers. They are small and light enough to be able to be shipped at short notice using existing transportation infrastructure, and to be assembled on site quickly providing a temporary solution until the damaged unit can be repaired or replaced. Until now, mobile transformers have been limited to 250 kV, but ABB has recently delivered a 400 kV version.

One area that has permitted considerable improvements in productivity in recent decades is power electronics. Advantages include energy savings, improved controllability and simplified maintenance. *ABB Review* dedicates several articles to the company's offerings in the field of power electronics ranging from semiconductors to intelligent motor control.

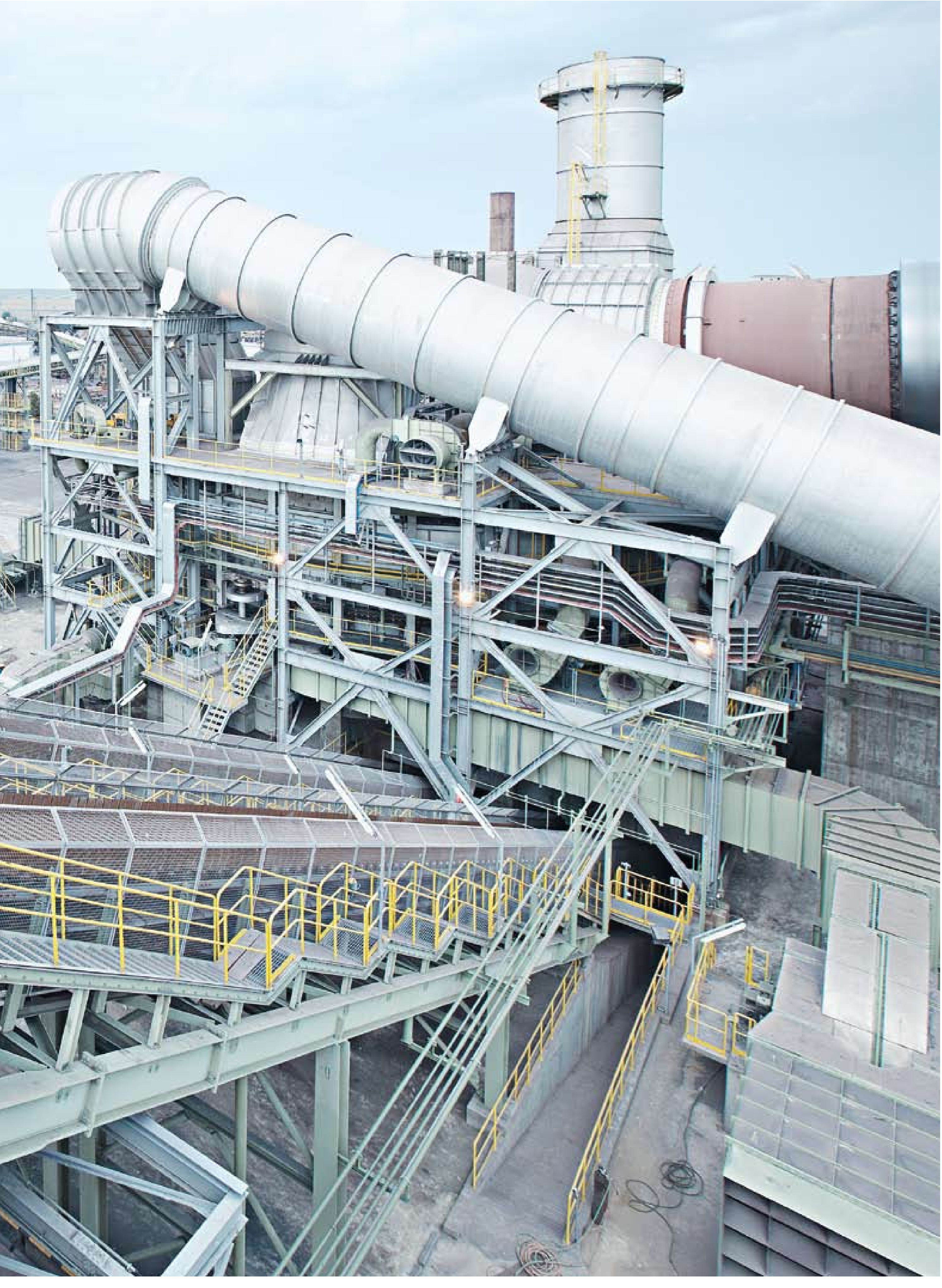
Further articles look at the latest generation of molded-case circuit breakers, active filters for power systems and reducing the fuel consumption of ships while in port.

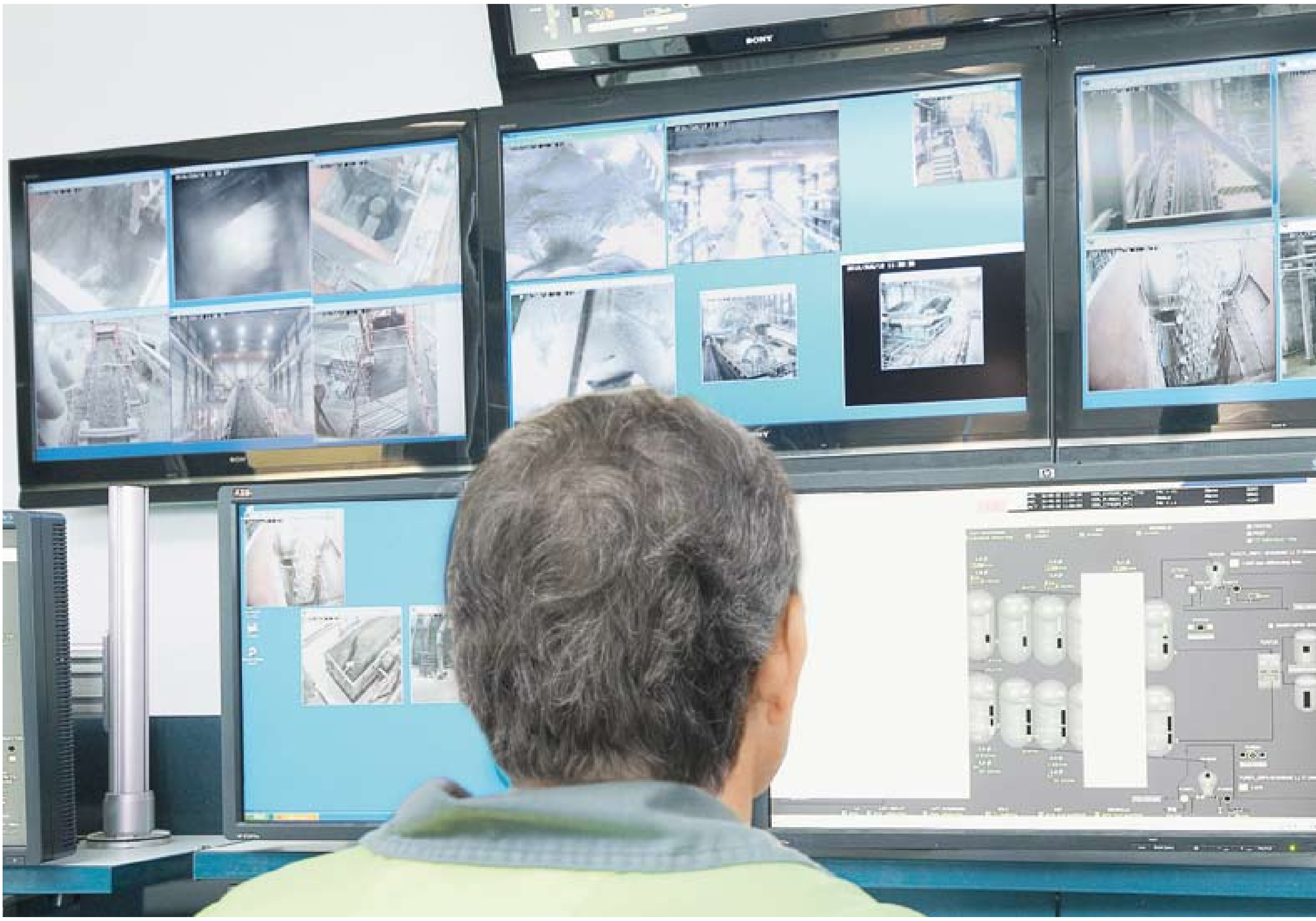
On a different matter, I would like to thank all readers who participated in the survey presented in the previous edition of this journal. We will present the results in an upcoming edition of *ABB Review*.

I hope that this edition of *ABB Review* will provide some novel insights into the fascinating world of industrial productivity and raise your awareness of the broad range of solutions that ABB can offer.

Enjoy your reading.

Peter Terwiesch
Chief Technology Officer
ABB Ltd.





The effective operator

System 800xA 's operator workplace is ready for the needs of today and tomorrow

HONGYU PEI BREIVOLD, MARTIN OLAUSSON, SUSANNE TIMSJÖ, MAGNUS LARSSON, ROY TANNER – Global process industry losses are estimated at around $20 billion annually, corresponding to five percent of total production[1]. 80 percent of these losses are preventable and 40 percent thereof are primarily due to operator errors. This means that the total improvement potential – if a way can be found to help avoid mistakes – totals $6.4 billion. Operator effectiveness is a fundamental element for sustaining the economic value of process control and management. It can be improved by empowering operators through improved situational awareness and better handling of abnormal conditions. Operators can then make better decisions and so improve process safety and process uptime.

ABB's System 800xA provides customers with the ability to consolidate and rationalize data from various sources seamlessly.

Striving for operator effectiveness implies facing a number of significant challenges regarding both technology and management. For instance, the management and monitoring of industrial processes is characterized by inevitable changes in technology, a diminishing knowledge base due to demographic changes in the workforce, and the ever-increasing complexity of operations. These factors may lead to huge cost escalations if operator effectiveness is not rigorously taken into account.

ABB believes that the development of an effective HMI (human machine interface) needs to look at the operator's workflow and requirements. A recent survey on operator effectiveness shows that this view is also shared by many of ABB's customers.

Footnote

1 Atkinson, T., Hollender, M., 2010, Operator Effectiveness, Collaborative Process Automation Systems, ISBN 978-1-936007-10-3.

Four pillars of operator effectiveness

According to the philosophy of ABB's Extended Automation System 800xA, there are four main pillars affecting the performance of the operator. These are:

- Integrated operations
- Design for high-performance
- Attention to human factors
- Operator competence

These are discussed below.

Integrated operations

ABB's System 800xA provides customers with the means to consolidate and rationalize data from various sources seamlessly. It achieves collaboration between different computer programs and systems. Operators are supplied with all necessary information. They have intuitive access to actionable information and can manage views dynamically and effectively. These features reduce the time required to identify necessary actions.

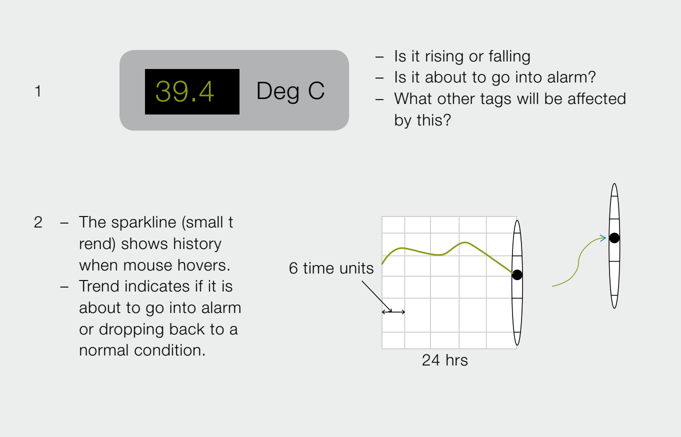
Today, an operating plant may include multiple controller platforms including PLCs (programmable logic controllers), DCS (distributed control systems), safety systems, FASs (facilities automation systems), and ECSs (electrical control systems) to name just a few. In addition, plant information systems such as CMMS (computerized maintenance management systems), ERP (enterprise resource planning), video monitoring systems and data historians are also available and contain valuable information that can support operators in their decision making.

System 800xA's Aspect Object technology allows not only the access and seamless presentation of information from all these sources, but can also filter it based on user roles and responsibilities. For instance, it takes no more than a right mouse click and a selection in the context menu to trace the various data displayed in a graphic to its sources.

Design for high performance

Many standards organizations and research institutes have made and continue to make valuable contributions to

1 The traditional versus a customized way of presenting data with different effects on situation awareness



2 ABB's Extended Operator Workplace

With a simulator, process operators and instrument technicians can learn to master the process in a safe and realistic environment.

HMI philosophies. This knowledge has flowed into guidelines for interface design, ergonomics, situation awareness and alarm management. Drawing on this as well as its own extensive expertise, ABB is seeking to support the establishment of good standards through its active participation in the various technical committees, working groups and scientific committees of standards-development organizations.

One key area affecting HMI development is the handling of abnormal situations. Abnormal situations are disturbances or incidents with which the control system is not able to cope of its own accord, and which thus require operator intervention. ABB is active in identifying effective supervision and intervention practices to improve the operator's capability to detect and respond to abnormal situations. The company implements these measures in System 800xA. For example, System 800xA supports customization of the workplace layout based on the end user's operational philosophy, and provides support for the implementation of high-performance alarm-management strategies with features such as alarm shelving (operator-driven alarm suppression) and alarm hiding (condition-based alarm suppression). These features reduce the number of nuisance and non-critical alarms and so help end users meet or exceed current guidelines and standards such as EEMUA 191 [2] and ISA SP 18.2 [3].

Another driving factor of high-performance design for HMIs is situation awareness. According to the abnormal situation management expert, Ian Nimmo (of the company User Centered Design Services and co-author of the High Performance HMI Handbook [4]), "Having good situation awareness means the operator has an accurate perception of the current condition of process and equipment, and an accurate understanding of the meaning of various trends in the unit." Some of the key concepts that situation awareness reflects are color definitions and usage to maximize visibility of abnormal situations. The situation awareness concept is not new. It is, however, still a matter of debate between multiple organizations. One aspect being debated is the use of grayscale or "cool" process graphic schemes. In addition, navigation methodology, graphic-level definition for fast response under abnormal conditions, and presentation of information are used to seek to predict and avert abnormal situations completely.

One good example on situation awareness as described in the High Performance HMI Handbook mentioned above concerns two graphics that both embed the same information, but have totally different effects on situation awareness. The graphic with a black background and an abundance of colors leads to poor situation awareness even in non-abnormal situations, whereas the graphic with gray scales and the sharp color for alarm depiction represents good situation awareness.

Footnotes

2 http://www.eemua.co.uk/ (August 2010)
3 http://www.isa.org/ (August 2010)
4 Hollifield, B., Oliver, D., Nimmo, I., Habibi, E., 2008, The High Performance HMI Handbook, ISBN-10: 0977896919, ISBN-13: 9780977896912, Plant Automation Services.

3 Design for the layout of a control room

Situation awareness can make a huge impact by:
- Increasing the success rate in handling abnormal situations and returning to a normal mode of operation.
- Reducing the time it takes plant operators to complete required tasks during an abnormal situation.
- Leading to a higher incidence of control room operators detecting an abnormal situation prior to alarms even occurring.

An example of a process value being presented in two different ways is shown in ➔ 1. The difference results in different levels of informational knowledge reflecting on situation awareness and an operator's ability to make the right decision quickly.

> Abnormal situations are disturbances or incidents with which the control system is not able to cope, and which require operator intervention.

Attention to human factors

The need to explicitly address attention to human factors is well-recognized by ABB. One main reason is that the company knows that a better working environment can reduce an operator's stress, which in turn substantially increases the operator's performance and effectiveness for handling abnormal situations, as well as reducing health issues and turnover of resources.

A good example of increasing this awareness and thus boosting operator effectiveness is ABB's Extended Operator Workplace ➔ 2. The workplace is equipped with advanced keyboards featuring hotkeys for multi-client handling, an operator desk system with motorized adjustable desk/monitor positioning, a directional sound system and integrated dimmable lighting. Furthermore, a productive design when creating control room environments is of major impact on the performance of operator teams. An example is shown in ➔ 3. All these factors contribute to the enhancement of the operator environment and alertness level of control room operators.

Control room procedures are important to be able to ensure consistency of operation. They can also support an operator in activities that may be performed infrequently. An example of useful supporting mechanisms is the use of checklists to guide operators throughout the required procedures under certain circumstances.

The clear definition of job roles and responsibilities is another vital element that characterizes successful operations. This means that all the tasks that an operator needs to perform should be recognized and documented, including the tasks that go beyond operating in the normal mode.

ABB and System 800xA are defining a new standard for how control rooms (intelligent control centers) should be built with the operator in focus. With the help of the control-room furnisher CGM, ABB is getting involved very early on in projects and can, jointly with the end user, define an optimal control room layout with focus on human factors and ergonomics. The "Future Operations Centre" in Borås, Sweden is the place to visit to get the latest information about how to build the optimal control room. It covers, among others, such topics as sound, noise absorption, floor material, light control and the color status of the process.

Operator competence

When operators interact with processes, their actions often have huge business consequences, especially when the process is in an exceptional situation and operators need to understand and manage complex operations to support recovery. ABB's System 800xA provides a foundation for advanced training for such situations using simulations that feature the exact operator environment (graphics and control logic). The simulator provides a safe and realistic environment in which process operators and instrument technicians can learn how to master the process and increase their confidence ➔ 4.

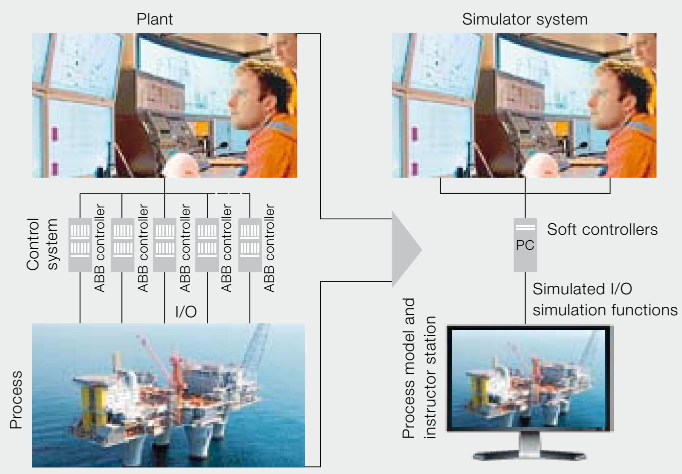
Underlying activities to operator effectiveness

In view of the rapid evolution of technology, generation shifts in workforces and increasing complexity of operations, there is a need to explicitly address operator effectiveness throughout the whole lifecycle of a process-control system. To leverage the four pillars of operator effectiveness, a number of fundamental activities are continuously going on:
- User-centered design
- Looking into the future

User-centered design

The design of an effective HMI requires focus on the control room operator's

4 A System 800xA simulator providing a safe yet realistic environment for training



Another effective way to increase user focus is the establishment of a customer reference group (CRG) comprising customers from various domains. The purpose of the reference group is threefold:

– Provide customers with first-hand information about ongoing and planned development projects
– Permit customers to actively influence ABB's development of System 800xA's operator interface
– Establish a forum for exchanging and testing ideas in user needs, trends and future ventures in order to increase productivity and profits for customers.

Operator feedback was sought on good practices as well as potential areas for improvement with regard to daily tasks.

workflow and tasks. In order to achieve a good understanding of the operators' workflow process and to obtain knowledge on how well the operator manages the significant number of operational tasks, ABB performs operator task analyses together with operators through user studies. The methods for user study include interviews, field studies and observations.

Interview questions are sent to the operators before a planned interview to ensure that the users have the right profile and knowledge, and that they are well-prepared. The interview questions may be structured or unstructured both in the form they are asked and in the way they can be responded to.

Field studies and observations represent a way to identify and prioritize operators' goals and needs. By visiting users in their own working environment and observing how they perform operational tasks, first-hand information is acquired with respect to the operators' challenges and needs. This method is ideal for discovering incorrect or inefficient use that the operators are not aware of. Operators' opinions are also sought and direct feedback collected both for good practices and in areas with potential for improvement.

The collected data is analyzed and synthesized. The data synthesis process includes identification of the main concepts and indications from each user study, and analysis of how they relate to the improvement of operator effectiveness.

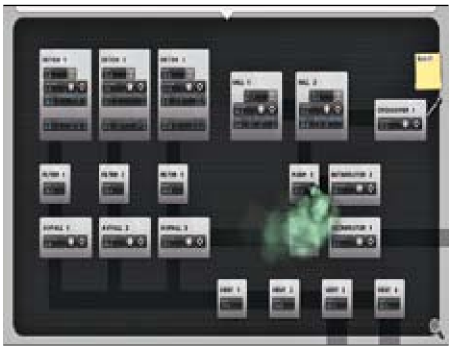
Looking into the future

The continuous progress in software techniques related to user experience and interaction raises the need to permit existing-human machine interface to evolve. ABB has a well-equipped user experience and interaction lab. The researchers look into the future, analyze the impact of emerging technologies, and explore efficient utilization and the reasonable combination of existing and emerging technologies. In particular, ABB has just created a new research area dedicated to operator effectiveness. One of its tasks is to look at new technologies in the market and their applications in industry domains. Examples include interaction techniques, visualization and design techniques.

Many ground-breaking ideas arise from ABB's innovation and development processes. For instance, → 5 illustrates a novel process display that supports operators in abnormal situations, providing intuitive depiction of an alarm that captures an operator's full attention.

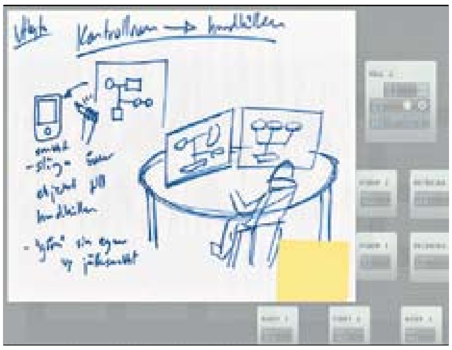
Another example of innovative ideas comes from the viewpoint of centering operators' work process and tasks to develop effective HMI. It is common knowledge that process operation is teamwork. Different shifts need to communicate and cooperate with each other. Accordingly, to assist operators in undertaking these activities, one innovative idea from ABB is the emergence of a so called collaboration board, permitting operators to leave messages on process displays → 6, or using a drop-down white board for sketching discussions → 7. This collaboration board is designed for vari-

5 A concept of a process display only viewed during abnormal situations



6 Electronic desktop notes on the collaboration board

7 Drop-down white board screen for discussions



ous roles, including plant management, system management, managers, and maintenance and operation staff.

Operator effectiveness is a timeless characteristic and will always continue to be important. Accordingly, in addition to improving operator effectiveness for the present generation of operators, ABB also takes future generations into account. Some customers are telling ABB that as the current workforce matures,

> Operator effectiveness is a timeless characteristic and will always continue to be important.

operator expectations are evolving. Many operators being hired today grew up with computers and are "digital natives". For these new generations, visual learning is an ideal method to teach how the plant behaves. Studies of how such people operate the process show that they have more screens open than older crew. They also ask for more customization of their screens. Newer operators tend to visualize the plant's behavior graphically whereas older operators seek to understand the plant in a sequential manner. ABB is therefore actively monitoring and applying future technologies and design concepts to address younger generations whose operating skills are different from those of today.

