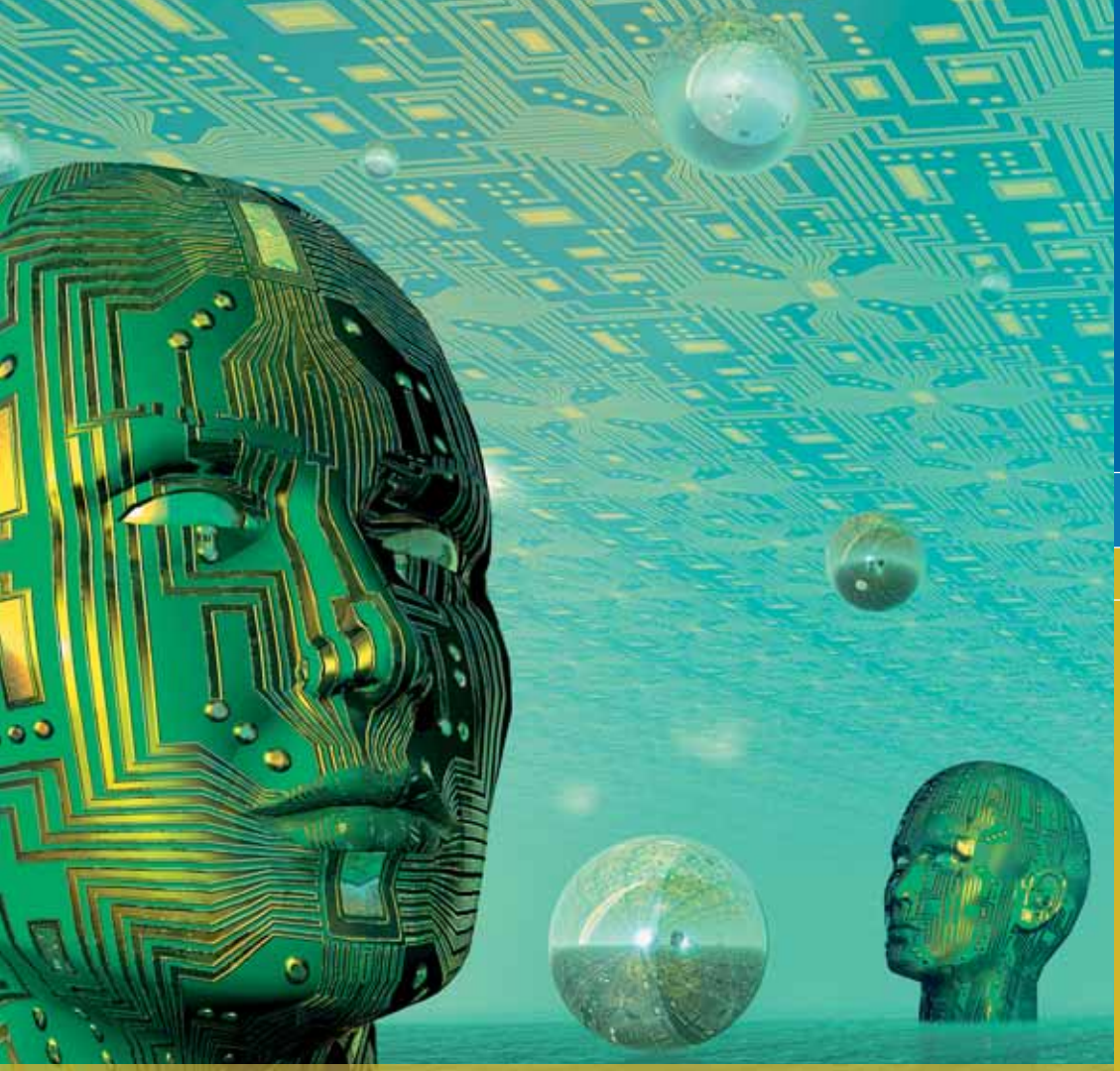

ABB Review

The corporate technical journal of the ABB Group

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3 / 2007

Pioneering collaboration

The optimal way to cooperate
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Combining forces to provide stability
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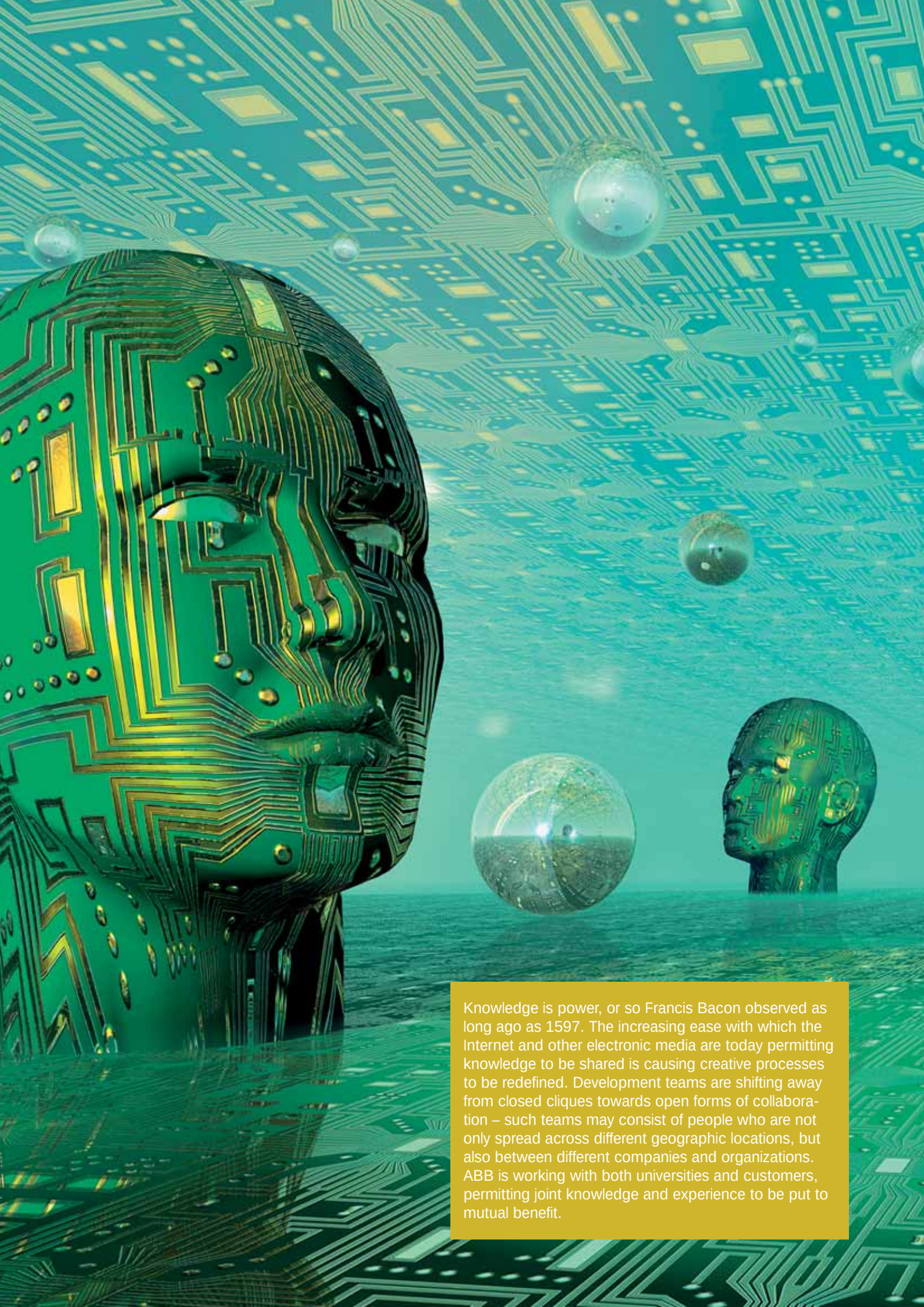

Knowledge is power, or so Francis Bacon observed as long ago as 1597. The increasing ease with which the Internet and other electronic media are today permitting knowledge to be shared is causing creative processes to be redefined. Development teams are shifting away from closed cliques towards open forms of collaboration – such teams may consist of people who are not only spread across different geographic locations, but also between different companies and organizations. ABB is working with both universities and customers, permitting joint knowledge and experience to be put to mutual benefit.