The secret to operator effectiveness

Operator effectiveness is a challenging area. ABB is taking a leading role in facilitating the pillars of operator effectiveness by:

1 Leveraging an automation platform that can natively promote and provide the level of integration and centralization required to promote a collaborative environment.
2 Being an automation supplier that can provide assistance to meet standards and design philosophies in situation awareness and abnormal condition handling, as well as leveraging an automation system that has the flexibility to meet specific customer requirements.
3 Being an automation supplier that has the ability to integrate human factors and best practices in order to provide the best in operator effectiveness.
4 Being an automation supplier that can provide more than operator training but rather an environment that uses the most valuable asset and existing intellectual property to build operator's confidence and competence.

In addition, ABB is also taking active measures in striving for a process environment that provides operator effectiveness, and conducting continuous activities in, eg, user-centered design, and looking into future technologies and their applications in the area of operator effectiveness. This could reduce the scope for errors, eg, through more efficient use of the operator's technological experience, quick access to relevant data in every operational situation, and assistance to operators in decision-making processes. All of these imply sustained economic value for customers.

ABB has so far achieved considerable success in boosting operational excellence by truly putting operators in focus and by providing outstanding process control interfaces that facilitate operators to take the right decisions during all modes of operation. ABB is committed to remaining at the forefront of these developments through continued research and development, helping customers achieve operational excellence.

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Safety in drives

Functional safety in machinery, especially in AC drives

MIKKO RISTOLAINEN – Safety is paramount to manufacturing and should be every company's highest priority. This objective may sometimes appear to be in conflict with the goal to be as productive as possible. Thanks to improved control and monitoring concepts however, these goals can now be complementary rather than conflicting. Whereas safety was previously often assured through separate external equipment, integration is permitting safety, control and monitoring to increasingly go hand-in hand using common data and functions and thus create combined functionality that would previously have been unthinkable. One area where this is happening is in AC drives. Offerings from safe stopping to more elaborate monitoring functions are being introduced and are heralding new opportunities in machine safety.

Safety is important. National laws in the European Union require machines to meet essential health and safety requirements. This means that all new machinery must meet the same legal requirements when supplied within the EU. Fulfilling these requirements is the responsibility of machine manufacturers or importers.

Behind the harmonization of the national requirements is the Machinery Directive 2006/42/EC (which replaced the old directive 98/37/EC on 29.12.2009). It aims to ensure that machinery is safe and is designed and constructed so that it can be used, configured and maintained throughout all phases of its life to cause minimal risk to people and the environment.

According to the requirements, manufacturers (or their representatives) must perform and document risk assessments and take the results into account in machine design. Any risks must be reduced to an acceptable level through design changes or by applying appropriate safeguarding techniques. After all risk reduction measures have been applied, any residual risks must be documented. One way to carry out the risk reduction process and to ensure conformance with the requirements is to apply suitable harmonized standards under the Machinery Directive.

When machines are designed and implemented according to relevant harmonized standards, it is presumed that the machinery complies with essential health and safety requirements and generally does not require certification by a third party. Manufacturers can self-declare the conformity to the Directive via documentation and attach the CE marking to the machine as a sign of conformance to the set requirements.

> Configurable safety systems today can be used to realize numerous standard safety functions for drives according to EN 61800-5-2.

The harmonized standards also provide a guideline for determining the machine's scope of application and its operating limits, potential hazards, as well as the means to assess and evaluate the identified risks. Standards will assist in deciding whether risk reduction is required and outline a strategic approach to reducing the risks to an acceptable level.

The most effective way to reduce or eliminate risks is to design them away. But when risk reduction by design is not possible or feasible, safeguarding with static guards or by functional safety may be the answer. As a bonus, functional safety can often be used to achieve higher machine productivity, uptime and less abrupt behavior of the safety system, while at the same time meeting the legal requirements. Machines can be stopped quickly and safely – or even better – operated at a reduced speed during specific times to reduce risk.

In industries where people work in close proximity to machines, functional safety technology can be utilized to ensure their safety while keeping the processes running. When safety systems are designed into work processes, safety is part of the process, people are kept safe and high productivity is maintained.

Updated standards for updated technology

Due to developments in technology and in the field of standards, requirements to

The installation cost for an advanced safety system with an integrated system is usually lower than if the same functionality is achieved with external safety components, especially when several safety functions are implemented.

implement safety-related control systems have been updated. Previously, it was relatively easy to design safety systems according to the standard EN 954-1 (Safety of Machinery – Safety-related Parts of Control Systems – Part 1: General Principles for Design), which provided straightforward design rules for achieving a certain safety level (safety category). This standard is based on a cause-effect approach and the emphasis is on the use of proven components and methods.

The EN 954-1 is a relatively simple standard mainly for mechanical and electromechanical systems. It does not cover complex or software-configurable safety-related electrical control systems, which have become the standard approach in functional safety. The deterministic design oriented approach of EN 954-1 has been replaced by concepts such as failure probability and lifecycle thinking. They thus aim to cover the entire life of the machine from the first concepts to decommissioning.

The transition period for EN 954-1 ends December 2011, when it will become obsolete. Although the EN 954-1 still provides the presumption of conformity with the Machinery Directive until the end of 2011, it is no longer state of the art.

The modern harmonized standards under the Machinery Directive are EN 62061:2005 (Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems) for electronic control systems, and EN ISO 13849-1:2008 (Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design) for various types of safety related systems (including for example hydraulics and pneumatics). Both these standards are based on the umbrella standard IEC 61508-1…7 (Functional safety of electrical/electronic/programmable electronic safety-related systems), which defines the overall requirements and processes for designing safety related electrical / electronic control systems.

Support makes the difference

Implementing a machine safety system from start to finish following the new standards can be a complicated undertaking. Which standard should be used? Which steps should be taken? How should the necessary calculations be performed and designs validated? And so on. As a result, business for safety consulting services is booming. Furthermore, component suppliers need to provide customers with support to help them get through their safety design processes. It has been forecasted that companies providing safety design support and knowledge in addition to components will increasingly be in a better position to get business. Such support may well become a standard requirement in selling safety products, with safety component suppliers being required to offer safety consultation along with their safety products.

Evolution of functional safety solutions in AC drives

Evolution in electronic control systems has also affected the safety technology used with AC drives. Traditionally, automation systems involving drives have typically used electromechanical safety relays. These relays monitor various safety input devices such as limit switches and emergency stop buttons, and operate contactors to safely cut off power to the power drive system when given parameters are exceeded.

Electronics is increasingly used in modern safety systems for AC drive applications. The trend has been so strong, that a new standard for functional safety requirements for drive systems, EN (IEC) 61800-5-2:2007 (Adjustable speed electrical power drive systems – Part 5-2: Safety requirements – Functional), was harmonized in 2008. This standard sets requirements for design principles of safety-related drive systems, as well as defining a number of standardized safety functions for drives. These definitions help in harmonizing the marketing terminology used to market safety functions.

The contactors to safely stop the motor movement in emergency or start-up prevention situations can now be eliminated thanks to a new feature integrated into the drive's power section. The safe torque off (STO) feature simply disables drive output modulation and safely eliminates the drive's capability to make the motor produce torque.

Processes can become more productive when STO is used to safely stop the motor without disconnecting the power supply or the drive's DC circuit. The drive can quickly be re-started without having to recharge the DC circuits or re-establish control parameters.

When additional functionality is needed, STO benefits can be complemented by combining the function with more advanced monitoring functions. External offerings include, for example, time-delay relays or so called configurable safety systems. These are typically intermediate between PLCs and solid state safety relays. Configurable safety systems today can be used to realize numerous standard safety functions for drives according to EN 61800-5-2. Typical functions include different safe stopping functions (EN 60204-1 stop categories 0, 1, 2), safely-limited speed (SLS), safe direction (SDI), safe operating stop (standstill) (SOS), safe (mechanical) brake control (SBC) and so on, some 17 functions in total.

Such configurable systems become feasible alternatives when several safety functions are implemented in the same system. For single safety functions, dedicated single purpose components such as time delay relays or two hand control relays remain the more feasible approach.

The contactors to safely stop the motor movement in emergency situations can now be eliminated thanks to a new feature integrated into the drive's power section.

External safety components are usually wired and configured to operate together with the drive. The development of an application usually requires wiring and configuration of the two devices individually so that they can work together. This can potentially result in a considerable effort in designing, installing and commissioning the system. There is thus a need for clear instructions from the drive supplier to support this configuration.

If safe communication is used, the system often has two separate fieldbusses, one for safety communication to the safety device and the regular fieldbus to the drive for control purposes. On the other hand, configurable safety systems, often with an abundance of extra inputs and outputs, can provide additional control functionality for other generic machine systems outside the actual safety realm.

Moving beyond the use of external components, the next logical step in drive-based safety is to integrate the safety functionality into the drive. This yields a number of advantages: Wiring is reduced, drive inputs and outputs are freed, space is saved, and the configuration can be performed through a single connection with one set of tools. Because integrated safety functions are drive-specific, the commissioning process is basically concerned with setting parameter values and behavior options. The actual programming of the basic functionality is no longer required, an improvement over the external systems which require the functional logic to be block programmed. Furthermore, a single fieldbus connection can be used for both regular and safety communication. The overall safety functionality can be optimized when safety and control parts of the drive share status information over a bus connection. And of course the system looks much cleaner without all the separate units and all the wiring.

Developing drive-integrated safety is a challenging process for drive manufacturers. However, the installation cost for an advanced integrated safety system is usually lower than if the same functionality is achieved with external safety components, especially when several safety functions are implemented.

Seeing through the hype

Integrated safety systems are frequently promoted in trade magazines, trade fairs and research articles. Safety features thus often become a product differentiator, with safety being promoted as a "must-have" feature.

Functional safety features can help boost performance and usability of machines while meeting the safety regulations. But it also takes time to really understand the opportunities that safety functions offer and their implications and to ensure that these match the real needs of the application.

Many machine builders are currently developing plans and specifications for their future machinery. However, because the modern functional safety offering is not always fully understood, there is a risk of buyers following the marketing hype and products being selected that do not actually meet their needs. Instead products are selected because they offer the most safety features or the highest safety rating, "just in case it is needed". It is therefore important for buyers to clearly understand and define their safety needs in advance and select products that meet those needs.

Even though tools, techniques and regulations have evolved, the main purpose of safety is still to protect people and the environment. The more information a buyer has on safety, the better he or she will be able to differentiate marketing hype from real advantages, and so prevent the wrong purchasing decisions. ABB advises its customers to be informed and to be prepared and is ready to offer support and advice.

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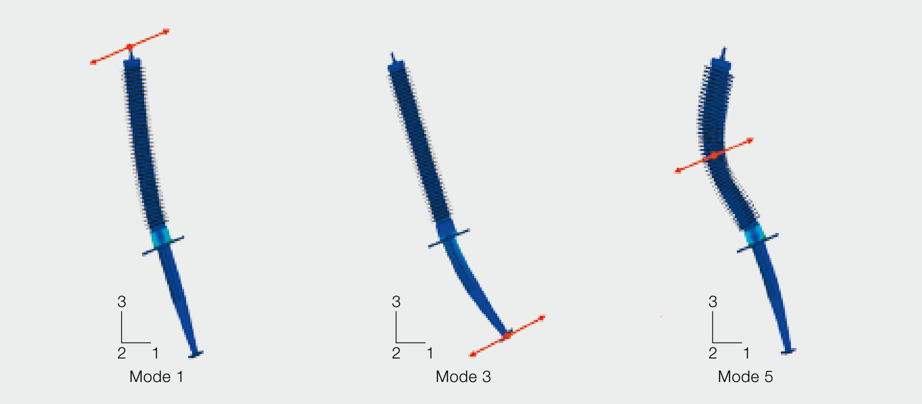
Seismic performance

Advanced seismic analyses of power products

ROBERT PLATEK, BOGUSZ LEWANDOWSKI – Earthquakes have the potential to wreak great havoc, including loss of human life, and cause extensive damage to infrastructure. Besides the actual damage caused to utility installations, the time taken to reestablish normal operation translates into further costs in terms of lost opportunities and productivity. Just as construction technology is continuously making progress and buildings are becoming more and more earthquake-proof, electrical equipment is also being designed to survive such events unscathed. Making power products earthquake-proof is no easy task. A large transformer including its foundations, tank, bushings, top-plate and connections is too large to fit on a shake-table, and the individual testing of these components is not necessarily representative of their performance when assembled as a system. Furthermore looking at these components together is still insufficient as the liquid inside the system will further modify overall seismic performance. ABB has developed a sophisticated combination of testing and different simulation methods leading to a better understanding of the seismic performance of the combination, permitting the development of transformers ready to survive the next earthquake.

1 Selected mode shapes for 230kV SeismicRIP™ transformer bushing (deformations are magnified by a scale factor).



Several different methods exist for investigating the seismic performance of electrical equipment. These methods usually involve static calculations to estimate the forces generated during a seismic event of a given ground acceleration, and then compare these to the capability of the equipment. The latter data may be derived from calculations or from actual measurements.

The two main international groups of standards used for this work are IEEE 693 and IEC 61463. IEEE 693-2005, "Recommended Practice for Seismic Design of Substations" [1] is a newly revised document covering the procedures for qualification of electrical substation equipment for different seismic performance levels. IEEE 693 strongly recommends that equipment should be qualified on the support structure that will be used at the final substation.

In contrast, IEC 61463 "Bushings – Seismic qualification" [2] is an IEC recommendation covering the seismic qualification of transformer bushings. Bushings meeting the requirements of IEEE 693 will, in most cases, also meet the requirements of IEC 61463.

Even though shake-table tests are strongly recommended for seismic qualification of critical components, numerical analyses can be very helpful in determining seismic withstand of these products. Furthermore, in some cases where tests are impossible due to the great weight of the equipment (eg, power transformers), the latter is the only one way to determine the dynamic characteristic of the system.

SeismicRIP bushing analysis

Complex structures may have many different resonant modes [1] within the dangerous seismic range. ABB thus performs modal dynamic analyses on them. The numerical analyses of the 230 kV SeismicRIP™ transformer bushing under seismic loads were performed using the finite elements method (FEM). In the approach presented here, the structural evaluation for seismic events is based on linear analysis, using the structure's modes up to a limiting cut-off frequency, (33 Hz).

New simulation tools should be always verified experimentally. Accuracy can then be evaluated and advantages and limitations recognized.

Once the resonance modes are identified, their orthogonality property [2] allows the linear response of the structure to be constructed as the response of a number of single-degree-of-freedom systems. In other words, the mechanical behavior of the bushing structure under ground-motion is derived as a linear superposition of its natural frequency modes. Depending on the excitation spectrum, individual natural frequencies can have different influences on the resultant movement → 1.

Simulations show very good agreement with test measurements. Natural resonant frequencies were found to differ by a maximum of one to four percent. For maximum accelerations at the measurement point (top of the bushing) the deviation was between 3 and 14 percent [3]. The results of this verification are valuable in the further development of numerical tools for seismic calculations.

Dynamic behavior of the bushing-transformer system

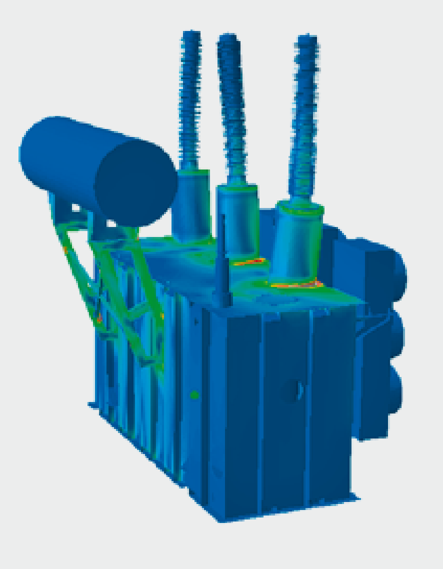
Many experts claim that the dynamic behavior of a bushing is different mounted on a transformer than it is when tested separately. Indeed, the seismic response of the transformer-bushing combination

Footnotes

1 A mode is the pattern of motion in which a body vibrates. Normally a body can vibrate in several basic modes as well as various possible superpositions thereof. For example a beam with fixed ends can vibrate in the shape of a half-period sine-wave, but can also be made to vibrate in the shape of higher-frequency sine waves. A complex three-dimensional solid can display many more modes than this simple one-dimensional example.

2 Orthogonal vibration modes are modes that do not lead to mutual excitation.

2 Distribution of stresses in a power transformer under seismic load



3 The first natural frequency of the bushing is affected by its mounting.

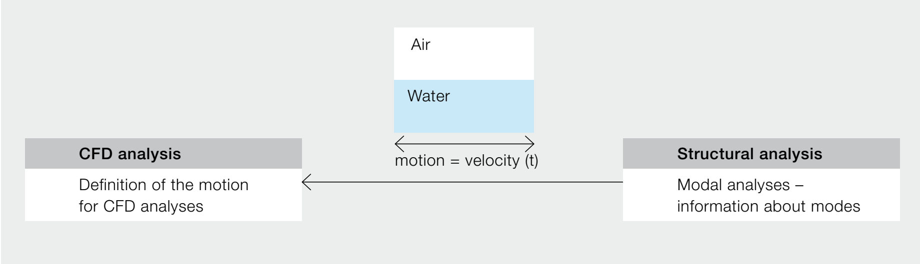
	Frequency (Hz)	
LP	Bushing	Bushing with top plate, turrets, and tank
1	14.13	7.08
2	14.13	7.38
3	–	8.36
4	–	8.74

The first natural frequencies of the bushing are different when mounted on the rigid frame than they are when mounted on the power transformer.

can be influenced by interconnecting components. Furthermore, equipment installed in the field can cause damage through its connectors [4]. Further investigation is required to quantify this effect. The FEM (for the RIP-type 230 kV bushing) appears to be a good area for additional research in order to understand the dynamic characteristic of the transformer-bushing system.

The simulations performed for both cases (separate transformer bushing, and power transformer with bushings ➔ 2) show that the dynamic behavior is different for each case. The natural resonant frequencies of separate simulated transformer bushings are different from simulated bushings mounted on the transformer ➔ 3.

4 First step of an FSI-based seismic analysis



The results clearly confirm that comprehensive seismic analyses of transformer bushings require the entire system to be considered.

Fluid structure interaction (FSI)

There have been numerous studies looking into the correct dynamic characteristic of the transformer-bushing system (including the tank, top plate, turrets and bushings [4, 5]). None of these studies, however, consider a very important influence: the coolant fluid. Studies do exist that look at the influence of fluid on the seismic response of elevated tanks [6], and also at such structures in marine applications and sea transportation [7]. But, none of these lessons was clearly applicable to the dynamic behavior of a transformer-bushing system.

To examine the fluid's influence on dynamic characteristics, an investigation using fluid structure interaction (FSI) was proposed. The FSI approach is based on data exchange between the simulation tools that model fluid flow and mechanical behavior.

FSI-based seismic analyses

The whole seismic analysis (sine sweep, earthquake time history and sine beat test) is a complex procedure. Thus, the sine sweep test, in which the modes and their shapes are identified, must be prepared in such way that the fluid is modeled as an acoustic medium. Based on this step it is possible to define initial conditions (motion) for CFD (computational fluid dynamics) analyses ➔ 4.

The full FSI method is then applied in the next step ➔ 5. In the CFD part, the structure (tank) is modeled with fluid, while in the structural calculations it is considered in isolation. CFD code is also used to simulate the effects of air flow on the fluid. The forces on the structure's walls are thus supplied to the structural tool and used as boundary conditions. The new shape of the structure is in turn given back to the CFD where the mesh update is prepared for next time increment. Stresses, strains and deformation of the structure are obtained taking into account fluid dynamics.

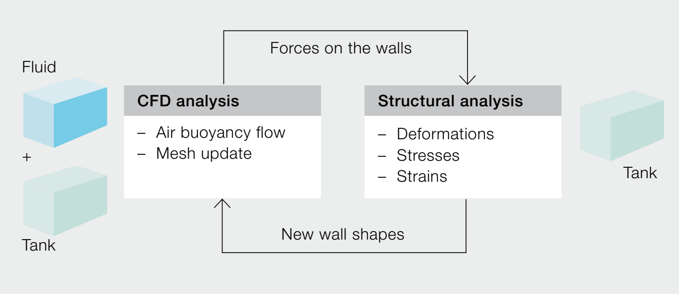
Experimental verification of proposed methodology

New simulation tools should be always verified experimentally. Accuracy can then be evaluated and advantages and limitations recognized. One of the objects used for this experimental verification was a prototype JUK 145 high-voltage combined instrument transformer. The measurement stand is shown in ➔ 6a.

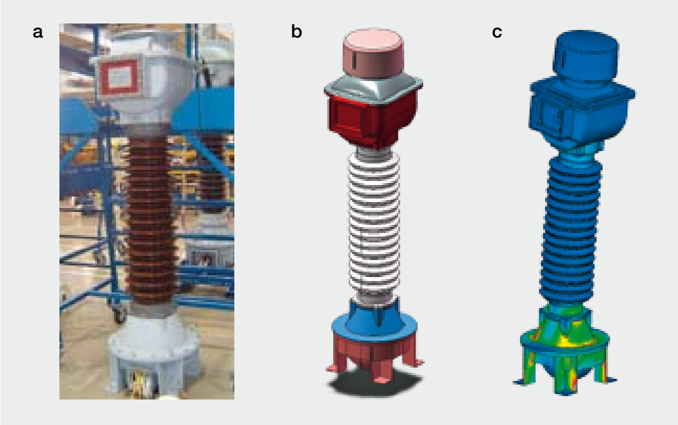
Simulations show very good agreement with test measurements. Natural resonant frequencies were found to differ by a maximum of one to four percent in case of SeismicRIP bushing analysis.

Using the simulation approach based on FSI (acoustic medium), a 3D model was prepared ➔ 6b and the modal analyses of the transformer were performed on this ➔ 6c. The comparison of results (measurements vs. simulations) is presented in ➔ 7.

5 Second step of an FSI-based seismic analysis



6 Experimintal verification of simulation



6a Analyzed HV IT product
6b 3D model of HV IT
6c Stress distribution during the first calculated mode

7 Comparison of natural frequencies, measurements versus simulations using FSI based approach

LP	Measured frequency (Hz)		Calculated frequency (Hz)	
	Dry	Oil-filled	Dry	Oil-filled
1	8.5	5.4	6.21	5.09
2	10.5	6.2	13.88	11.17
3	24.6	24	25.39	16.52
4	25.4		27.5	19.56
5			28.64	20.64
6			28.85	23.75

The next step was to prepare seismic tests in the laboratory. The JUK 145 successfully passed seismic qualification based on IEC 60068. Full FSI-based seismic simulations are planned and these will permit the tool to be further verified.

A step forward in seismic simulations

Shake table testing of bushings has demonstrated good performance of these components in terms of the general response based on the IEEE 693 [8].

> The coolant fluid was found to have a significant effect on the seismic performance of the transformer and bushing assembly

Applied FEM methodology for SeismicRIP bushings displays the potential to be able to predict relative acceleration and displacement with good accuracy for seismic qualifications [3]. However, to go beyond this, understanding of seismic interactions between substations equipment and fluids is vital. Development of this can improve seismic performance of substations and liquid-filled products.

The further study of fluid influence on the seismic qualifications of liquid-filled products is continuing. Undoubtedly, the proposed approach is unique and helps to understand the dynamic behavior of entire systems, permitting their seismic performance to be improved.

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Further reading

[1] IEEE Std 693-2005, IEEE Recommended Practice for Seismic Design of Substations, IEEE Standard Department, 2005.
[2] IEC 61463 Technical Report II; Bushings – seismic qualifications, Luglio, 1996.
[3] Rocks, J., Koch, N., Platek, R., Nowak, T. (2007). Seismic response of RIP-transformer bushing. INMR World Congress on insulators, arresters and bushings, Brazil.
[4] Ersoy, S., Saadeghvaziri, M. A. (2004). Seismic response of transformer-bushing systems. IEEE Transaction on Power Delivery, Power Engineering Society, Institute of Electrical and Electronics Engineers, Vol. 19.
[5] Filiatrault, A., M.EERI, Matt, H. (November 2005). Experimental seismic response of hight-voltage transformer-bushing systems. Earthquake spectra, Vol. 21.
[6] Livaoglu, R., Dogangun, A. (2005). Seismic evaluation fluid-elevated tank-foundation/soil systems in frequency domain. Karadeniz Technical University, Department of Civil Engineering, Trabzon, Turkey.
[7] Warmowska, M. (2006). Numerical simulation of liquid motion in a partly filled tank. Opuscula Mathematica, Vol. 26, No. 3.
[8] Whittaker, A. S., Fenves, G. L., Giliani A. S. J. (2001). Evaluation of seismic qualification procedures for high-voltage substation equipment. In P. Chang (Ed.), Proc. Structure Congr. Expo., Washington, DC.

Power electronics applications in utilities

Semiconductors are a key enabler for power networks

CLAES RYTOFT, PETER LUNDBERG, HARMEET BAWA, MARK CURTIS – The power sector is changing rapidly due to ever increasing levels of electricity consumption, increased use of alternative, often remote, energy sources, and a greater focus on energy efficiency and grid reliability. Developments in power semiconductors and the use of this technology in various power-electronics-based applications are facilitating many of these changes. Power semiconductors are the key building blocks of power-electronics-based switching devices that control the flow of electricity and convert it to the wave form and frequency required for different applications. Semiconductors lie at the heart of many power technologies and are a key enabler shaping the grid of the future.

Traditionally, power networks were built around large centralized power plants, generating predictable and controllable power that was supplied to the power grid in a stable manner. One-way power flow was maintained in these grids despite hourly fluctuations in demand. Today, similar hourly fluctuations in demand exist, but increased reliance on renewable power sources installed to help reduce CO_2 emissions has meant that power grids also must cope with fluctuations in power supplies. These intermittent and variable energy sources (eg, solar and wind) highlight the need for energy storage, as well as systems to coordinate available sources of power generation with varied patterns of consumption.

Fluctuations in the supply and demand for power can, to some extent, be attuned to one another through energy trading; however, transporting power efficiently from source to consumer, across adjacent networks, possibly over long distances and in both directions, presents a variety of challenges. These challenges are further exacerbated by the ever increasing demand for power, which must be satisfied while lowering greenhouse gas emissions. The provision of greater capacity to cope with electric vehicles and greater demand management will add further complexity, providing the impetus for the evolution of smarter, more flexible and reliable grids.

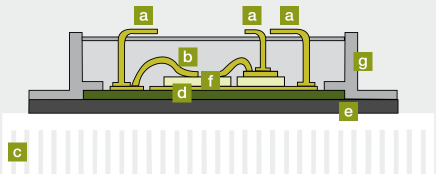
A variety of technologies pioneered by ABB have been developed and introduced to help the power industry fulfill these obligations. The technologies rely upon power semiconductors, which explains ABB's recent expansion of its production facilities. The manufacture and continued development of specialized power semiconductors ensures that ABB remains at the forefront of this technology. ABB will join the power industry in its task to develop flexible, efficient and reliable grids through the introduction of innovative power-electronics-based solu-

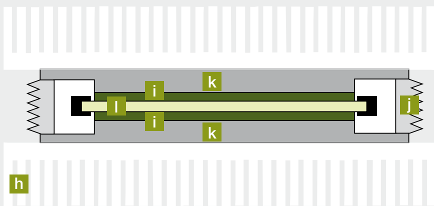
Semiconductors lie at the heart of many power technologies and are a key enabler shaping the grid of the future.

1 Semiconductor housing technology

In insulated housing the semiconductor → f is galvanically isolated from the heat sink → c. Electric contacts within the module are provided by bonding wires. In case of device failure, these wires tend to evaporate and the module ceases to conduct. In pressure-contact housing the load current enters through one surface → k and leaves through the opposite surface. Low electrical and thermal resistances of the contacts are assured through high mechanical pressure on the surfaces. In the event of failure, the silicon semiconductor → l and the molybdenum in → i will melt and fuse so that the current can continue to flow.

→ a Power and control connections
→ b Bonding wire
→ c Heat sink
→ d Ceramic (usually AlN)
→ e Base plate (usually AlSiC)
→ f Semiconductor
→ g Housing
→ h Heat sink
→ i CTE [1] compensation (Mo)
→ j Housing (ceramic)
→ k Copper
→ l Semiconductor





Virtually all commercial power semiconductors are silicon-based; however, continuous optimization of silicon material technology has brought its performance very close to its physical limits. This means that the potential for further improvement in this aspect of the design is limited; however, semiconductor device housing still has considerable potential for improving performance.

There are essentially two forms of high-power semiconductor housing. The main difference between them is that in the insulated module, the electrical circuit is galvanically isolated from the heat sink by a ceramic insulator, whereas in the pressure-contact design, the current flows vertically through the entire module, ie, also through the heat sink.

Both of the housing forms are suitable for insulated-gate bipolar transistors (IGBTs) and integrated gate-commutated thyristors (IGCTs). However, in practice, IGCTs are currently available only in a pressure-contact housing, while IGBTs are available in both variants. The insulated housing currently dominates systems with low output powers (mostly below 1 megawatt), since the circuit can be constructed at lower cost. The pressure-contact housing, on the other hand, is preferred for output powers in excess of 10 MW. There are several reasons for this preference. The two most important are discussed here:

- In systems with very high power outputs, semiconductors must be connected in parallel and/or in series. For the latter, pressure-contact housings present a considerable advantage, as the modules can be arranged in a stack, separated only by heat sinks. One example of this is in HVDC power transmission installations, in which up to 200 modules are connected in series.
- A pressure-contact housing must be used if the application requires a guaranteed uninterruptible current flow (eg, a current-source inverter). In a pressure-contact housing, the metallic poles fuse if a semiconductor fails, thereby ensuring a low-impedance current path. Conversely, in an insulated housing, the current flows through bonding wires, which evaporate upon a high-current pulse, during a fault, leaving the circuit open.

Footnote

1 CTE is the coefficient of thermal expansion

tions using high-power semiconductors designed and developed to provide better performance characteristics → 1.

Renewable energy

Generally, the most reliable renewable energy sources, such as high winds, intense solar radiation or large volumes of moving water, are found in remote regions of the world, far from population and industrial centers. Long-distance power transmission, using a conventional alternating current (AC) transmission system, is less efficient in some such cases and cannot be deployed, for example, where undersea cables are required to connect offshore wind turbines to the mainland. The problem is that AC oscillates at 50 or 60 cycles per second (ie, 50 / 60 Hz) regardless of whether it is at extra-high voltage, high voltage, medium voltage or low voltage. For each cycle, an AC cable is charged and discharged to the system voltage. This charging current increases with cable length. At a certain length, the charging current of the cable and its sheath become so large that no useful power remains, but long before reaching this length, power transmission becomes uneconomical. A direct current (DC) cable, on the other hand, has no corresponding charging current. In the DC cable, all current is usable. To transport energy efficiently to consumers over large distances with low losses, ASEA, ABB's Swedish forerunner, developed a DC transmission system with a power rating of 30 megawatts (MW) in the early 1950s. The system was first used to link the island of Gotland to the Swedish mainland → 2. This link was significant because it was capable of bulk electricity transmission with low losses through undersea cables, giving the islanders reliable supplies of cheap electricity. Since that first installation, ABB has continued to develop the technology, replacing earlier fragile mercury-arc valves, used to convert AC to DC and DC to AC, with robust power-semiconductor-based applications. Today some of the largest cities, including Shanghai, Delhi, Los Angeles, and Sao Paulo, rely on the delivery of huge amounts of electricity, often over thousands of kilometers, through HVDC transmission systems. Similarly ABB has installed several submarine HVDC cable interconnections between various western European countries, such as the NorNed project, which connects Norway with the Netherlands. Furthermore, ABB has connected offshore wind farms to the mainland, including the BorWin1 project, the most remote offshore wind farm in the world located 128 kilometers from the German mainland in the North Sea. To achieve these feats, ABB has developed a range of HVDC transmission systems to suit a variety of specialized applications.

> ABB will join the power industry in its task to develop smarter, more flexible, efficient and reliable grids.

2 Cable laying for the Gotland HVDC link in 1954

3 Thyristor valve hall

4 2,071 km UHVDC connection from Xiangjiaba to Shanghai

HVDC Classic

HVDC Classic, as the name suggests, was the pioneering technology and initially made use of mercury valves. Today the power conversions are made using thyristors (see devices described in "Semiconductors demystified" on page 26 of *ABB Review* 3/2010). The thyristors are series connected and arranged in thyristor modules, where each thyristor can withstand 8.5 kilovolts (kV). These modules (in pressure-contact housing) are then series connected in layers to create thyristor valves of full voltage → 3. The switching frequency of each thyristor is 50 Hz (or potentially 60 Hz) in this application. This system is used primarily to transport bulk electricity over long distances, either overland or underwater, allowing electricity grids to be interconnected for greater stability where conventional AC methods cannot be used. Today's HVDC transmission systems have very high power handling capability and excellent reliability records. Converter losses are low and equipment costs are minimized in this comparatively mature technology. HVDC will play a major role in the emerging grids of the future. ABB is uniquely positioned with the capability of manufacturing all the key components from cables, converters, and transformers to power semiconductors.

Ultra-HVDC

More recently, advances in technology have allowed voltage ratings of up to 800 kV using UHVDC (ultra-HVDC). In order to reach this power level a new 6" (inch) thyristor of 130 cm^2 was introduced that increased the normal current to 4,000 A, without affecting the switching frequency. Such innovations represent the biggest leap in transmission capacity and efficiency in more than two decades. The technology is being used to transmit 6,400 MW of power over a distance of 2,071 km from the Xiangjiaba hydroelectric power plant in southwest China to Shanghai in the east, providing clean electricity for around 31 million people → 4.

HVDC Light

A useful adaptation of HVDC Classic has been the 1990s development of ABB's HVDC Light®. This system uses transistors rather than thyristors for the power conversion process. HVDC Light also enables long-distance transmission using low-impact underground and underwater cables or overhead lines. However, the use of high-speed gate-controlled semiconductor switches, ie, insulated-gate bipolar transistors (IGBTs), have made it possible to generate state-of-the-art voltage source converters (VSC) as an integral part of the system, able to rapidly inject or absorb reactive power. Their superior ability to stabilize AC voltage at the terminals has made this technology ideal for wind parks, where the variation in wind speeds can cause severe voltage fluctuations. Similarly, their outstanding controllability and flexibility has seen their increasing use to connect oil and gas rigs to the mainland and to provide grid interconnections.

5 StakPak™ module containing IGBTs

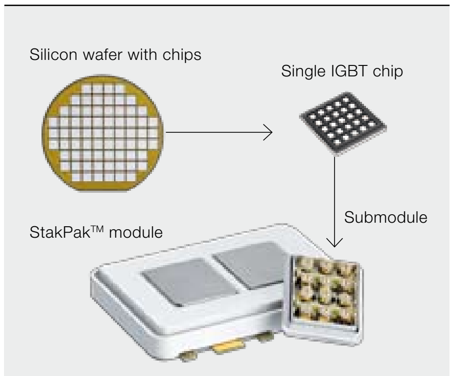


ABB has installed several submarine HVDC cable interconnections between various western European countries, including the NorNed project, a 580 km link between Norway and the Netherlands.

6 IGBT valve hall

The characteristic, above all others, that makes HVDC Light so controllable is mainly due to the IGBT semiconductor devices used in its assembly. Like thyristors, IGBTs can be connected in series to increase the voltage ratings.

However, unlike thyristors, which are controlled by a gate current, only a small voltage signal is required to control their switching. To build an HVDC Light system with power rating of 300 MW, 6,000 StakPak modules, containing around 200,000 IGBT chips, are connected in series → 5 and → 6. Each StakPak module is made of several sub-modules (can be two, four or six). The switching frequency of the IGBT can be determined according to the application and is normally in the range of a couple of hundred hertz up to 1 kHz. The assembly of IGBTs in this way creates a compact, highly controllable power electronic converter able to provide voltage stability even in regions of the network with no additional power sources. The first HVDC Light project was the 10 kV trial transmission in Hällsjön-Grängesberg, which was completed in 1997. Since then many converter stations have been built, the largest of which has a maximum turn-off current of 4,000 A in normal operation and can withstand about 18 kA during short-circuit conditions → 7.

7 Major HVDC Light and SVC Light installations

Project	Number of converters	Year in operation
Hällsjön	2	1997
Hagfors (SVC Light)	1	1999
Gotland	2	1999
Directlink	6	2000
Tjæreborg	2	2002
Eagle Pass	2	2000
Moselstahlwerke (SVC Light)	1	2000
Cross Sound Cable	2	2002
Murraylink	2	2002
Polarit (SVC Light)	1	2002
Evron (SVC Light)	1	2003
Troll A	4	2005
Holly (SVC Light)	1	2004
Estlink	2	2006
Ameristeel (SVC Light)	1	2006
ZPSS (SVC Light)	1	2006
Mesnay (SVC Light)	1	2008
Martham (SVC Light)	1	2011 1)
Asia Special Steel (SVC Light)	1	2009
Siam Yamato (SVC Light)	1	2009
BorWin 1 (Nord E.ON 1)	2	2010
Caprivi Link	2	2010
Valhall	2	2010
Cerro Navia (SVC Light)	1	2011
Danieli – GHC2 (SVC Light)	1	2011
Danieli – UNI Steel (SVC Light)	1	2011
EWIP	2	2012
SOLB (SVC Light)	2	2011

1) with energy storage

Flexible AC transmission systems (FACTS)

The AC power system has always faced challenges with reactive power. This component of AC power is consumed by capacitors, transformers and inductive motors, which are common elements in an AC grid. The power loss due to these elements on the system results from the production of magnetic fields (in the case of inductive elements), or electric fields (in the case of capacitive elements), which effectively reduce the real power available in the system (for an explanation of active and reactive power see page 35 of *ABB Review* 3/2009). Reactive power compensation devices, such as capacitor banks → 8, can be switched in to the system automatically under inductive conditions, providing a higher system voltage, or reactors can be used to consume vars (Volt-ampere reactive power) from the system, lowering the system's voltage under capacitive conditions. If reactive power is not compensated locally it will be pulled across transmission lines, destabilizing the network, which can cause blackouts. The term FACTS encompasses a group of technologies that enhance the security, capacity and flexibility of power transmission systems. These technologies can be installed in new or existing power transmission lines, either in series, eg, using thyristor controlled series capacitors (TCSCs) or thyristor-controlled series reactors (TCSRs); or in parallel, eg, with static var compensators (SVCs) or static synchronous compensators (STATCOMs). These devices optimize power flow and stabilize voltages by compensating for reactive power using power electronics.

ABB is uniquely positioned to help build the grids of the future with the capability of manufacturing all the key components from cables, converters, and transformers to power semiconductors.

TCSCs and TCSRs

Thyristors can be used to automatically switch in capacitors, using TCSC, or reactors, using TCSR, to stabilize the voltage. TCSCs are especially useful in stabilizing voltages at interconnections in transmission grids and have been used to interconnect Brazil's northern and southern power systems. Since the spring of 1999, Eletronorte of Brazil has been operating a TCSC and five fixed series capacitors (SC) supplied by ABB in Eletronorte's 500 kV interconnector between its northern and southern pow-

8 Capacitor bank

9 TCSC at Imperatriz, Brazil

er systems → 9. ABB has installed about 1,100 Mvar of series capacitors providing dynamic stability for both interconnected electric utility systems.

SVC

With both HVDC Classic and UHVDC, SVCs must be deployed at the point at which these systems join the AC network to inject or absorb reactive power. This is because HVDC systems can only transmit active power, which means such systems form an effective barrier to reactive power flows. While this can prevent the cascading domino effect of reactive power flows that can spread across the entire network, causing voltage collapse and blackouts, it can also reduce available sources of reactive power. To compensate for this shortfall in reactive power, SVCs must be installed at the HVDC connection point to ensure stability, providing a local facility to absorb or inject reactive power.

One of the consequences of interconnecting electricity networks for power trading has been an increased vulnerability of the grid to spreading problems. The advantage of using HVDC systems to connect AC grids has been twofold; they form a barrier to reactive power flows, as described above, and they allow electricity mains of different frequency or networks of the same nominal frequency, but with no fixed phase relationship, or both (ie, different frequency and different phase number) to be connected. Of course, such connections do not have to be long; all that is required is a short back-to-back HVDC station with both static inverters and rectifiers in the same building.

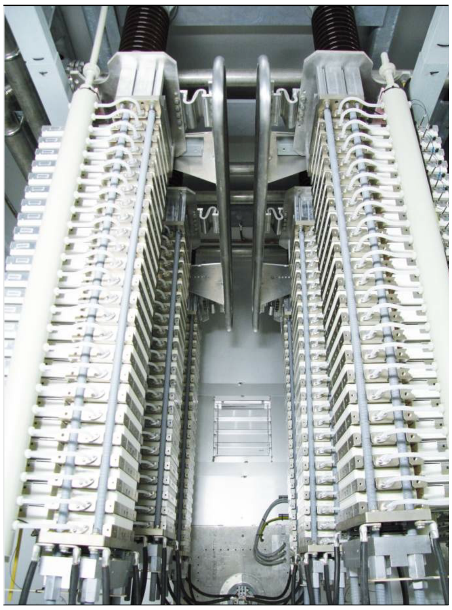
STATCOM

In addition to HVDC Light, which in itself uses IGBTs to provide VSC capabilities to rapidly inject or absorb reactive power, SVC Light® uses IGBTs in a similar way. SVC Light is a static synchronous compensator (STATCOM) that is similar in function to thyristor-based SVCs, but based on a VSC. The IGBT semiconductors for SVC Light are packaged in StakPaks and connected in series to cope with the required voltage → 10. The greater control afforded by IGBTs provides power quality improvements capable of mitigating voltage flicker caused by customers running electric arc furnaces. These furnaces are heavy consumers not only of active power, but also of reactive power. To compensate for the rapidly fluctuating consumption of reactive power of the furnaces, an equally rapid compensating device is required. This rapid response is brought about by state-of-the-art IGBT technology. The advent of such continuously controllable semiconductor devices capable of high power handling, enables SVC Light to handle highly dynamic reactive power requirements in the grid ranging from tens of megavolts ampere (MVA) up to ratings exceeding 100 MVA.

DynaPeaQ®

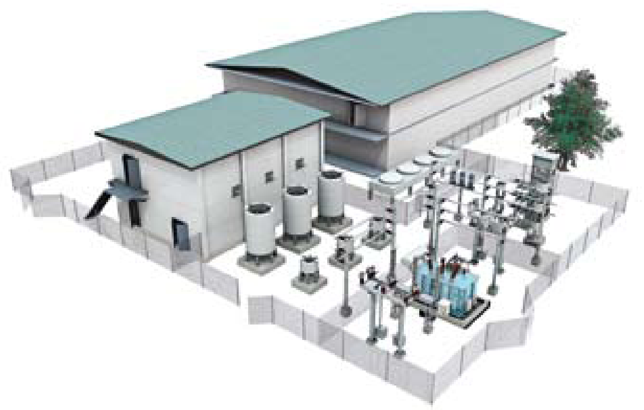
With greater reliance on renewable energy comes a degree of grid instability. To further enhance stability and reliability, ABB has introduced its latest addition to the FACTS family, DynaPeaQ® → 11. This is a dynamic energy storage system based on Li-ion batteries that can not only deliver reactive power, like ordinary SVC Light, but can also deliver active power, hence providing an alternative to transmission and

10 SVC Light stack

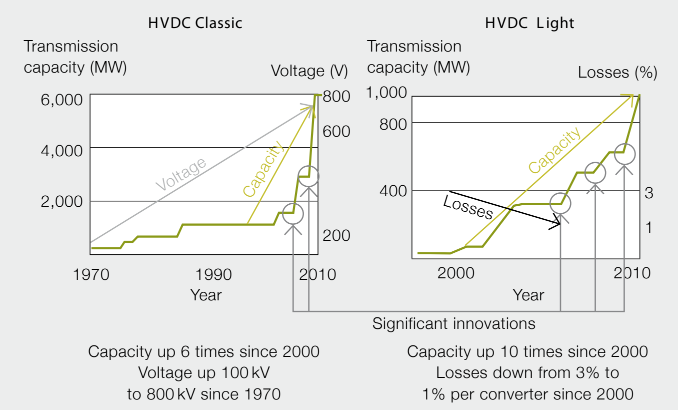


The provision of greater capacity to cope with electric vehicles and greater demand management will add further complexity to the power system, providing the impetus for the evolution of smarter, more flexible and reliable grids.

11 DynaPeaQ®



12 Growing transmission capacity in recent years



DynaPeaQ enables the inde pendent and - dynamic control of active as well as reactive power in the grid.

distribution reinforcements for peak-load support. The present rated power and capacity of storage is typically in the 20 MW range for periods of approximately 15 to 45 minutes, but this technology can be scaled up to 50 MW of power for 60 minutes and more.

MACH2 ™ control system

The introduction of power electronics technology to the electric grid presents an opportunity to effectively manage the magnitude and direction of power flow. To maximize and safeguard performance, efficient tools to control, monitor, and analyze HVDC transmission systems have been developed. ABB's MACH2™ system is a high performance HVDC control and protection system. It is used today in conventional HVDC, SVC and SVC Light and a number of other applications to control the switching of semiconductors at very high speed and accuracy to precisely control voltage and power.

In today's power grids a greater degree of sophistication is required to ensure that stable, reliable power is delivered on demand despite the intermittent nature of the renewable energy sources, such as wind, solar, wave and tidal power. To facilitate the new demands placed on the power grid, innovative power electronic devices with better performance characteristics are continually being added to new and existing grid structures.

The performance characteristics of HVDC Classic and HVDC Light have grown rapidly over the last 10 years → 12. Advances in the application of semiconductor technology will continue into the future as visionary projects such as Desertec and DC grids become a reality.

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Intelligent motor control

The UMC100 is an excellent example of a flexible, modular and scalable motor controller

PETER O. MÜLLER, ABHISEK UKIL, ANDREA ANDENNA – In large industrial plants that often contain several thousand motors to provide the necessary motion, any unplanned or sudden motor stops can lead to faults in the process sequence, which can be very cost-intensive. For this reason, reliable management and protection of these motors is of vital importance for ensuring a controlled production sequence. Some current motor feeders are often built up discretely, using for example thermal motor protection based on a bimetal relay. In such a system implementing protection and control functionality is cumbersome and complex; motor control and interlocking functions must be programmed in the process controller, and control and feedback signals are exchanged via input and output modules that must be designed and wired. Additional protective functions such as motor winding temperature monitoring via a thermistor require additional devices and wiring. These and many other functions are now integrated in a single device, the intelligent universal motor controller UMC100. Sometimes referred to as an “intelligent motor management module,” the UMC100 offers motor control, motor protection, fieldbus communication with the control system and diagnostic functions. Compared to conventional motor feeders, motor controllers offer many advantages throughout the entire lifecycle of an industrial plant.

Changing global markets is one reason many companies are being forced to reduce their operating and production costs while increasing output and quality. Energy efficiency is another factor that manufacturers in particular are interested in improving. In fact, there is now an increasing demand for more modular, flexible and integrated solutions. This in turn is causing many providers to look at their portfolios and find ways of enhancing their product offerings in response to this demand.

Integrated solutions are fast becoming more commonplace, in part because technology advances are making integration easier and also because such a solution functions more effectively as a whole rather than the sum of the individual elements that comprise it. In addition, future trends suggest it is a factor that may make or break a company.

For some time ABB has been focusing on the further development of many of its portfolios in response to the trend for the seamless integration of devices, and the success of this effort can be seen in one device, the intelligent motor controller UMC100.

UMC100 – a closer look

This universal motor controller (UMC), also known as an intelligent motor management module, is designed for 3-phase AC induction motors, and combines the functions of motor protection and motor management in a single device, as well as diagnostic and fieldbus communication.

The UMC100 operates fully independently and ensures that the motor is protected at all times, even if the control or bus system fails. The high precision of the electronic measurement system enables the most optimized utilization of the motors and ensures constant tripping behavior.

Parameters can be configured conveniently via standard device description files (eg, GSD/EDS), the control panel or via the device type manager (DTM). The DTM enables the grouping of associated parameters, the graphical display of the parameters' operation and it allows all measurement data to be read out via an online connection to the device. The DTM dialog panel for the configuration of the protection parameters based on the motor current measurement is shown in → 1.

All control functions most commonly needed in practice are already integrated in the UMC100 and can be simply configured via parameters. The control functions allow the flexible adaptation to different customer requirements and can be adjusted over a wide range. This considerably reduces the engineering effort in the control system as the entire control function is executed in the motor controller. Application-specific control functions can be implemented using the freely programmable logic. If existing motor management modules are to be re-used in the distributed control system (DCS), the position of the control and monitoring signals can be adapted to the current situation. This is particularly beneficial for the retrofit of older plants.

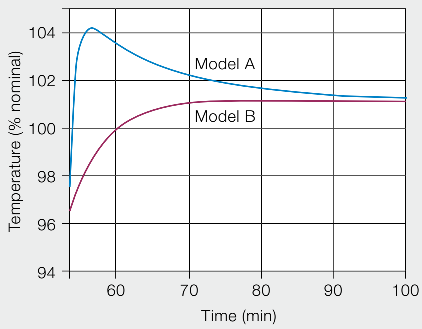
Motor models

Every intelligent motor controller needs a motor model. The model estimates the motor temperature over time in order to produce a trip signal to switch off the motor when a specified threshold is exceeded. The choice of motor model is a critical step in the design of a motor controller, as it affects the performance of the main function of the device. This design choice involves a basic trade-off: On the one hand, the model should be as simple as possible. A complex motor model may not fit the electronic platform of the motor controller and may have too many parameters which are difficult to identify and set for the customer. On the other hand, the motor temperature should be accurately estimated in order to effectively protect the motor.

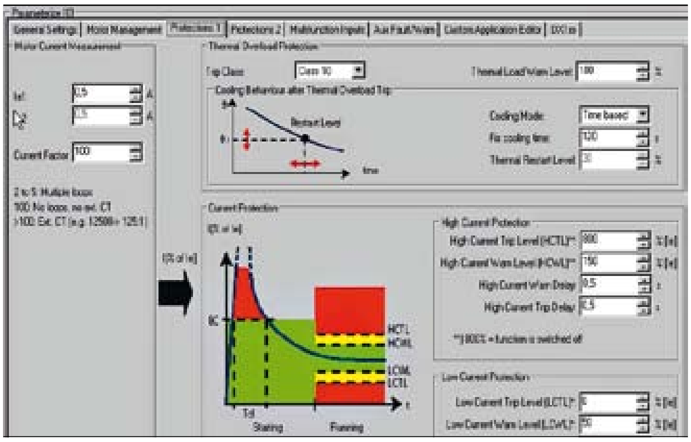
The minimum requirements for the motor models can be derived from the IEC 60947-4-1 standard [1], which defines the minimum and maximum trip times for different motor sizes (trip classes) and motor current values. For example, the standard specifies that an overload relay or motor controller protecting a motor of trip class 20 should switch the motor off within 6 to 20 seconds when the current is 7.2 times the rated value.

Fulfilling this standard is a minimum requirement for an intelligent motor controller. An oversimplified model of the motor may not capture the dynamics of the motor temperature accurately enough and in the worst case may not trip when the real motor temperature is too high. For example, the motor winding temperature is influenced directly by the stator current due to the Joule effect and indirectly by thermal conduction with other motor parts. A reliable motor model (model A) should consider both effects, a simpler one (model B) may consider only the first effect, which is the predominant one. The output of these two models that demonstrate a motor running in overload condition for a while before it was switched off and loaded again to nominal condition is shown in the enclosed graph. The thermal behavior of the two models (blue curve for model A, red curve for model B) is shown during the final phase (loading to nominal condition). In this case, the thermal conduction effect is not negligible as the motor was overloaded shortly before, and the winding temperature could temporarily increase to a value higher than the nominal value, as the output of model A shows. Therefore, a more sophisticated model like model A would in this case provide better protection for the motor.

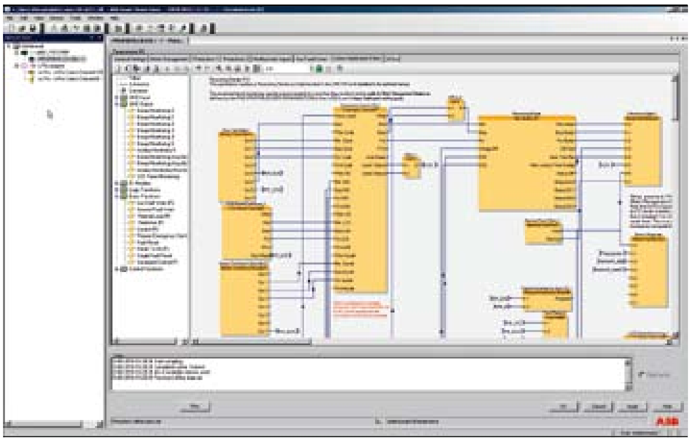
Different motor model outputs



1 Configuration of protection parameters with the UMC100 DTM



2 Editor for customized control functions



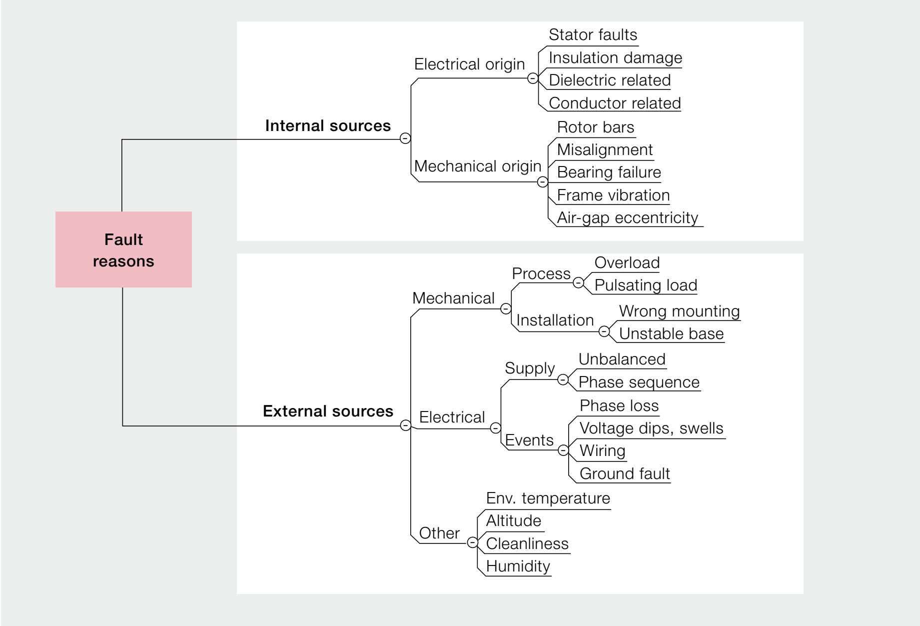
Four different control points (bus, "on the motor," cabinet door, service laptop) are supported ➔ 2. For each control point, the motor control can be enabled or disabled depending on the current mode (auto or local). The basic device is equipped with six digital inputs, three relay outputs and a 24 V switching output. For more complex applications with a large number of I/Os or special signals, expansion modules are available.

Motor controllers are often integrated into a DCS. For worldwide use, different fieldbuses must be supported. The UMC100 supports the Profibus DP, DeviceNet, Modbus and CANopen standards, but full stand-alone functionality is also ensured without fieldbus.

The UMC100 covers the entire current range from 0.24 A to 850 A. Only currents above 63 A require an additional external current transformer, which acts more as a prescaler. And even for small rated currents, the motor leads must be routed through the current transformers only once. Planners do not have to select different types of devices according to the rated current of the motor. Problems caused by unfavorable overlaps of the current measuring ranges will not occur. Overall, the number of typical features to be implemented by the planner can be reduced, thereby facilitating planning, inventory and servicing.

This universal motor controller (UMC), designed for 3-phase AC induction motors, combines the functions of motor protection and motor management in a single device.

3 Fault sources of induction motors

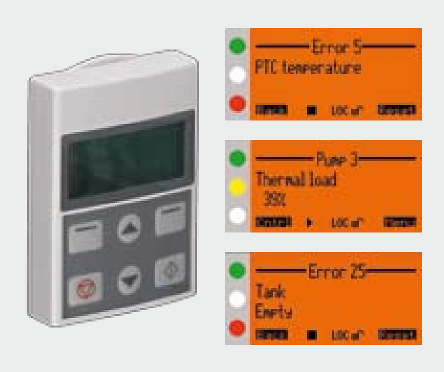


Diagnosis

Motor failure usually results in a process halt, which in turn seriously impacts the overall operational and maintenance costs. Very often diagnostic information is only used after a failure has actually happened to find out the cause. Therefore, the clear and comprehensive diagnosis of induction motors in their process environment is of prime importance to avoid faults and make it possible to rectify them quickly when they do occur.

There are different kinds of induction motor faults, the sources of which could be external and/or internal due to various electrical and mechanical reasons ➔ 3. Diagnostics of induction motor faults (especially problems related to internal sources) using the motor current signature analysis (MCSA) [2, 3] is currently used in the industry. However, for cost reasons MCSA-based diagnostics mainly target larger motors and advanced motor/drives diagnostics systems, for example, which are more sophisticated and expensive. Other problems like bearing faults are also of interest. However, bearing problems may not directly influence the induction motor's electrical circuit so intensely and might therefore be difficult to detect using MCSA. For this reason

4 The control panel enables the display of all data on-site



The UMC100 enables a huge step towards a predictive maintenance strategy, which until recently had been associated with cost-intensive specialized measures.

other types of diagnostics, namely vibration analysis, might be more effective.

Rather than having to configure different diagnostic systems to ensure all possible motor fault angles are covered, the ideal solution would be to have a comparatively low-cost motor controller which could provide standard protection and diagnostic functions as well as online motor diagnostic functions.

The UMC100 is such a controller and offers comprehensive test and analysis options, such as the continuous measurement of motor operating hours, motor start and overload trip count, diagnostic data logging, determination of motor starting time and maximum starting current, etc. All data is accessible via the fieldbus and can be used for the planning of maintenance operations. For example, an increase of the starting time may indicate the sluggish behavior of the connected load. In addition, information from the motor model can be used to support the plant operator during operation of the plant. For example, if the indicated thermal loading of a motor exceeds a predefined threshold, the plant operator could reduce the amount of material fed to an agitator to prevent a trip.

Advanced diagnostic options are among the key benefits of intelligent motor controllers. The diagnostic functions of the UMC100 can be accessed from the LCD control panel, from a service laptop or via the bus. In the event of a motor fault, a fast and comprehensive diagnosis is of particular importance. Practice has shown that although a laptop is often available, it is not always ready for immediate use. To overcome this, the UMC100 offers a fully graphical multilingual LCD control panel attached to the cabinet door that displays all status data and parameters in an easy-to-understand way → 4. Error messages are displayed in clear text, and plant-specific message texts can be defined for the freely configurable fault inputs. Hence no laptop is required for fault finding!

Predictive maintenance pays off

In combination with ABB control systems, the UMC100 Asset Monitor helps to quickly identify whether a fault is in the device itself, in the external electrical wiring or in the connected process. For this purpose, the Asset Monitor collects all diagnostic data provided by the UMC100 in configurable intervals and maps them to the following categories as defined in NAMUR recommendation NE107:

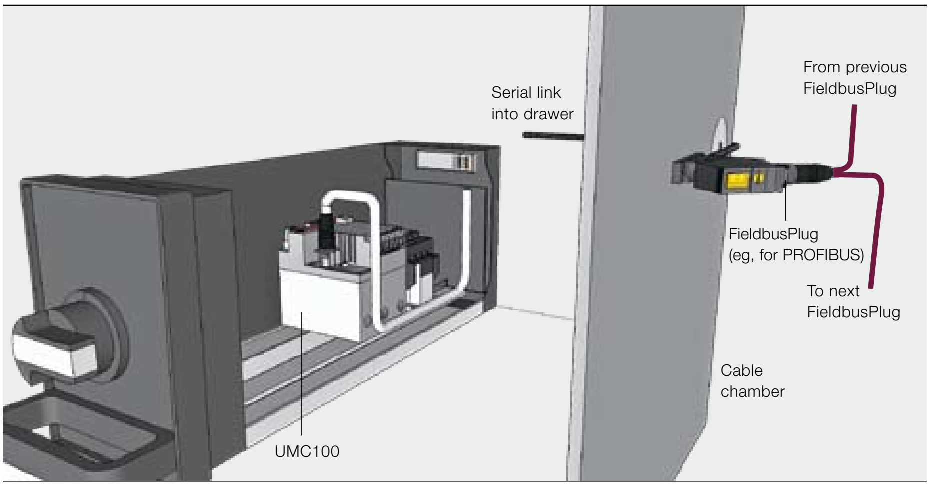
- Failure – The motor is not available due to a functional disturbance in the field device or its periphery (eg, thermal trip).
- Function check – The output signal is temporarily invalid due to work being carried out on the motor feeder (eg, test position during commissioning).
- Out of specification – The motor feeder is still available, but outside the specified limits (eg, motor current above/below the preset limit value).
- Maintenance required – The feeder is still available, but immediate need for maintenance is indicated (eg, wire breakage on the PTC).

These messages help the plant operator to derive appropriate actions for the respective plant without becoming overwhelmed by device details.

The maintenance personnel on the other hand can easily view all available details via the LCD panel on the device or DTM via the bus, for example, to derive concrete plant and device-specific instructions for action. The described condition monitoring and reporting functions can be used to collect, combine, analyze and compare this information with historic data to see, for example, how the starting time of the motor has changed over time. In addition, warnings of incipient wear of devices and components and their possible failure can be identified more easily and presented to the maintenance personnel in an understandable way. This allows better planning of maintenance operations and the minimization of downtime. All maintenance-related data is openly accessible via the fieldbus, ie, the information is also available to already existing maintenance management tools, if required.

Overall, the UMC100 enables a huge step towards a predictive maintenance strategy, which until recently had been associated with cost-intensive specialized measures and has now become economically viable for many applications.

5 When used for applications with drawers in motor control centres, the UMC100-FBP is positioned within the drawer while the fieldbus connection is mounted externally



Simple integration in the tightest of spaces

Thanks to their compact design and integrated measurement system, motor controllers fit even into the tightest of spaces. This is a huge advantage, especially for applications using withdrawable low-voltage switchgear with limited space or for retrofitting existing systems to accommodate a modern motor management system ➔ 5. In such applications, a direct integration of the fieldbus node into the motor controller would be disadvantageous as a drop line would be needed to every single device. This often leads to stability problems on the fieldbus. As a result, the baud rate has to be lowered, which in turn leads to longer cycle times. The separation of the bus node and motor controller is the better solution. The separate fieldbus node remains in the cable compartment and communicates with its controller in the drawer. The fieldbus line is linear and has no drop lines. This is also beneficial for a secure operation. If the drawer is removed, the node address will not be lost, and drawers exchanged accidentally will be automatically detected!

Because all of the required protection, monitoring and control functions are integrated into a single device, the time and effort needed for wiring is reduced considerably.

An excellent solution

By continuously supplying comprehensive operational, service and diagnostic data from the motor to the control system, the UMC100 enables disturbances to be detected at an early stage and appropriate measures taken to prevent or at least limit their effects. The modern LCD control panel conveniently shows all operating and maintenance data and supports rapid fault finding without the need of a laptop. The modular structure of the device offers advantages already in the planning and design stage. And the time and effort needed for wiring is reduced considerably due to the fact that all of the required protection, monitoring and control functions are integrated into a single device.

Compared to conventional technology, the UMC100 is an excellent solution for the implementation of motor feeders in industrial plants as it provides many advantages throughout the entire lifecycle of the plant.

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References

[1] IEC-60947-4-1 International Standard. Contactors and motor starters – Electromechanical contactors and motor starters. Ed. 3.0 (9/2009).
[2] Benbouzid, M. E. H. (2000). A Review of Induction Motors Signature Analysis as a Medium for Faults Detection. IEEE Transactions Industrial Electronics, vol. 47, no. 5, pp. 984–993.
[3] Thomson W. T., Fenger M. (July/August 2001). Current signature analysis to detect induction motor faults. IEEE Industry Applications Magazine, pp. 26–34.

Saving the best for last

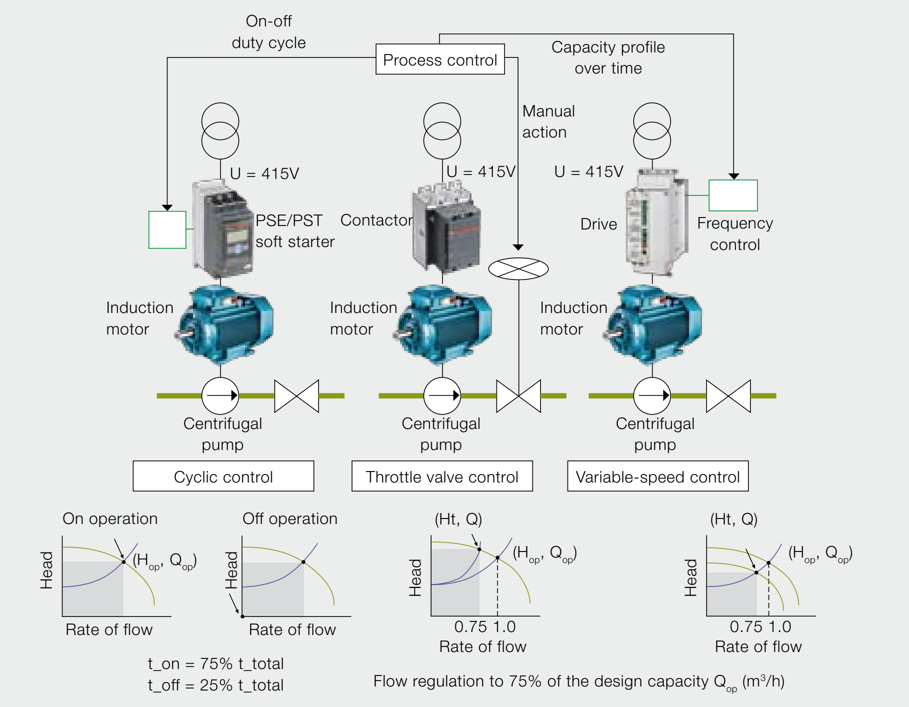
Softstarters or variable-speed drives, or both?

JUAN SAGARDUY, JESPER KRISTENSSON, SÖREN KLING, JOHAN REES – In water applications, centrifugal pumps are driven by an induction motor directly fed from the network. Flow regulation is accomplished by a few different means, namely throttling, a highly inefficient method as hydraulic losses increase dramatically when the flow is strangled by a valve; variable-frequency drives (VFD), recommended as an effective means of saving energy, ensure flow regulation by controlling the rotational speed of the motor shaft; and alternatively, on and off pump operation following a precise duty cyle – the pump is not operated continuously, but switched on for the time needed for pumping the target water volume and disconnected for the rest of the time. Given that many different hydraulic systems recommend the use of frequency converters or cyclic control (ie, softstarter technologies), which one of these two solutions is the most cost-effective in reducing energy consumption and providing the most satisfactory payback time?

Nomenclature

H_{bep} [m]: Hydraulic head at the best efficiency point of the centrifugal pump
Q_{bep} [m³/s]: Capacity at the best efficieny point of the pump
H_{st} [m]: Total static head. This is defined as the vertical distance the pump must lift the water. When pumping from a well, it would be the distance from the pumping water level in the well to the ground surface plus the vertical distance the water is lifted from the ground surface to the discharge point. When pumping from an open water surface it would be the total vertical distance from the water surface to the discharge point.
Q_{op} [m³/s]: Capacity at the system design point. In practice, this is determined for peak flows arising occasionally (ie, around 5 percent of the time in water treatment plants).
H_{op} [m]: Hydraulic head at system design point.
$H_{op,id}$ [m]: Hydraulic head at the design point in an ideal system.
H_t [m]: Hydraulic head associated with a generic capacity Q [m³/s] in fixed speed and throttled flow regulation
H_d [m]: Hydraulic head associated with a generic capacity Q [m³/s] in variable frequency flow regulation
H_{max} [m]: Maximum height at which liquid can be lifted by a given pump
Q_{max} [m³/s]: Maximum capacity for a given pump

1 System illustration for throttled, cyclic and VFD flow control methods



Energy efficiency is a very important aspect that customers seek in products and systems and something that suppliers work hard at improving in their product offering. In fact, the general view held is that the investment linked to the purchase of electrical equipment, as well as the downtime cost incurred from installation and commissioning is offset by a decrease in electricity consumption due to energy efficient operation.

ABB's commitment to energy efficiency is unquestionable and the company has devoted time, know-how and resources in order to offer market-leading low-voltage solutions – in the form of frequency converters and softstarters [1] – which are especially suitable for maximizing energy savings in water pump and waste applications.

As throttling is highly inefficient, which one of the two technical solutions, variable-speed or cyclic control, is the most cost-effective in reducing energy consumption → 1? In fact, the nature of the hydraulic system in which the centrifugal pump operates is the determining factor in selecting one or the other control method.

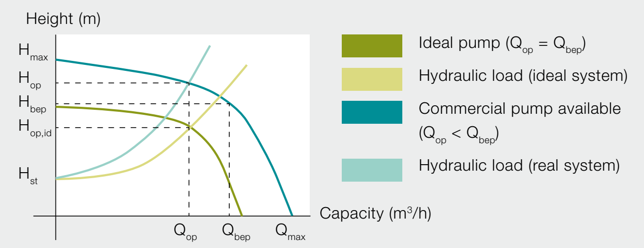
In wastewater processing for example, the on/off operation of the centrifugal pumps is, in general, process control based. Residual water (ie, effluent from residential or commercial buildings) is commonly collected in septic tanks or sewage basins until it is pumped to municipal treatment plants [1]. Owing to several start events, the use of softstarters significantly reduces the risk of pump clogging due to sludge in the water → 2. In general cyclic control is an attractive

2 ABB's PSE compact softstarter range is used primarily for pumping applications

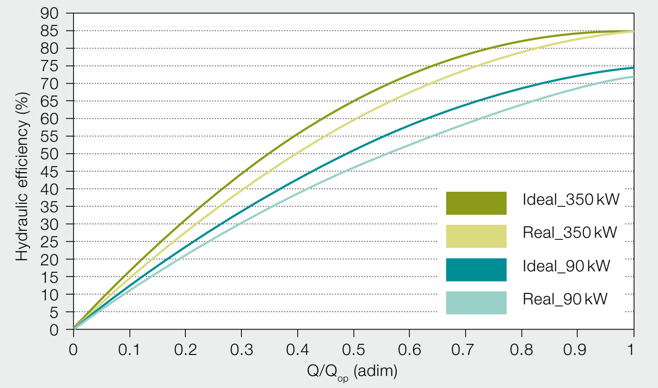
Footnote

1 By reducing the applied voltage, a softstarter allows smooth starting of AC motors. During pump stop, water hammer in the hydraulic system is avoided by a controlled decrease in torque enabled by a dedicated algorithm in the softstarter.

3a Pump selection for an industrial installation



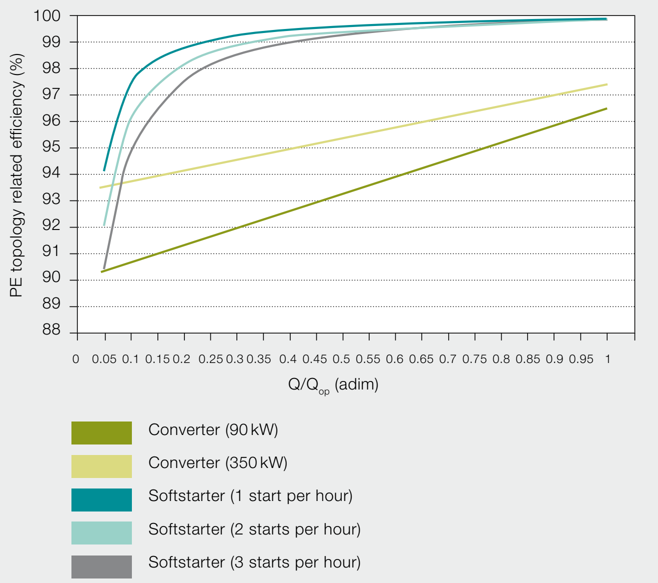
3b Hydraulic efficiency drop in 90 kW and 350 kW pumps due to 15% oversizing



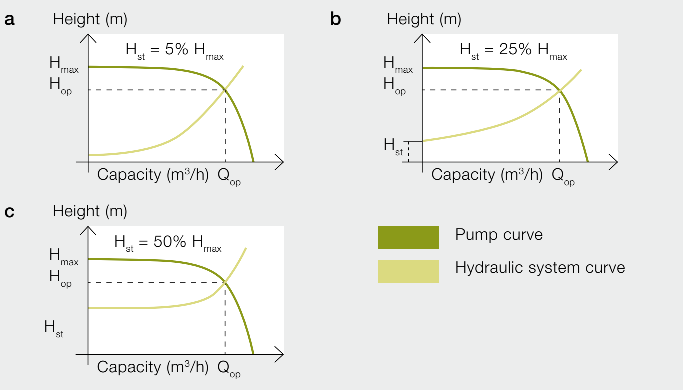
4 Characteristic data of the two pumps studied

Manufacturer	Power (kW)	H_{max} (m)	H_{bep} (m)	Q_{bep} (m³/h)	η_{max} (%)
Aurora	90	43.6	27.6	575	74.8
Aurora	350	52.7	33.8	2,500	84.5

6 Variation of electrical efficiency (%) in the power electronics circuit (softstarter and converter) with hydraulic load



5 The hydraulic systems selected for energy saving potential analysis



a Friction head dominated
b Mixed head dominated
c Static head dominated

alternative to the variable-frequency drive (VFD) strategy despite it losing flexibility in flow regulation. In other words, a soft-starter is seen as a suitable and competitive technology which preserves the induction motor from electrical strain, mechanical shock and vibration during start up and prevents water hammering as the pump stops. Additionally, the motor is used at its best efficiency point and switched off the rest of the time.

In the following sections, energy savings and payback of variable-speed and cyclic control solutions are analyzed for two centrifugal pump systems (90 kW and 350 kW).

A typical pump system

When a pump system is assembled, a target flow Q_{op} [m³/h] must be guaranteed. In an ideal system, the selected pump has a coincident Q_{bep} [m³/h] with Q_{op} [m³/h]. In reality, however, a larger pump is chosen → 3a. As a result, the pump works under reduced hydraulic efficiency for most of the capacity range. This point is illustrated in → 3b for two Aurora centrifugal pumps with power ratings of 90 kW and 350 kW respectively → 4 [2].

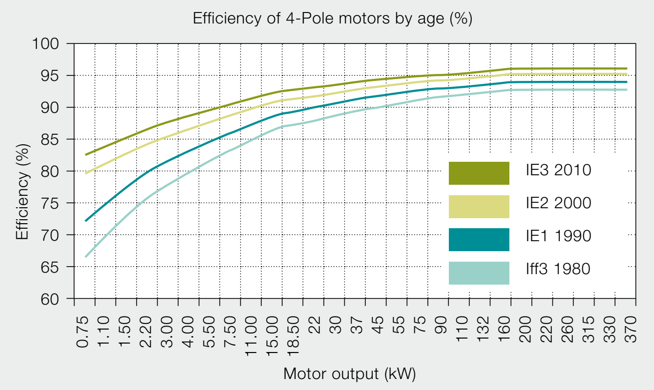
To analyze the potential for energy savings in these pumps three different hydraulic systems were taken into account: friction head dominated, ie, the ratio (υ) of static head H_{st} [m] to maximum hydraulic height H_{max} [m] is 5 percent; static head dominated (υ is 50 percent); and mixed (υ is 25 percent) → 5.

Converter, softstarter and motor performance

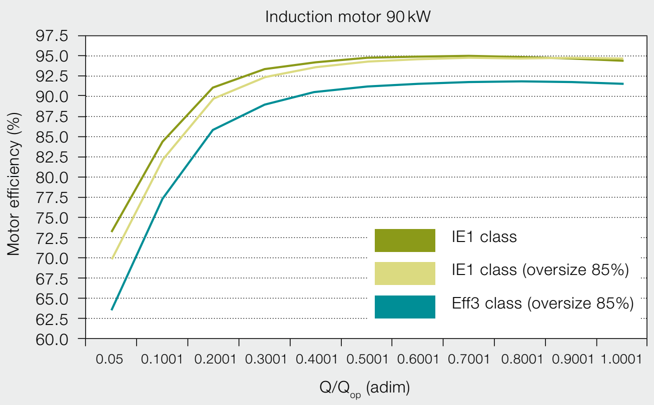
Frequency converters have a high efficiency (ηconv), which drops naturally

ABB has devoted time, know-how and resources in order to offer market-leading low-voltage solutions that are especially suitable for maximizing energy savings in water pump and waste applications.

7a Impact of class type on motor efficiency



7b Variation of motor efficiency with hydraulic load



8 Effect of system oversizing, motor class and harmonic losses on electric power consumption (Pn =90 kW – switching frequency 4 kHz)

	Load (%)				
Efficiency drop (%) caused by	**5%**	**25%**	**50%**	**75%**	**100%**
1 – Oversized pump (by 15%)	-1.3	-3.8	-6.0	-4.5	-2.1
2 – Oversized motor (by 15%)	-3.2	-1.2	-0.4	-3.0	0.2
3 – Motor class (Eff 3)	-9.5	-3.4	-3.0	-3.0	-3.0
4 – Harmonic loss	-7.0	-2.1	-2.4	-1.9	-1.3
Increase in power consumption (%)	26.5	11.7	13.3	10.3	6.6

when the output power decreases with respect to the rated value. The efficiency of softstarters is practically 100 percent when the motor bypass is activated. Their efficiency decreases noticeably with the number of starts per hour and shorter operating time intervals owing to additional joule losses during motor start and stop ➔ 6.

Tighter standards (IEC classes) nowadays guarantee high motor efficiency – in general greater than 90 percent – for loads [3, 4] ➔ 7a and ➔ 7b. This efficiency (strongly dependent on its graded class) is affected by the use of either a frequency converter or softstarter: it decreases when supplied by a fast switching converter due to harmonic current and voltage distortion but is not altered when the motor is bypassed after softstarting due to a purely sinusoidal supply.

The impact of system oversizing, motor class and harmonic losses (drive control) in a real system is given in ➔ 8.

Energy savings

Energy savings made using VFD and cyclic control in a 90 kW and 350 kW pump system are illustrated in ➔ 9a and ➔ 9b respectively. In friction head dominated systems (υ = 5 percent), VFD control ensures higher energy savings across almost the entire operating range (ie, 7 to 98 percent) in both pump systems. In a 90 kW pump and static head dominated system (υ = 50 percent), cyclic control is a better technical solution than VFD control for all working points, while for the 350 kW system VFD control guarantees slightly higher energy savings but only between 75 and 92 percent pump capacity. When a combined hydraulic system (υ = 25 percent) is considered, VFD control only ensures a larger economic benefit for pump capacities above 28 percent (for the 90 kW system) and 24 percent (for the 350 kW system). In fact the highest gain with VFD control is found at between 15 and 20 percent capacity.

The total initial investment associated with VFD and cyclic solutions is calculated as the cost of the drive or softstarter plus a percentage of the life-cycle costs to cover production downtime.

Unlike frequency converters (characterized by semiconductor losses at nominal load), softstarters operate in bypass state at nominal load ➔ 9c. No additional losses in the thyristors are thus accounted for. The operating and system conditions when either cyclic control or VFD is the preferred solution for pump flow regulation are illustrated in ➔ 10 [2].

Return on investment

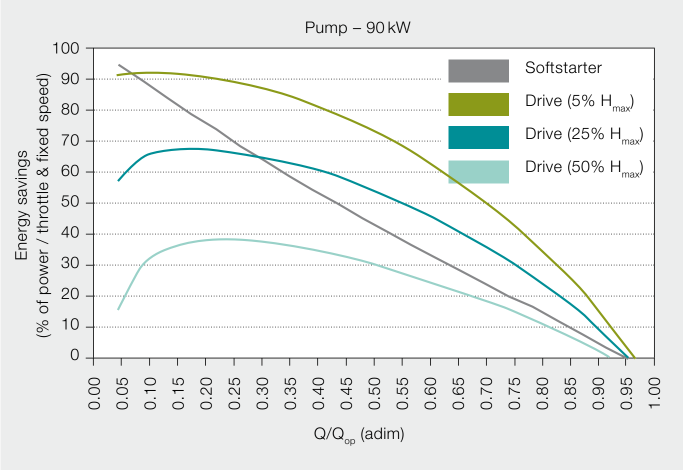
Customers will inevitably want to know when they can expect a return on their investment, which includes the additional costs incurred by production downtime while the drive or softstarter is being installed and commissioned.

For pumps with a power rating of around 25 kW, the price ratio of converter to softstarter is around three and reaches an approximate value of five for 350 kW pumps [6]. The total initial investment associated with VFD and cyclic solutions is calculated as the sum of the cost of the drive or softstarter plus a percentage of the life-cycle costs to cover production downtime [7]. For both power electronic

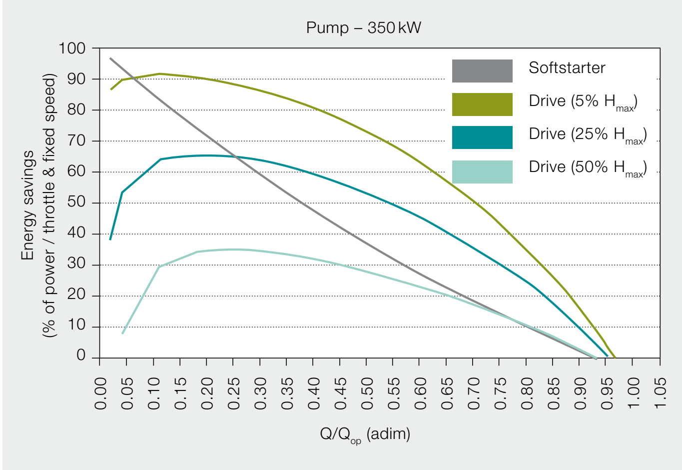
Footnote

2 Converting percentage energy savings (with respect to fixed speed and throttle) into economic benefits assumed that the pump works for 8,760 hours per year (330 x 24) at a price of $0.065 for 1 kWh of electricity [5].

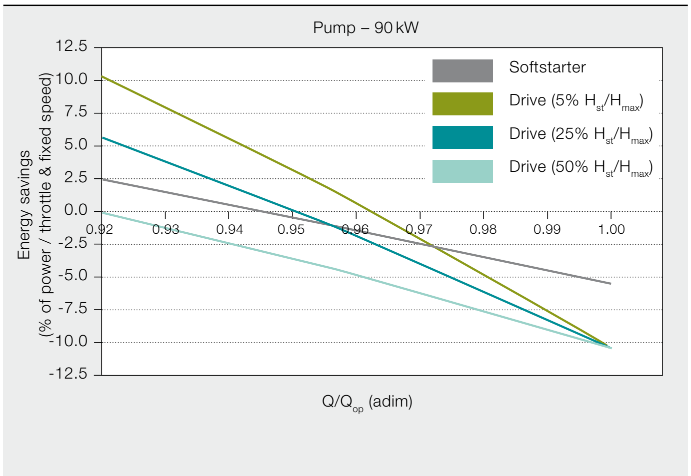
9a Energy savings [%] of VFD and cyclic control in the 90 kW pump system



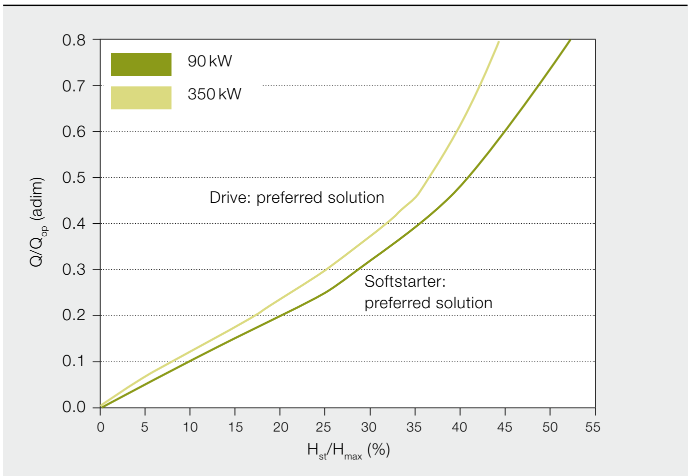
9b Energy savings [%] of VFD and cyclic control in the 350 kW pump system



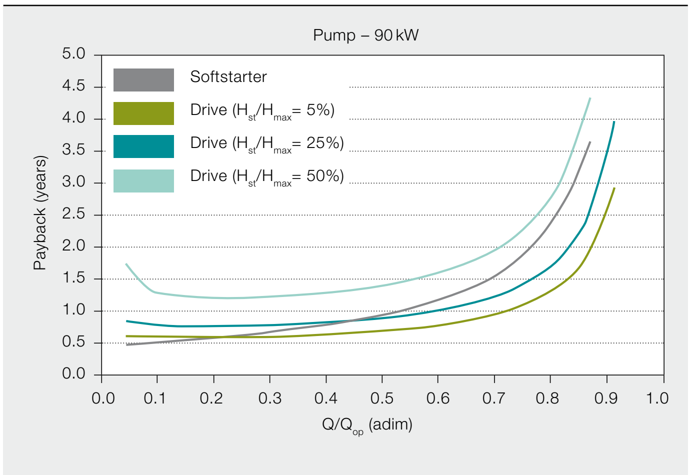
9c Optimum efficiency in the 90 kW pump due to softstarter bypass capability at high loads (90% – 100% of design capacity)



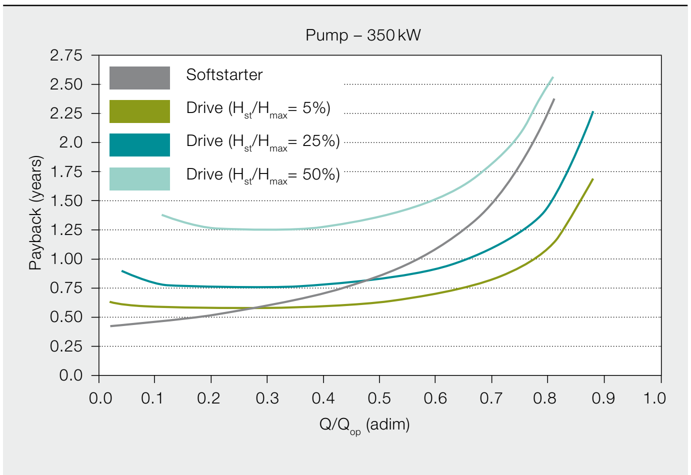
10 Breakpoint where economic savings with cyclic control (softstarter) become higher than with VFD solution



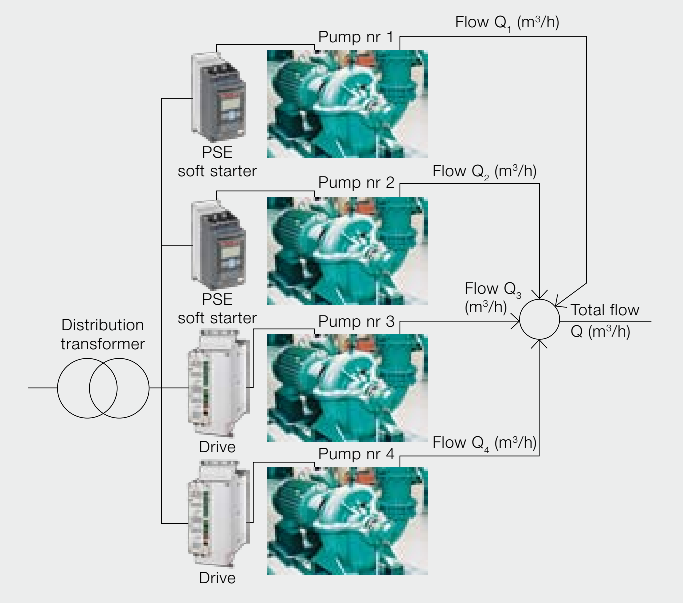
11a Payback time of VFD and cyclic (soft starter) solutions for the 90 kW pump



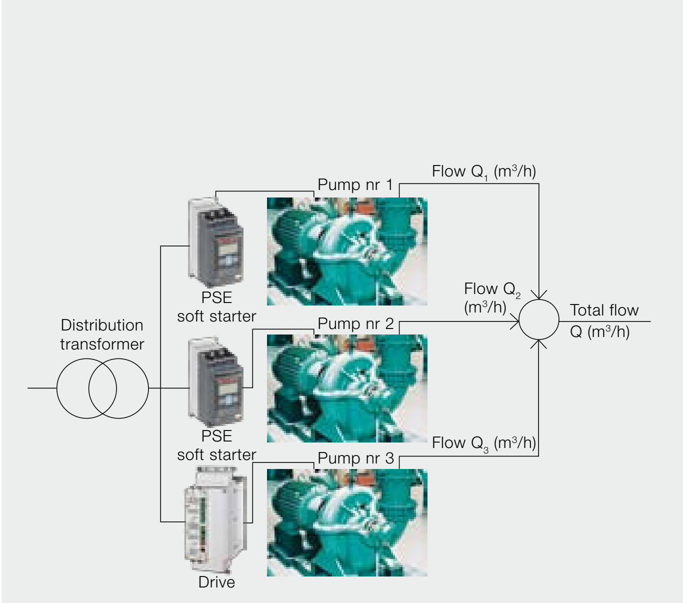
11b Payback time of VFD and cyclic (soft starter) solutions for the 350 kW pump



12 Recommended power electronics solution for a four parallel-pump system (friction dominated hydraulic system)



14 Recommended power electronics solution for a three parallel pump system (Static head/friction dominated hydraulic system)



13 Flow control scheme in a four parallel pump system (friction loss dominated)

	Pump 1	Pump 2	Pump 3	Pump 4
PE	Softstarter	Softstarter	Drive	Drive
Flow control	Cyclic	Cyclic	VFD	VFD
Flow Q(m³/h)				
0–1,130	On-off (0–22.5%)	On-off (0–22.5%)	Off	Off
1,130–2,500	Off	Off	On (22.5–50% Pn)	On (22.5–50% Pn)
2,500–4,740	On-off (27.5–45%)	On-off (27.5–45%)	On (22.5–50% Pn)	On (22.5–50% Pn)
4,740–5,790	On-off (60%)	On-off (60%)	On (35–85% Pn)	On (35–85% Pn)
5,790–8,000	On-off (75%)	On-off (75%)	On (70–85% Pn)	On (70–85% Pn)
8,000–10,000	By-pass	By-pass	On (60–100% Pn)	On (60–100% Pn)
Higher than 10,000	By-pass	By-pass	On (> 100% Pn)	On (> 100% Pn)

topologies, a value of 7.5 percent is used.

The cost of the individual components may vary for a number of reasons. Primarily, low-voltage VFDs operate more on a continuous rather than a stop-start basis and enable more sophisticated control. However, they use insulated gate bipolar transistors (IGBTs) and must be designed with sufficient cooling capability, making them more expensive when compared to softstarters with the same power rating. Softstarters, on the other hand, which operate during reduced time intervals of up to 15 seconds incorporate robust and cost competitive thyristors and benefit from natural cooling.

The payback times for VFD and cyclic flow control are illustrated in → 11a and → 11b for the 90 kW and 350 kW pumps respectively for the three hydraulic systems: υ = 5 percent, 25 percent and 50 percent.

Parallel pump system solutions

In many hydraulic systems, optimum energy savings with a good return on investment can be achieved using parallel pump solutions [3] that combine drives and softstarters.

For example, in a friction dominated hydraulic system (υ = 5 percent), a recommended power electronics solution for a four parallel pump system – each pump with a power rating of 350 kW (2,500 m³/h) – consists of two converters and two softstarters → 12. The scheme which gives the most optimum solution in terms of payback time and control functionality equips pumps 1 and 2 with a softstarter and pumps 3 and 4 with a frequency converter → 13. Pumps equipped with a softstarter are directly connected to the network at high capacity. By increasing the rotational speed in a pre-defined range (over 50 Hz), pumps driven by converters can deliver a peak flow if occasionally required.

In a mixed hydraulic system (υ = 5 percent), the scheme which gives the most optimum solution in terms of payback time and control functionality uses three pumps, the first two of which are equipped with softstarters and the third with a drive. → 14 and → 15.

For both systems the initial investment in power electronics solutions is translated into economic profit in less than 1.5 years provided the regulated flow

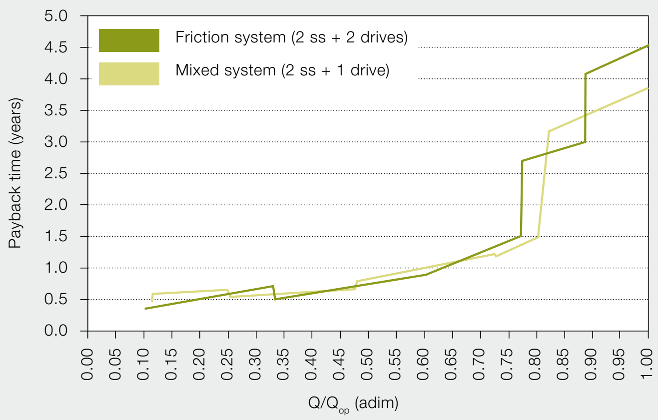
Variable-frequency control is the best solution in friction-loss dominated hydraulic systems while cyclic control is recommended for static-head dominated systems.

15 Flow control scheme in a three parallel pump system (mixed hydraulic system)

	Pump 1	Pump 2	Pump 3
PE	Softstarter	Softstarter	Drive
Flow control	Cyclic	Cyclic	Variable frequency
Flow Q(m^3/h)			
0–2,500	On-off (0–50%)	On-off (0–50%)	off
2,500–4,500	On-off (30–60%)	On-off (30–60%)	On (40–60% Pn)
4,500–5,760	On-off (60–75%)	On-off (60–75%)	On (60–80% Pn)
5,760–6,630	By-pass	On-off (75%)	On (55–90% Pn)
6,630–7,500	By-pass	By-pass	On (35–100% Pn)
> 7,500	By-pass	By-pass	On (> 100% Pn)

17 Pump system in a water treatment installation

16 The estimated payback time for two installations consisting of parallel pumps and different power electronics solutions



is below 80 percent of the total capacity → 16.

The best solution?

The suitability of variable-speed and cyclic flow regulation in centrifugal pump applications has been analyzed for two pumps (90 kW and 350 kW) in the low-voltage range. The data show that variable-frequency control is the best solution in friction loss dominated hydraulic systems (fluid transportation without height difference) while cyclic control is recommended for static head dominated systems. Speed control in systems with very flat pump and load characteristics should be avoided due to the risk of instability and pump damage [9].

Softstarters are a very competitive technical solution, especially for water and waste applications in which the regular on/off operation for emptying a tank and pumping up fluid for further treatment is common practice. They are robust, have good bypass capability and dedicated control algorithms for start (kick boost) and stop (no water hammering) sequences. However, optimum energy savings and good payback times can be achieved in a wide range of hydraulic systems by employing parallel pump schemes that use a combination of drives and softstarters → 17. Supported by their know-how and strong low-voltage automation portfolio, ABB reasserts its commitment to energy efficiency while ensuring customer value.

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Footnote

3 For optimal flow regulation in parallel systems, one individual pump is operated until a breakpoint in the target flow is reached, after which two pumps simultaneously share the hydraulic load [8]. When a second breakpoint is attained, three pumps become active and so on.

References

[1] ITT Industries (2007). ITT's Place in the cycle of water: Everything but the pipes.
[2] Aurora Pump (Pentair Pump Group) June 1994, United States.
[3] IEC 60034-31:2009. Rotating electrical machines. Part 31: Guide for the selection and application of energy-efficient motors including variable speed applications.
[4] Brunner, C. U. (4–5 February 2009). Efficiency classes: Electric motors and systems. Motor energy performance standards event, Sydney (Australia). www.motorsystems.org.
[5] Department of Energy (DOE). Energy International Agency (EIA) (June 2009). Average retail price of electricity to ultimate customers.
[6] Sagarduy, J. (January 2010). Economic evaluation of reduced voltage starting methods. SECRC/PT-RM10/017.
[7] Hydraulic Institute (August 2008). Pumps & Systems, Understanding pump system fundamentals for energy efficiency. Calculating cost of ownership.
[8] ITT Flygt (2006). Cirkulationspumpar med våt motor för värmesystem i kommersiella byggnader.
[9] Vogelesang, H. (April 2009). Energy efficiency. Two approaches to capacity control. World Pumps Magazine.

Simply XTraordinary

Introducing ABB's new Tmax XT family of highly advanced molded case circuit breakers

LARA CORTINOVIS, LUCIO AZZOLA – A circuit breaker is one of the most important and essential safety mechanisms in modern electrical systems. Many different classifications of breakers can be made, based on voltage class, construction and interrupting type, and structural features. However, current market trends indicate that customers are looking for more modular, flexible and integrated circuit breakers and ABB has responded with its new family of high-performing molded case circuit breakers. This family, known as Tmax XT, contains four devices that can be used for distribution, motor and generator protection, oversized neutral and as switch-disconnectors. They are available as three or four-pole versions that can be fixed, plugged in or easily withdrawable, and are fitted with the very latest generation of interchangeable, precise and reliable thermomagnetic and electronic trip units. And uniquely, a new and large number of dedicated accessories are available to meet the most stringent of applications.

ABB's new generation of Tmax circuit breakers are standard-compliant, modular and intelligent devices that can be easily integrated or interfaced with other components or systems.

ABB has been designing and producing low-voltage molded case circuit breakers (MCCBs) and air circuit breakers (ACBs) since 1934. The first family in the MCCB series, known as "Isol," featured a thermomagnetic trip unit (TU) and was characterized by a maximum breaking capacity of up to 25 kA (at 415 V AC). Each decade following the launch of the Isol family saw the emergence of new generations of MCCBs, including the Fusol, Modul, Limitor and Isomax families. The well-known Tmax T family of circuit breakers was launched in 2001.

The last ten years or so have seen some dramatic changes in customer and market demands that have in turn affected suppliers. For example, new and improved applications necessitate greater speed and reliability in a protection system to maintain safety, stability and continuous service. For suppliers – many of which have emerged in the last decade – this means the development of standard-compliant modular, smaller and intelligent devices that can be easily integrated or interfaced with other components or systems.

ABB's new generation of Tmax circuit breakers, the Tmax XT, are examples of such devices (*see title picture*). Characterized by high performance in a small device with the most modern electronic TUs, this family of circuit breakers combines over 60 years of experience and know-how in breaker design with modern technological developments.

The Tmax XT family album

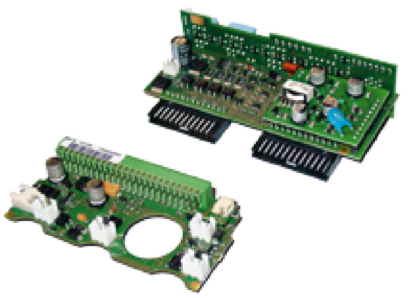
The Tmax XT family is composed of four frames (XT1, XT2, XT3 and XT4) with a rated current that extends up to 250 A and a rated ultimate short-circuit breaking capacity, Icu, that goes up to 150 kA (at 415 V) and 90 kA (at 690 V):

- XT1 (160 A) with an Icu up to 70 kA (at 415 V)
- XT2 (160 A) with an Icu up to 150 kA (at 415 V)
- XT3 (250 A) with an Icu up to 50 kA (at 415 V)
- XT4 (160 – 250 A) with an Icu up to 150 kA (at 415 V)

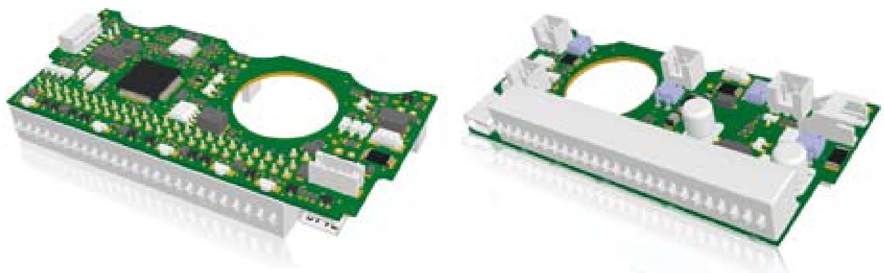
The XT1 and XT3 frames can be used in large scale distribution installations, hospitals and generally in all service-sector applications that require high reliability, while XT2 and XT4, with the highest breaking capacities on the market, are more suited to heavy industries, metallurgy and marine (cruises, oil rigs, container ships), where extremely high performance is required. Unique to the market, these two frames can be equipped with the latest generation electronic TU, allowing interchangeability and integrated communication from rated currents of 10 A.

XT1 and XT3 are both available in the three and four-pole fixed and plug-in versions. With a depth of 70 mm and a compartment door cut-out of 45 mm, they can easily be installed, side by side, on a DIN rail or on a back plate without using spacers.

1 Old Tmax trip unit (TU) size versus the new TU size



2 3D views of the new TU printed circuit board (PCB)



Innovation in research and development

In order to reduce the development and validation time needed for the breakers and to increase project quality, ABB engineers developed advanced design tools that could be used during the initial design phase:

– A common design platform to develop, select, integrate and interface the individual components of the Tmax XT breaker family
– Multi-physics simulation to design and calibrate the full range of Tmax XT over-current relays
– An Arc Imaging System (AIS) that allows the optical diagnostics of low-voltage arcs
– The highly accelerated life test (HALT), which exposes failure modes, allowing corrective action to be taken in the design or production process

A common design platform

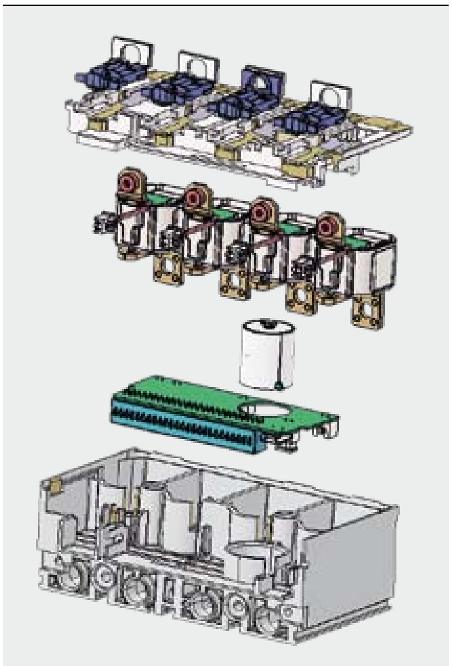
One of the requirements for the new "Ekip" electronic TU (used in the XT2 and XT4 frames) was enhanced performance in a smaller device. While greater performance generally means increased complexity, calculation power and functionality, all this is now possible in a unit that is 50 percent smaller than its predecessor → 1 and → 2. To achieve this, the designers first looked at the core of the unit and selected a very powerful 32-bit ARM[1] microcontroller, which is characterized by its high energy efficiency and high performance using a single processor architecture in a small footprint. It provides a high level of connectivity, allowing the integrated development of different communication buses.

Then it was necessary to develop, select, integrate and interface the individual components of the complete mechatronic assembly, ie, the plastic box, current sensors and terminals, electronic TU, trip coil and interconnections → 4, at the same time. This included ensuring the correct components were chosen, their most optimal position on the printed circuit board (PCB) and observing how they integrated with other mechatronic assembly components. These steps were possible using a common design platform long before the physical construction of the assembly began.

Thanks to its scalability and wide availability, this platform can be reused as a basis for future developments that feature a high level of software code portability (ie, the same hardware and software platform). This guarantees a reduction of time to market and increased reliability. The firmware has been developed according to international software quality standards, such as the UL489 supplement SE[2], and the latest software engineering guidelines.

The Ekip TU is a complete series that provides protection for plants at 400 Hz (eg, airports, ships). To ensure this, an extensive frequency analysis is needed, which requires the right current sensor (CS) frequency response, an adequate analog channel bandwidth for the measurement of harmonic components and correct digital filter design for accurate signal reconstruction → 4. These requirements are executed using Simulink and Matlab simulation tools.

3 Breaker mechatronic assembly view



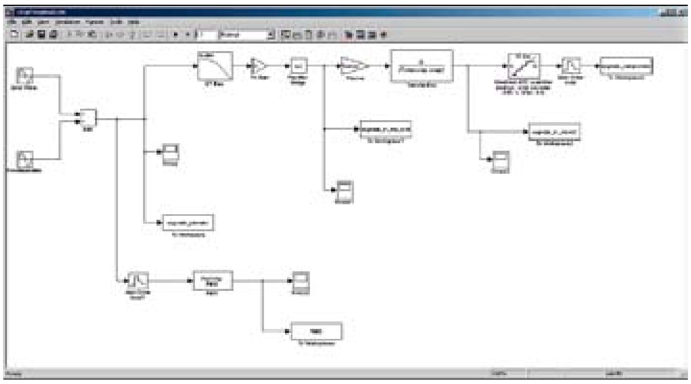
The Tmax XT family of breakers contains four devices that can be used for distribution, motor and generator protection, oversized neutral and as switch-disconnectors.

Footnotes

1 ARM, headquartered in Cambridge in the United Kingdom, is the industry's leading provider of 32-bit embedded microprocessors.

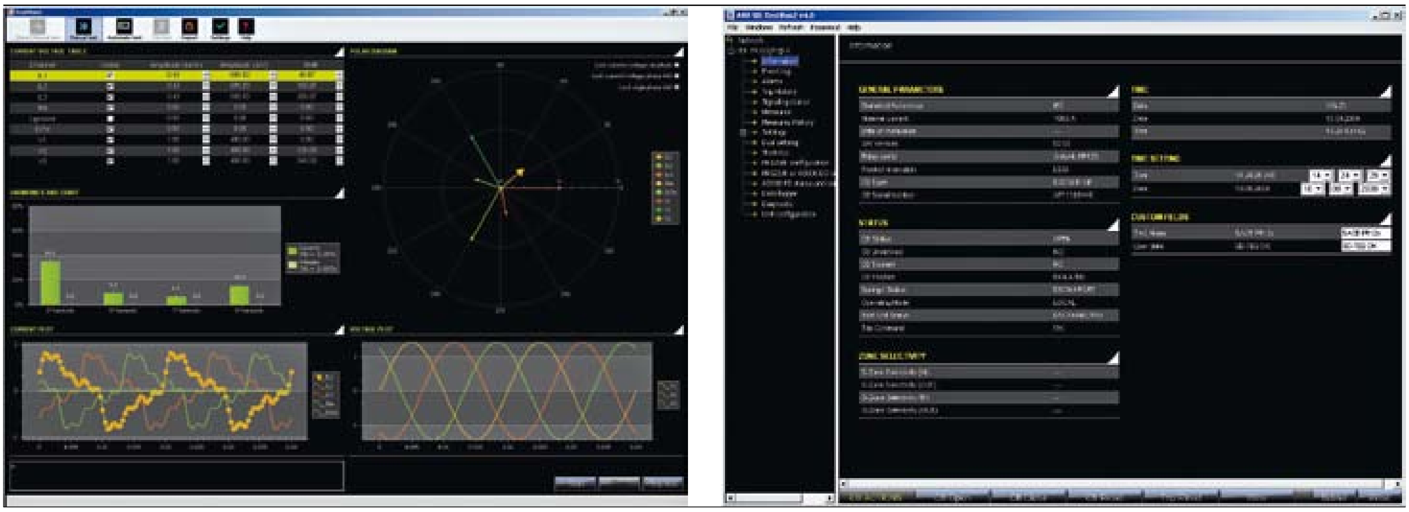
2 The UL489 supplement SE standard outlines the requirements for molded-case circuit breakers and molded-case switches with software in programmable components.

4 An example of a hardware and software simulation model for frequency analysis



5 Tmax XT Ekip display

6 Tmax XT Ekip Connect screenshot



The functionality of the Ekip TU can be extended by means of plug and play accessories, such as an LCD graphic display with backlight (Ekip display), an LED meter, a local communication interface (Ekip T&P and Connect), a system communication interface (Ekip COM), and a device for trip test and last trip detection. The Ekip display, an innovative device for ABB MCCBs, is a graphical HMI that allows the local configuration of enhanced TU functions that were previously only available via a communication bus or handheld device → 5. The display is powered directly by the TU and it is a plug and play device that can be easily moved from one TU to another. The Ekip T&P enables the TU to directly interface with the USB port of a PC and it works together with Ekip Connect, a software tool for supervising, setting and testing → 6. The Ekip COM is a module that can be embedded into the circuit breaker and provides an interface between the TU local bus communication and the system bus. Moreover, it is possible to remotely control the TU and the circuit breaker with motor operating equipment.

Multi-physics simulation

A bi-metallic strip is a mechanical device that transforms a change in temperature into a change of shape, and because of its simplicity, reliability and the low cost of production, it is considered the most common solution for MCCB over-current protection. Even though the working principle of bimetals is well documented and known for many years, designing and calibrating the full range of Tmax XT over-current relays has been quite a challenge because of the technical specifications that have to be met, including:

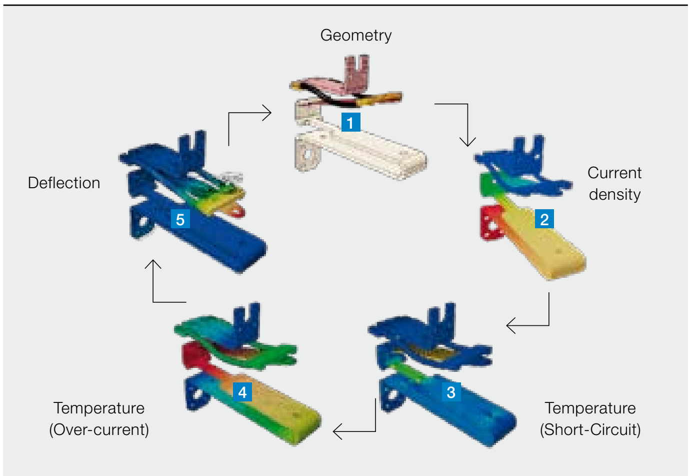
- A low regime over-temperature with rated current In
- Low sensitivity to environmental temperature
- A non-tripping current of 1.05 × In
- A tripping speed with 1.3 × In of less than 10 minutes
- A tripping speed with 2.0 × In of less than 3 minutes
- A tripping speed with 6.0 × In of less than 20 seconds
- Reduced temperature rise during a short circuit (Icu, Ics).

In order to meet these conditions, which involve different branches of physics, an iterative multidisciplinary procedure has been implemented → 7. Starting from an approximate geometrical configuration (material properties included), a sequence of electrical simulations at imposed current rates provide the relevant heat sources for the subsequent thermal computations. Once the satisfactory temperature distributions are obtained, all mechanical unknowns (deflection, speed and the force of the bi-metal) become available. The initial geometry is therefore revised until all of the aforementioned conditions are fully met.

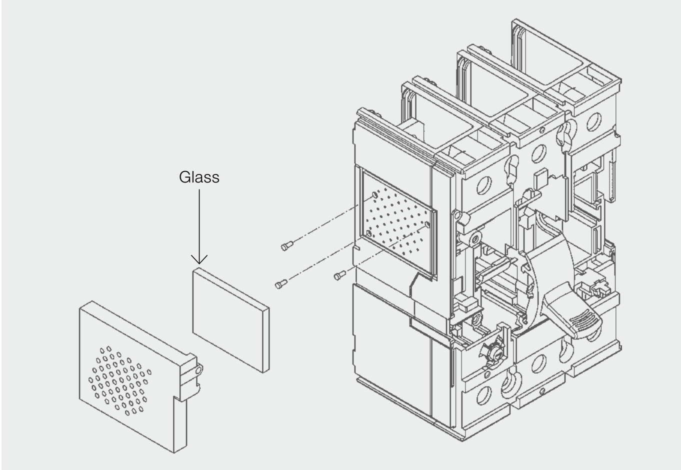
Compared to the classical analytical approach, this procedure revealed two advantages:

- It has a wide range of applicability (from the higher to the lower currents)
- It is geometrically independent (every solution can be analyzed).

7 Multidisciplinary procedure



8 To monitor arc movement optical fibers are placed on one side of the breaker with a protection glass interposed.



9 Overview of the Arc Imaging System (AIS)

The highly accelerated life test (HALT), is based on the accelerated tests principle and is performed directly on complete breakers, accessories and single components in the design phase.

Optical diagnostics of low-voltage arcs

The study of short-circuit interruption is challenging for designers. For example, during an interruption the arc plasma can reach temperatures of up to 20,000 K and needs to be extinguished very quickly. An enhanced technique, the Arc Imaging System (AIS), has been developed to observe arc movement during a short circuit. It consists of an array of optical fibers, mounted on one side of the breaker, which read the light intensity inside the arc chambers → 8. The acquisition system, developed together with the University of Southampton, is a self-contained mobile system supplied with a range of optical-fiber lengths → 9. It comprises a purpose built PC, and an integrated computer screen and keyboard. The system hosts a total of six cards, each capable of accommodating 16 channels for data acquisition (giving 96 channels in total). The hardware is assembled on vibration proof mountings and can be sealed for transportation.

An automatic post-processing routine has been developed which produces a movie of the arc evolution: stills of one example are shown in → 10. In other words, for any sampled time instant, the light intensity value from each fiber is mapped onto a suitable color scale and superimposed to a picture of the circuit breaker arc chamber in the correct location.

AIS has proved to be an amazing tool in that it correctly interprets the outcome of a test and, analyzed together with test lab oscillograms, has contributed enormously in clarifying many aspects of current interruption.

The highly accelerated life test (HALT)

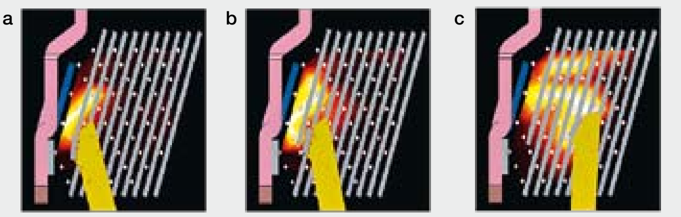
Tmax XT breakers have been developed using modern techniques, which have led to increased reliability and robustness. They have also been designed and tested in accordance with the requirements of all the relevant international standards as well as the Naval Register requirements. One of the approaches implemented, the highly accelerated life test (HALT), is based on the accelerated tests principle and is performed directly on complete breakers, accessories and single components in the design phase.

The goal of HALT is to quickly break the product and learn from the failure modes the product exposes. The key value of the test lies in the failure modes that are uncovered and the speed at which this happens. Under real conditions, it could be years before these failure modes actually appear. HALT is considered a success when failures are induced, the failure modes are understood and corrective action is taken in the design or production process → 11.

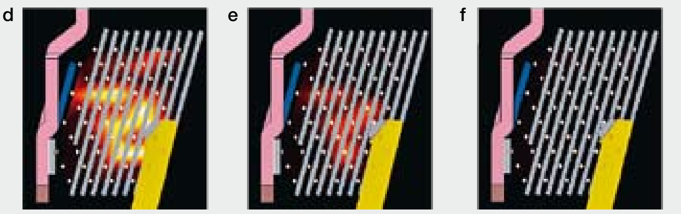
According to the HALT procedure, the product is stressed far beyond its specifications and typical environmental conditions. The actual functional and destruct limits of the product are found and extended as far as possible (for example, vibration up to 40 g, temperature from –80°C to 180°C and thermal shock with a ramp rate of 15°C/min) → 12.

Every step of HALT foresees:
– Test design, using the design of experiment (DOE) technique, to define the appropriate number of samples and variables

10 A successful interruption captured using the Arc Imaging System (AIS)

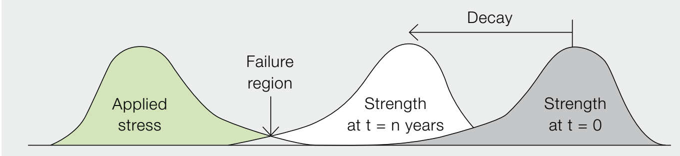


a Contact repulsion and arc ignition (1 ms)
b Arc movement from the contact to the arc runner (2 ms)
c Arc expansion in the arc chamber (3 ms)

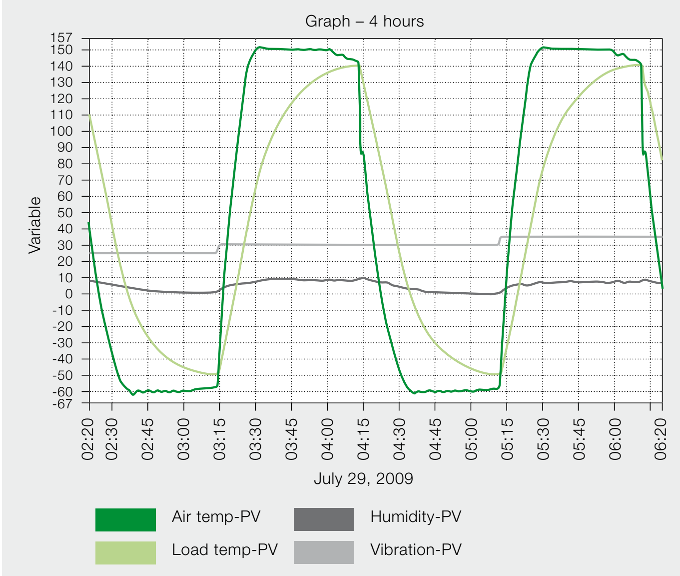


d Arc cooling (4ms)
e Electrical rigidity almost restored (5 ms)
f End of the phenomenon: successful current interruption – (6 ms)

11 Stress-strength in the HALT sequences



12 A HALT testing cycle



– The execution of the tests with the HALT procedure at defined stress levels and step durations
– The result analysis, which is performed by fitting a failure with statistical models, such as Arrhenius' law for thermally driven failures; Eyring's theory for temperature and humidity; the inverse power law (IPL) for pressure, mechanical stress; voltage supply and thermal non-thermal (T-NT) (eg, temperature and vibration)

Tmax XT circuit breakers are developed and produced in accordance with the RoHS Directive, and the LCA approach was used to assess and minimize products' environmental impact.

Overall, this approach improved the XT developing process, gave the designers a greater insight into the expected behavior during the product life and reduced time to market.

A lifetime of experience

ABB's new Tmax XT circuit breakers have been made to respond successfully to all plant engineering requirements, from the most standard ones to the technologically advanced ones. They feature a new range of both thermomagnetic and electronic protection plug and play trip units, which are interchangeable right from the smallest frame and which guarantee absolute tripping reliability and precision.

In addition, the circuit breakers are designed with the environment in mind, ie, they are developed and produced in accordance with the Restriction of Hazardous Substances (RoHS) Directive and other environmental regulations concerned with such substances. In addition the life cycle assessment (LCA) approach was used to assess and minimize products' environmental impact in terms of emissions, resource depletion and waste throughout the whole life-cycle, from manufacturing to disposal.

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Mobilizing transformers

Fast deployable modular transformers for high-voltage transmission systems

MIGUEL OLIVA – The installations that deliver power to your home or factory are designed and maintained to provide the highest levels of reliability. However, despite good design and maintenance, failures can never be ruled out altogether. A severe incident can put a transformer out of service for months or even over a year while a replacement is procured or heavy repairs effected. To be able to serve customers in the interim, an alternative is needed. One solution is to deploy a mobile transformer. Such a transformer is sufficiently small and light to be able to be moved by road, either in one piece or in a way that permits rapid assembly and commencement of service. Until now, mobile transformers have been limited to 230 kV. Through innovative design, ABB has now been able to deliver a 400 kV mobile transformer.

The continuity and quality of the power supply are the two most important operational objectives of electrical utilities. Managing the increased demand for power requires new investments and even more effective utilization of existing equipment. In that context, utilities need to have strategies in place to minimize the operational and maintenance costs while reducing the number of forced outages and failure rates.

Power transformers represent a significant asset in the utility delivery chain. They are one of the most important and costly components and critical nodes in the high-voltage transmission networks. Large power transformers are a major concern to any electric utility when it comes to reliability. Transformers are critical to the operation of the delivery system and their replacement requires considerable time and expense. A transformer is a complex piece of equipment representing high cost, engineering expertise and manufacturing effort. Furthermore they have relatively long delivery times and require adequate maintenance to optimize operation and life expectancy.

Depending on the strategic importance of the unit, the unplanned unavailability of a transformer can imply a significant loss of production or income for the utility and have a major impact on the system. In the extreme case, a failure can lead to a blackout with the corresponding loss of public image, customer complaints and administration fines.

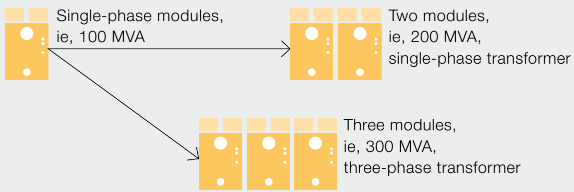
To avoid these problems, contingency planning is required to be able to react to the failure of transformers that would result in prolonged outages. There are different contingency planning strategies

> The time required to install a transformer in an emergency can be improved from several weeks or months to 10 to 15 days including mobilization and transportation.

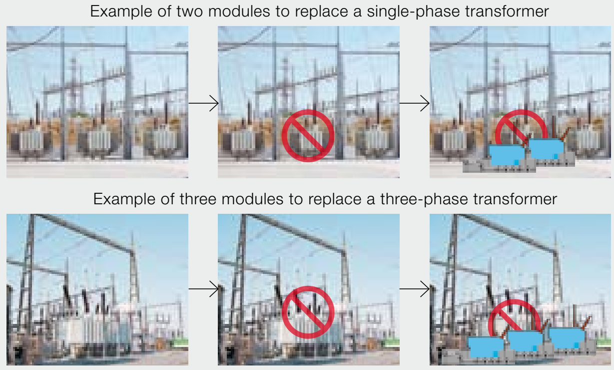
1 The flexiformer: Smaller sized single-phase transformer modules are combined to build a larger unit

Modular approach

Single-phase modules combined to have larger single-phase transformers or three-phase transformers



2 Modular concept: 400kV mobile transformer for contingencies



for incidents related to power transformers. These include:
- Meshed grid
- Redundant transformers
- Standardization of transformers
- Spare units
- Polytransformers
- Mobile transformers

The procurement of a new transformer with a required specification consumes from several months to more than a year. Installing an existing spare may take from weeks to months as it involves transportation, hauling, assembly and other activities if the replacement unit is not already at the site of the failure. Emergency recovery plans with quick response are essential. Mobile transformers can play an important role here.

Mobile transformers are not a new concept. They have, however, traditionally been limited to 230 kV applications. Typical mobile transformer characteristics range from 35 to 245 kV with power ranging from 5 MVA to 100 MVA three-phase units. High temperature insulation is normally used to minimize dimensions and weights. To permit fast deployment they are transported fully assembled and already filled with oil.

Increased weight and dimensions are the major constraints for making mobile transformers for ratings above 230 kV. Hence the capability of mobile transformers has hitherto been limited to that voltage level. ABB has been working to address this challenge and provide solutions for quick-reaction contingency plans for transmission networks of higher voltage.

The concept

Power transformers above 100 MVA are relatively heavy and large. Their transportation requires dedicated vehicles, thorough evaluations and planning as well, and require administrative permits which can take a long time → 4.

ABB thus set out to meet the challenges of MVA rating and transportability for mobile transformers. The requirement was to manufacture a transformer of large rating in reduced dimensions, permitting it to overcome shipping limitations so that it could be moved by road and using simplified administrative procedures.

ABB adopted a modular approach. Smaller sized single-phase transformer modules are combined to build a larger unit → 1. For example, two single-phase modules for a larger single-phase unit and three modules for a three-phase unit → 2. To provide optimization in terms of size, shell transformers are used. Some advantages of shell transformers are:
- Compactness of the design with magnetic core enclosing the windings

The project's main focus was to get the maximum rating within the existing shipping restrictions for road transportation.

3 Mobile transformers at a glance

Main features of the high-voltage mobile transformer:
- Modular concept for 345 kV, 400 kV and 525 kV applications
- Fast deployability
- Quick and simple transportation
- Possible polytransformer units to cover additional number of voltages

Advantages and applications of mobile transformer of higher rating:
- Contingency plans with quick response and flexibility to recover service in critical substations in case of transformer failures with a reduce time target
- Temporary installations for important events and for allowing temporary increased capacity in critical areas in case of peak load seasons or for specific events
- Reduction of insurance premiums
- Reducing Homeland Security concerns
- Reduction of risks of blackouts, avoid administration fines for loss of service and reduce claims and complaints from customers
- The return of the investment is immediate once it is needed and the cost of opportunity is very high

4 Transportation by road of a standard large transformer requiring special permits and vehicles

5 The mobile transformer is ready for transportation

to match the transportation and hauling restrictions.
– Horizontal lay-down operation that allows better transportability and better optimization of the transformer design.

The transformer is assembled onto a platform vehicle to allow quicker transportation by road, with a minimum of administrative permissions. Traditional cellulose insulation was selected because high-temperature insulation had hitherto not been used for applications beyond 230 kV. Research work is currently ongoing to use high temperature insulation for increased ratings within the same dimensions or to reduce weights while maintaining the rating.

An important aspect is the fast deployability of these transformers. If transportation limitations governing weight and dimensions are exceeded, the transformers must be shipped partially disassembled and without the insulating oil.

The transformer design is customized to the application and aims to minimize any disassembly work. The transformer can also be engineered to be transported and assembled with coolers located on the vehicle. Depending of the type of external connections, the high-voltage bushings need to be removed for transportation, although plug-in terminations may be used.

The final assembly works had to be carefully planned to take into account all the practical aspects: oil filling, commissioning and testing while minimizing the time needed to put the unit into service. The installation time can be reduced if the unit is stored so as to be well-prepared for shipment and personnel are well trained for their task and the processes are defined.

With this concept, the time of reaction can be improved from several weeks or months to 10 to 15 days including mobilization and transportation. This provides greater advantages for the utilities to quickly restore failed transformers in the transmission network → 3.

A practical case

The fast deployable mobile transformer concept was developed to support strategic contingency plans for the Spanish transmission system operator and owner of the 400 kV system (REE: Red Electrica). This is the world's first reference of a 400 kV mobile transformer.

A collaborative approach was used to take advantage of synergies between ABB and the utility. The rating of the single-phase modules, 117 MVA, and other

The transformer is assembled onto a platform vehicle to allow quicker transportation by road, with a minimum of administrative permissions.

characteristics such as the impedance were selected to be able to substitute the utility's standardized system transformer (200 MVA single-phase units) and provide a high rating as a three phase unit (350 MVA) while fitting within the dimensional restrictions for road transportation.

A polytransformer was built with 400 kV on the high-voltage side and a selectable 230 kV or 138 kV on the low voltage side, with three different voltage levels on the tertiary side (33 kV, 26.4 kV and 24 kV). This facility provided additional usability and extended field of application of these transformers permitting them to substitute a wide number of units of the utility's existing fleet (either single or three phase).

The possibility of using of an on-load tap changer was rejected in order not to add additional weight and volume. However a de-energized tap changer was included to add some extra functionality and some off-line regulation capacity.

The project's main focus was to get the maximum rating within the existing shipping restrictions for road transportation. A horizontal lay-down shell transformer was used. The final product represented less than 60 tons for transportation, and less than 3.4 m height and 2.7 m width.

The transformer was prepared for mobile transportation being assembled onto a road vehicle, without oil ➔ 5. It was agreed with the utility to ship it with the bushings and coolers disassembled. A thorough assembly plan was prepared together with the utility in order to minimize the assembly time on-site and have service personnel adequately trained. The utility also developed all the arrangements needed for interconnection to the system, arresters and insulators for the line connections, cable connections, controls, etc. Safety and the environmental aspects were also addressed through a portable oil receptacle in case of oil leaks.

Mobile transformers are not a new concept. They have, however, traditionally been limited to 230 kV applications.

Three 400 kV units have been built. To be prepared for an emergency situation, the utility performed a trial installation which permitted it to verify the performance, the reaction time and the training of their personnel in a single exercise. The utility was satisfied with the test result, which in a real situation would have represented a quick recovery of service.

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Actively improving quality

ABB's PQF active filters enhance system performance and efficiency

KURT SCHIPMAN, FRANÇOIS DELINCÉ – The increasing use of non-linear loads in all types of industrial and commercial applications has resulted in the introduction of potentially harmful current harmonics into the power network that can lead to overheating of cables, motors and transformers, damage to sensitive equipment, tripping of circuit breakers and blowing of fuses as well as premature aging of the installation.

ABB modular PQF active filters provide a reliable and cost-effective solution to this problem by continuously monitoring the current in real time to determine what harmonics are present and then injecting harmonic currents in the network with exactly the opposite phase to the components that are to be filtered. The two harmonics effectively cancel each other out so that the feeding transformer sees a clean sine wave.

1 Examples of financial loss due to power quality incidents

Sector	Financial loss per incident (in euros)
Semi-conductors production(*)	3.8 million ($5.3 million)
Financial trade(*)	6 million ($8.4 million)
Computer center(*)	750,000 ($1 million)
Telecommunication(*)	30,000 ($42,000)
Steel industry(*)	350,000 ($490,000)
Glass industry(*)	250,000 ($350,000)
Offshore platforms	250,000 - 750,000 ($350,000 - $1 million)
Dredging/land reclamation	50,000 - 250,000 ($70,000 - $350,000)

Electrical networks with poor power quality result in financial loss, environmental impacts or safety concerns. There are three significant causes of poor power quality:

- Harmonic pollution
- Load imbalances resulting in voltage imbalance
- Reactive power

These conditions, when excessive, lead to frequent equipment failures or reduced lifetime of the equipment, production losses, reduced safety levels of installations, increased carbon footprint, non-compliance with utility regulations and other undesired effects. In addition to financial losses there are costs incurred due to extra kWh losses in typical network components such as transformers, cables and motors. These losses are cascaded back to the utility power plants and, depending on the process and fuel from which the electrical power is generated, result in increased CO_2 emissions. Nuclear power plants, for example, have almost no CO_2 footprint per kWh while coal power plants generate around 900 to 1,000 g/kWh.

If, due to poor power quality, the production is stopped, major costs are incurred. This is illustrated in → 1, which gives an overview of typical financial losses due to a power quality incident (stop) in electrical installations for various industries [1]. The data marked as (*) have been concluded after a European-wide power-quality survey undertaken by the European Copper Institute in 2002. The remaining information is based on ABB data.

One possible method to quantify theoretically the extra losses introduced by harmonics in transformers is to use the IEEE C57.110 standard [2]. The calculated impact will depend on the local situation but what is clear is that losses quickly accumulate.

Most of the harmonic pollution nowadays is created as harmonic current produced by loads in individual installations. This harmonic current, injected into the network impedance is translated into harmonic voltage (Ohm's law), and then applied to all the loads within that user's installation. In addition, the harmonic current produced in one installation, if not filtered, will also flow through the feeding transformers into the utility supply and create harmonic voltage distortion on the public network. As a result, any utility user connected to the same supply will become affected by the pollution created by another utility customer. This can result in operational issues in the other installations.

ABB modular PQF active filters are used to counter the effect of potentially harmful current harmonics into the power network.

Most utility plants have adopted and comply with power quality standards and regulations to limit this type of problem. Non-compliance with these regulations leads to a refusal of a new installation connection.

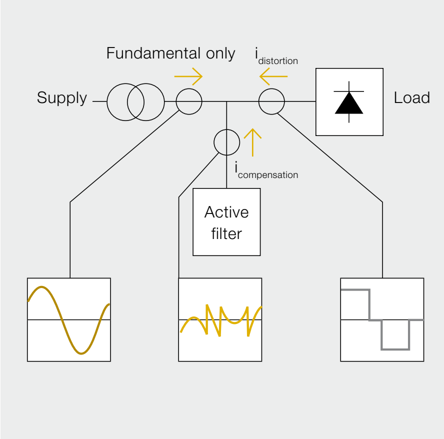
Addressing harmonic pollution and load imbalance

Historically, passive filters have been proposed to mitigate harmonic pollution. In low-voltage (LV) installations, these solutions become less and less applicable when:

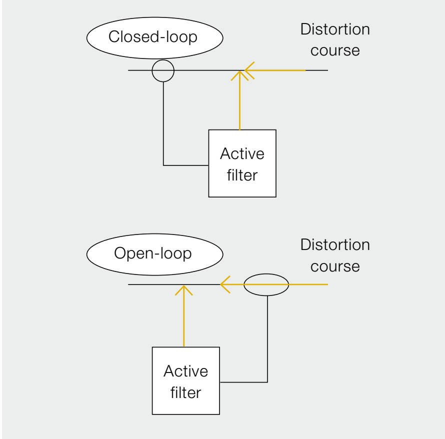
- LV installations are very dynamic leading to relatively fast passive filter overload
- Modern loads (eg, variable-speed drives, modern lighting systems) already have a very good cos φ (possibly even capacitive) leading to overcompensation when a passive filter is installed. This in combination with the limited capability of typical backup generators to run on capacitive cos φ reduces the reliability of the installation.
- Passive filters installed in LV installations typically address the lower harmonic orders. Currently, however, it is the higher frequency harmonics that are problematic in installations.
- The filtering efficiency of a passive filter is defined by the ratio of the passive filter impedance and the network impedance and therefore cannot be guaranteed. Hence, it is virtually impossible to guarantee compliance with regulations by using passive filters.

For these reasons there is a worldwide tendency to move away from passive filtering solutions in favour of active filtering solutions in LV and MV applications.

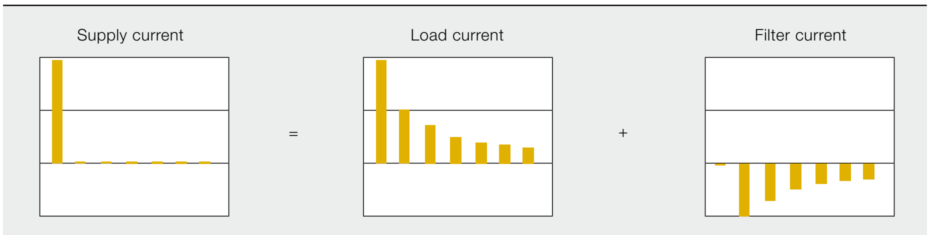
2 Connection diagram of the most commonly found active filters



3 Closed-loop and open-loop active filter principle



4 Principle of the frequency-domain filtering approach



The most commonly found active filters are power electronics-based electrical equipment that are installed on a parallel feeder to the polluting loads → 2.

The controller of an ABB power quality filter (PQF) analyzes the line current harmonics, as well as the customer requirements. It can then generate for each harmonic frequency a harmonic current (compensation current) that is opposite in phase to the measured polluting current.

Since the PQF does not operate according to the conventional low harmonic impedance principle employed by passive filters, it remains unaffected by changes in network parameters and can not be overloaded. Also, compared to passive filter units, active units can be easily extended.

In order to obtain effective performance throughout the filter bandwidth, two control aspects, both of which can be implemented in the PQF, are critical:
– The use of a closed-loop control system
– The frequency domain approach for processing and controlling the polluted current.

For active filters the closed-loop and open loop aspect can be found in the location where the active filter measurement current transformers (CTs) have to be installed → 3.

The tendency now is to move away from passive filtering solutions in favour of active solutions in low and medium-voltage applications.

In closed-loop systems, the current upstream of the load and filter connection are measured and corrective action is taken. Any measurement or other inaccuracies can be automatically cancelled out and compensated by the closed-loop concept. In open-loop systems, the load current is measured and processed and the resultant inverted signal drives the insulated gate bipolar transistor (IGBT) bridge. As no feedback exists, the resulting line current may typically contain error components, which are not detected by the control system.

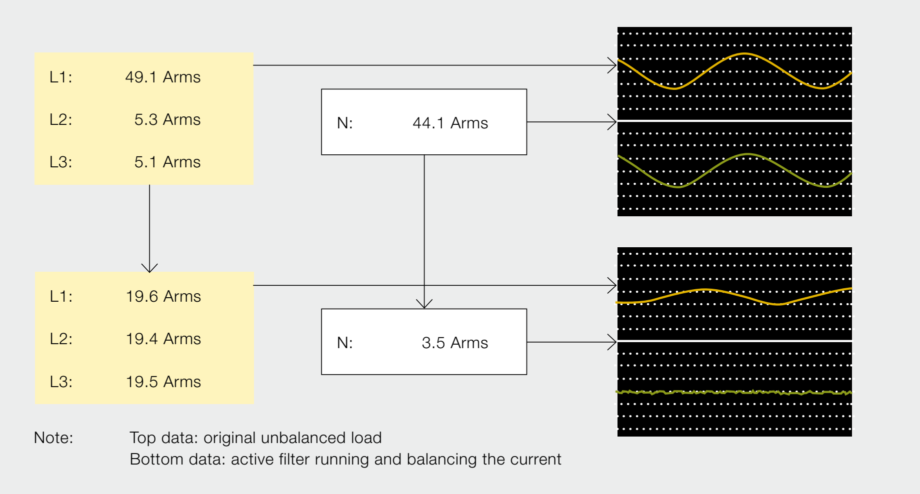
In summary, the advantages of using a closed-loop system over an open-loop one are [3]:
– Closed-loop systems allow the canceling of errors in the control loop and in the behavior in response to external disturbance. Open-loop systems do not have this capability.
– Closed-loop control systems can react as fast as open-loop control systems providing that the control loop parameters are set for this behavior.

The frequency domain approach is preferred over the time domain approach, and the following paragraph explains why.

In the time-domain approach, the fundamental frequency component is removed from the measured current signal. The remaining waveform is then inverted and the resultant signal drives the IGBT-bridge of the active filter. This approach ignores the fact that the network characteristics are different for different frequencies, as well as the characteristics of the CT's and the control system. The performance of active filters using this control approach deteriorates with increasing frequency. In the frequency-domain approach each harmonic and its corresponding system characteristics are treated individually and performance can be optimized for the harmonic components in the filtering bandwidth. As a result the same (high) filtering performance can be maintained through the filtering bandwidth. The principle of the frequency-domain filtering approach is illustrsted in → 4.

The best filtering performance will be obtained with an active filter using a closed-loop control system and an individual frequency domain approach. Other advantages of such filters include:
– User requirements can be preset for each harmonic (eg, standard compliance requirement).
– Individual harmonics can be selected to allow optimal use of the filter resources (eg, no need to filter the fifth harmonic if this harmonic is already filtered by another existing filtering device).

5 Example of a balancing application by using a closed-loop active filter



The best filtering performance will be obtained with an active filter using a closed-loop control system and an individual frequency domain approach.

- Precise targets for cos φ can be set and maintained. This allows such active filters to operate in applications where accurate cos φ control is required to avoid disturbances in the installation (e.g. tripping of a generator). ABB active filter units can compensate both inductive and capacitive loads.
- Precise load balancing can be implemented allowing neutral systems to be offloaded and ensuring that neutral to earth voltage is kept to minimal levels. Also, it can be ensured that the load seen by eg, a UPS is balanced. ➔ 5 gives an example of a balancing application by using a closed loop control ABB PQF active filter.

In addition to the functional aspects, more advanced active filters such as the ABB units contain functions that minimize equipment running losses and provide extra reliability to the installation. This is due to the presence of valuable secondary functions (eg, automatic temperature de-rating function etc.).

Field results

ABB PQF active filters and other ABB power quality equipment are applied in several fields.

For example, an oil field exploitation facility comprises one central power station feeding many pumping clusters. The vast majority of the loads are AC drive controlled. There are approximately 40 clusters, each with a load in the range of 2 MW. Without active filters, the total harmonic distortion voltage (THDV) at the LV side of the cluster would be equal to 12 percent and the total harmonic distortion current (THDI) would be 27 percent ➔ 6.

With active filters, the THDV has been reduced to 2 percent and THDI to 3 percent ➔ 7.

Overall, the power quality of the clusters has been hugely improved, allowing the plant to run within IEEE 519 standard limits and ensuring trouble free operation of the different clusters.

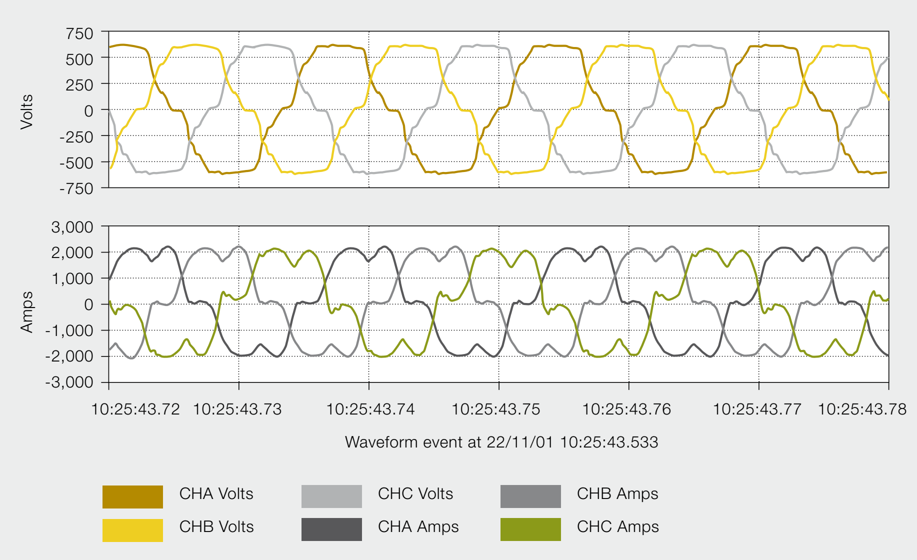
A second example considers the power quality on board a vessel ➔ 8. The vessel in question has an electrical power plant consisting of two generators running at around 600 kVA each. The main loads are two DC-drive based propulsion units. Before compensation, the THDI was around 25 percent and the corresponding THDV around 22 percent. The cos φ of the installation was around 0.76. Typical fuel consumption of the vessel was in the range 14,000 to 15,000 liters per month.

The customer requirements were to:
- Reduce the harmonic pollution to acceptable levels to avoid technical problems with the propulsion units.
- Perform reactive power compensation without the risk of overcompensation.

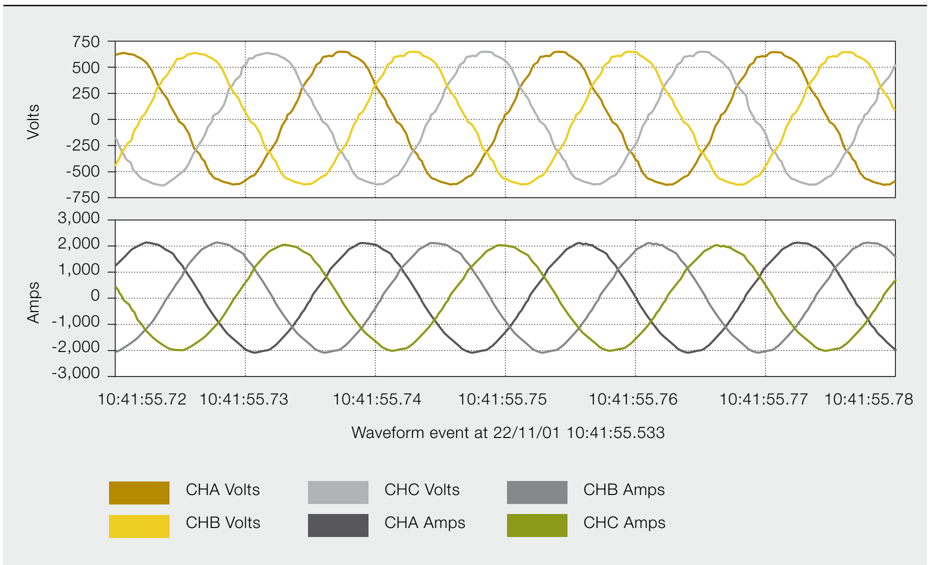
For this reason, ABB active filters were selected and installed. The customer feedback was highly encouraging since the technical problems were resolved and there was scope to save around 10 percent of fuel costs. On a yearly basis, the customer has the potential to save around 18,000 liters of fuel. The primary reason is that one generator could be switched off more frequently thanks to the improved network quality.

As seen in previous examples, power quality issues often arise in industrial networks due to the presence of a non-negligible number of (large) pollution loads. In commercial applications however, power quality is also a concern. In such applications, many single-phase polluting loads are present which create problems such as:
- Increased harmonic stress, which is put on equipment that is typically more vulnerable than industrial equipment.
- Resonance excitation due to the presence of 3rd harmonic compo-

6 Voltage (top) and current (bottom) waveforms before filtering at the LV cluster side



7 Voltage (top) and current (bottom) waveforms after filtering at the LV cluster side



nents in combination with capacitor banks with a wrongly chosen detuning reactor or no reactor at all.
- Neutral currents in excess of neutral conductors and bus-risers rating.
- Too high neutral to earth voltages which may not be acceptable for product operation and/or from a safety point of view.
- The presence of capacitive cos φ due to modern server hardware, eventually leading to the need to derate UPS-systems etc.

An example of a commercial application is the power quality in a prestigious multi-star hotel. This hotel incorporates guest rooms, suites, function rooms and business centers. Typical loads encountered are high-speed lifts, dimmer switches and other sophisticated lighting equipment, as well as typical office equipment including PCs, printers, etc. As a result of all these loads, the power quality had deteriorated to such an extent that the voltage was unstable. Simply changing the operating point of loads in one side of the building would affect the operation of other loads in other rooms. This was clearly unacceptable as it could lead to a loss of customers because of a low standard of service. ABB filtering equipment resolved these issues.

8 ABB reduced fuel consumption of this vessel by 10 percent

ABB PQF active filters contain additional functions that minimize equipment running losses and provide extra reliability to the installation.

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References
[1] European Copper Institute (2002). European power quality survey.
[2] IEEE C57.110-2008: IEEE recommended practice for establishing transformer capability when supplying non-sinusoidal load currents. 2008.
[3] Kuo, B.C. Automatic Control Systems. John Wiley & Sons, Inc. New York, NY, The United States.

Shore-to-ship power

ABB's turnkey solution is effectively reducing portside emissions

KNUT MARQUART, TON HAASDIJK, GB FERRARI, RALPH SCHMIDHALTER – In the shipping industry, harbor areas have been identified as a prime candidate for enabling significant emissions reductions. With this in mind, port authorities, ship-owners, industry suppliers and regulators are now focusing on the decade-old technology known as shore-to-ship power, for which universal electrical standards are on the verge of being ratified by IEEE, ISO and the IEC. Onshore power supply allows commercial ships calling at ports to turn off their diesel engines and tap into cleaner energy sources. Having successfully delivered the world's first shore-to-ship power connection to the port of Gothenburg, Sweden in 2000, ABB has not only the technologies but also the experience required to make the complete connection, onboard and onshore.

With ABB's shore-to-ship power connection, a large cruise ship can cut fuel consumption by up to 20 metric tons and reduce CO_2 emissions by 60 metric tons during a 10-hour stay in port.

Over 90 percent of the world's goods are transported by sea, and although shipping is a highly efficient means of transporting cargo with lower CO_2 emissions than trucking and far lower emissions than air transport, the industry is still responsible for around 4 percent of all global CO_2 emissions (aviation accounts for 2 percent). With ABB's shore-to-ship power connection [1], a large cruise ship can cut fuel consumption by up to 20 metric tons and reduce CO_2 emissions by 60 metric tons during a 10-hour stay in port – equivalent to the total annual emissions of 25 European cars. It is no surprise then that interest in shore-to-ship power is growing, not only for environmental but also for economical reasons. With a shore-based power connection, a ship is able to turn off its engines without interrupting its port services, such as loading and unloading, hotelling or any other activities that consume power at berth. The connection and disconnection of the ship takes as little as 15 minutes, and administration of power supply and consumption is handled by the port operator.

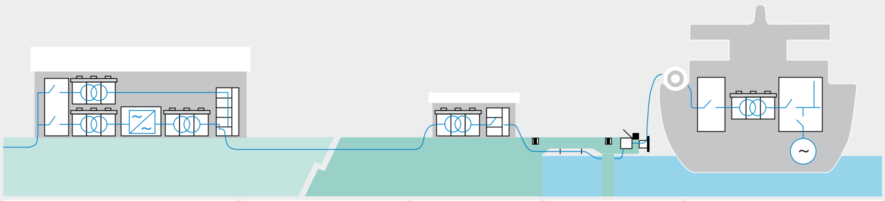
Establishing a shore-to-ship power connection necessitates investment by both shipowners and port authorities or terminal operators in the form of either a retrofit of existing assets or construction of new ones ➔ 1. The ship needs an additional electrical switchboard, cables connecting it to the ship's main switchboard, and, in many cases, a step-down transformer. The port requires a substation with breakers and disconnectors, an automated earthing switch, a transformer, protection equipment such as transformer and feeder protection relays, communications equipment to link ship and shore, and in most cases a frequency converter to adapt the frequency of electricity from the local grid to match that of each vessel. Further, a cable-management system is needed for either the port or the ship.

Such technology is readily available, and given the emission reductions implicit in onshore power as well as the technology's imminent standardization, the solution is gaining attention. It is increasingly appearing in regulations and discussions in the European Union, the United States and within the United Nations' organization for maritime policy, the IMO. EU directive 2005/33/EG, which went into effect January 1, 2010, exempted ships using shore-based electricity from a rule requiring use of reduced sulfur-containing marine fuels while in port. In the United States, legislation proceeds state by state; California, a regulatory forerunner, has begun to require shoreside electricity connection for some ship types. At the IMO level, new restrictions on the allowable sulfur content in fuels improves the economical case for onshore power, without explicitly mandating or supporting it.

Footnote

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

1 Overview of a shore-to-ship power connection



Onshore power supply is a well-established technology → 2, which is already available at several ports, including those in the United States, Belgium, China, Canada, Germany, Sweden, Finland and the Netherlands. With a new set of global shoreside electricity standards on the verge of ratification, the practice is expected to rapidly expand for all major types of ships and ports worldwide.

Regulations point to onshore power

As regulators realize that pollution stemming from the shipping industry is having a major impact on public health as well as costs, they have increased their attention on this industry. Since at least the late 1980s, the IMO has focused on how to reduce the environmental impact of shipping (oil spill prevention has a much longer history). National, city and port authorities are also initiating regulation of emissions generated by ships.

Currently, there is no law or rule requiring ships at port to connect to an onshore power supply, but standardization may well lead to increased adoption of onshore power technologies.

Regulations in Europe

In Northern Europe, mapping of global emissions began on a large scale in the 1970s. As a result of these studies, initial efforts to reduce emissions-based public health threats such as acid rain focused on land-based emissions sources. In the 1980s, the focus thus became power plants and automobile and truck traffic. However, as the studies showed higher levels of deposition of pollutants in coastal areas and along major sea lanes like the English Channel than could be accounted for by known polluters, it became clear that ships in international transit were responsible for a considerable amount of pollution. Sweden and Norway brought these studies to the attention of the IMO in 1988. Almost 10 years later, the IMO's convention (MARPOL Annex VI), which limits the amount of pollutants in marine fuels, won acceptance. This convention went into effect in 2005.

The EU has taken steps toward reducing emissions from ships in tandem with the IMO. When the EU was developing a strategy to deal with shipping-related pollution in 2001 and 2002, the potential for onshore power supply was already being discussed. This resulted in a directive requiring all ships berthed in EU ports to use marine fuels with a maximum sulfur content of 0.1 percent, with few exceptions – one was an exemption for ships using power from shore.

The EU has opted to pursue a policy that does not favor any particular kind of abatement technology, but rather reaches for overarching goals. In the case of shipping emissions, EU legislation has prioritized cutting emissions that immediately impact health in areas close to ports or major shipping lanes, but has taken a regional perspective. The lasting and widespread effects of acidification and particulate pollution also drove legislation. (Emission of CO_2 has not been in focus with respect to shipping, as CO_2 emissions have only a slight impact on local health compared with particulate emissions.) The issue has been addressed by the EU and the IMO, particularly with respect to a carbon emissions trading system, but there are no definitive outcomes as of yet.

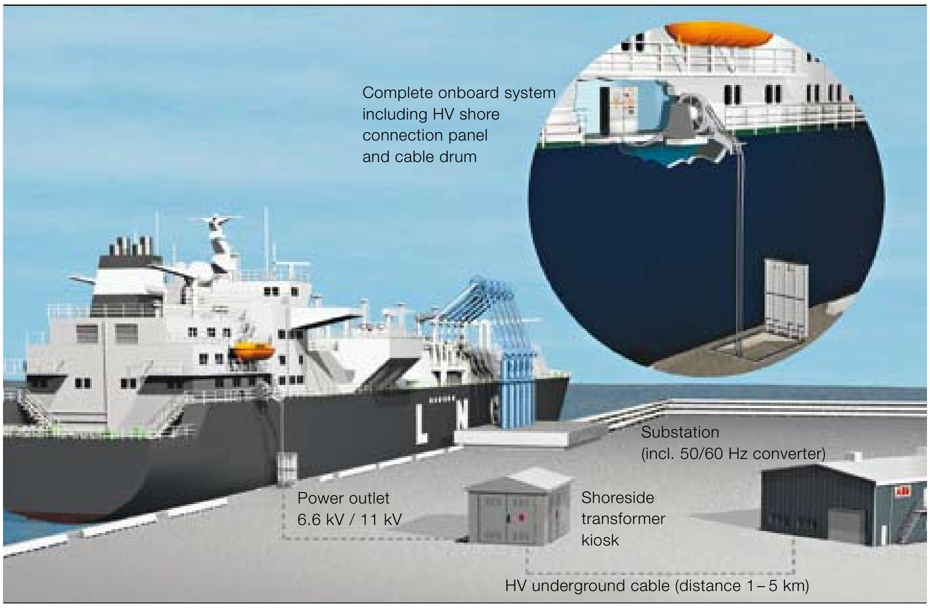
> The environmental profile of electricity generated by power plants on land versus ships' diesel engines running on bunker fuels is one of the main advantages of shore-based power.

Regulations in the United States

Compared with the EU, the Environmental Protection Agency (EPA) of the state of California has gone much farther toward stipulating shore-based power supply to docked ships, although it provides for alternative technologies. The EPA requires container ships, passenger ships and refrigerated cargo ships to either turn off their auxiliary engines for most of their stay in a Californian port and connect to another power source (eg, grid-based), or use other control techniques that achieve the same emissions reduction.

Initially, this regulation only applied to a few vessel types, and within fleets that call at Californian ports 25 or more times per year. Effective January 1, 2010, any ship that could connect to shore-based power and was part of an affected fleet would have to use shore power if it was available at the port and was compatible with the ship's equipment. The requirement for 2014 does away with the loopholes for ships not ready for shore power and sets a 50 percent fleet-wide maximum limit to power generated by auxiliary engines while docked. In 2017, 70 percent of a fleet's port visits must be shore-power visits and engine power generated by the ships must be reduced by 70 percent; in 2020, these numbers increase to 80 percent.

The regulatory developments in the IMO, the EU and the state of California are being followed closely by other jurisdictions, such as other American states and countries in Asia. Generally, it is expected that regulatory authorities will set increasingly strict rules for emissions from ships in port, increase taxes on sources of pollution and make exemptions for onshore power connections, opening the door to companies such as ABB that can supply the complete shore-to-ship power solution.



Evaluating the benefits

For port authorities and shipowners, the merits of shore-to-ship power supply versus the competing emissions-abatement technologies are debatable. The operational profile of the ship also has a big impact – eg, a ferry calling in a port every day is quite different from a container vessel calling in a port once a month. Thus, it is difficult for investors to calculate long-term return on investment as the regulatory picture changes. Fluctuations in the price of marine bunker fuels [2] compared with shore-based electricity also influence calculations.

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 shore-based power. Generally, when power production can be reduced to as few producers as possible, these producers can be more easily and efficiently optimized to reduce environmental impact.

Another argument for shore-to-ship power is the advantage of jurisdiction. With onshore power arrangements, regulators can deal with the specific, local problem of pollution with a specific, local response. Efforts to capture emissions from auxiliary diesel engines can be used throughout a ship's operations worldwide, but it takes away any scope of action by local or regional authorities.

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. The use of state-of-the-art frequency converters can provide both a stabilizing effect on the local grid and an improved power factor. Effectively, this means the local power system experiences lower losses.

Onshore power supply has an additional advantage over other emissions abatement technologies in that it reduces both noise and vibration in port areas. This is a benefit to merchant mariners, passengers and crews, port workers and the surrounding community of ports, particularly large ones. Some ports have encountered growth constraints related to their environmental permits, as their operations' emissions, noise or vibration levels have become too high.

Finally, shore-to-ship power is easily scalable; infrastructure investments are sustainable over decades with long-term revenues and relatively little maintenance. For each new port that invests in shore connections, the cumulative value of the technology increases by a factor, as more and more ships and sailing schedules are impacted.

Arguments against shore-to-ship power are related to the provenance of the shore-based power, the costs of investing in infrastructure, safety and efficiency concerns in port operations, and the need to use technologies that also influence emissions when a ship is at sail. Studies have shown that switching from ship-based diesel power generation to onshore coal-powered electricity has a limited environmental benefit (with increases in particulate matter and, potentially, sulfur oxides), while other forms of power have a more considerable benefit; renewable energy sources, in particular, improve port operators' environmental footprint.

The costs of investing in shore-based power infrastructure are considerable, and a template for how governments, port or terminal operators and shipowners share these costs has not yet been established. At the port of Gothenburg, for example, a ship charterer that was determined to improve the environmental profile of its supply chain invested in the infrastructure. At the Port of Long Beach and Port of Los Angeles, which are owned by the local government, port infrastructure is financed by taxpayer dollars. However, as the cost of emissions and the regulations that prevent them increase, more and more funds will be made available from both private and public sources.

> Onshore power supply has an additional advantage over other emissions abatement technologies in that it reduces both noise and vibration in port areas.

Safety and efficiency concerns in port operations are also very important. Container terminals, with large rolling gantry cranes, present challenges in terms of cable placement and shoreside infrastructure. In ports, space is at a premium. Additionally, both port authorities and shipowners are concerned with the possibility of injuries or deaths related to power connection. The intro-

Footnote

2 Marine bunker fuel is any fuel used onboard a ship.

3 ABB shore-to-ship power connections have already been installed on a variety of vessels, including oil tankers, container ships and cruise ships.

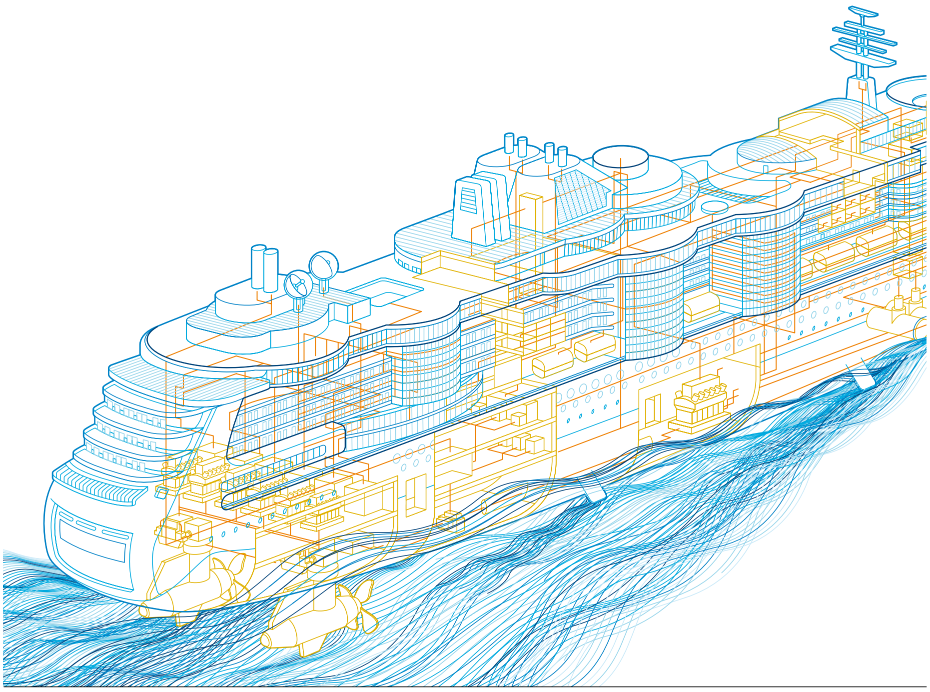


ABB has developed scalable and flexible installation solutions that meet the needs of shipowners and ports.

duction of strict shore connection standards and technical solutions that allow smooth dockside operations and safe cable handling should allay these concerns.

A shore solution

Shore-to-ship power connections have been implemented in approximately two dozen port terminals worldwide starting in 2000, and on over 100 ships ranging from cruise vessels to oil tankers and container ships → 3. Countless other port operators and shipowners are assessing an investment in the technology, on the condition that global standards for shore connection are realized.

Acceptance of and investment in shore-based power supply infrastructure has been limited due to the lack of a global standard. A public specification is already available, and this is being used by shipowners and port authorities to assess future installations. Existing technology solutions are largely built up around these specifications.

Regulatory moves by local, national and international bodies that spur adoption of shore-to-ship power supply include taxes on fossil fuels, requirements to marine fuels and stipulation of onshore power supply (or alternatives with equivalent emissions reductions).

Shore-to-ship power supply is in most instances a practical and effective means to reduce emissions in heavily used port areas. The technology is available, but its adoption is contingent upon its being available at a large number of ports, and in a large number of ships. ABB has developed scalable and flexible installation solutions that meet the needs of shipowners and ports. As part of ABB's shore-to-ship power solution, the company has engineered both shoreside and shipside connections, and is one of the few companies worldwide that has developed a reference list in this technology. Single or multiple shoreside connection points can be engineered and installed in the span of six months to one year; onboard installations can be engineered over a period of a few months and installed in the span of one week.

It is believed that a global standard will bring about a much higher level of investment in the infrastructure, thus stimulating an ever greater number of shipowners and port authorities to prepare their operations for shore-to-ship power. Already there are a growing number of portside expansion projects worldwide, and with its highly sustainable and efficient shore-to-ship power solution, ABB is fully equipped to provide the required technologies. To ensure its portside offerings are meeting the market needs, ABB continues to collaborate with customers worldwide.

A more detailed discussion of the technologies involved in ABB's shore-to-ship power will appear in the next issue of *ABB Review*.

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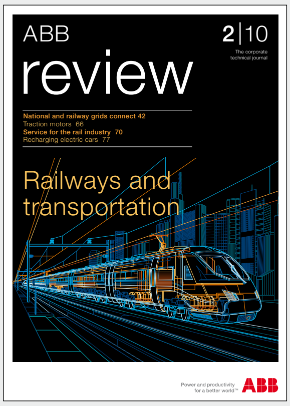

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Technology and innovation

Innovation is a major driver of technology. It brings about new solutions to both old and new challenges and provides technologies that break new ground in terms of efficiency, productivity or functionality. ABB has a strong committment to innovation.

For some time now, the last edition of *ABB Review* of every year has been dedicated to innovation, and has typically presented a selection of the company's most significant research and development breakthroughs as well as important product launches. This feature is now being moved to the first edition of the year. The changeover will make it possible to include innovations that occur late in the year, permitting the portrayal of the achievements of a complete calendar year.

Among the innovations to be presented are a new highly-efficient motor, advances in control systems and a customizable lighting concept for the home.