Peter Terwiesch: “Staying ahead requires the consolidation of knowing and pushing what will be possible with understanding what will be needed”.

Frank Duggan: “ABB is the undisputed market leader in most of our core businesses. An even greater focus on understanding our customer needs is the recipe for the further success of our products”.

Collaborating for results

This issue of *ABB Review* is dedicated to a very important business principle: collaboration. As defined in the dictionary, the term means “to work jointly with others”; in ABB, we additionally associate it with learning, sharing … and succeeding.

Many of ABB’s greatest innovations have been achieved in close cooperation with customers. From the very first steps towards a new product, such a collaboration permits the partners to share their wishes and ideas. In later stages it allows customers to “test-drive” the proposed solutions, permitting these to be perfected well ahead of their market introduction. Allowing developers to see products from the customer’s perspective has helped better attune development processes to real needs. It has furthermore extended the company’s eyes and ears to what the customers of its customers are seeking. The results of such projects have often found their way into ABB’s broader product palette and so benefited further customers.

Just as ABB is joining forces with its customers, the company is similarly entering partnerships with its suppliers. Cooperative agreements work from the presumption that successful businesses focus on their core technology strengths and permit others to fill in the gaps, thereby complementing the overall offering in terms of products and services. We are grateful to our partners for making this possible through the trust they place in us.

In the field of research too, ABB has built a number of significant partnerships. The company works together with more than 70 leading academic institutions, among them the Massachusetts Institute of Technology, Carnegie Mellon University, Imperial College London and China’s Tsinghua University. Such cooperation not only expands the scope and ability of ABB’s own research teams, but also unites some of the world’s leading minds in important research projects.

While cooperation has often helped ABB showcase new designs and concepts, it has also helped identify areas that can be developed further in future joint projects. Cooperation alone, however, is no guarantee for a breakthrough. In our experience, the recipe to success can be broken down into three main principles: seeking, pioneering and sharing.

The first of these principles, seeking, is about asking the right questions. If participants take the time to learn about the business of the partner and understand its challenges and constraints, they are better equipped to identify solutions that overcome these limitations. Cooperation and collaboration are essentially two-way processes, in which both sides must equally be prepared to ask and to answer. They must develop a feeling for the “pulse” of the situation at hand. This requires not just talking to one’s direct counterparts in the other organization, but seeking to learn from a broad range of stakeholders.

The second principle, pioneering, requires being prepared to think – and act – beyond the constraints of conventional practices. This is true not only for the collaboration partners individually, but also in terms of redefining their customer-supplier relationship.

The final principle, sharing, is about making results and insights available to the other participants. It encompasses the ability to not only learn from mistakes, but also to appreciate the real causes of breakthroughs rather than simply taking the credit for and moving on after incidental successes. This strengthens the partners’ joint position for the future, assuring that lessons learnt in one project must not be re-learnt for the next.

In this issue of *ABB Review*, we show how these principles have stood the test of practice. ABB employs some 6000 scientists and engineers across its organization in a wide range of different subjects and applications. Our collaboration partners may well jointly employ many times this number. We are grateful for the spirit of innovation that empowers all of them – and that makes possible the successes that enrichen the pages of this issue of *ABB Review*.

Enjoy your reading!

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

Frank Duggan
Head of Group Account Management, ABB Ltd.

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The optimal way to cooperate

Scientific analysis underlines the successful concept

Ellen Enkel

Customer input is critical to a company's success. By involving its customers in the innovation process, a company can improve its innovation capabilities and reduce the market risk inherent in discontinuous innovations. The earlier a customer's knowledge and experience can be incorporated into the process, the more the company can focus its R&D activities to satisfy customer demands. This integration helps identify information on customer needs, disseminates the information throughout the critical functional areas within a company and translates it into auspicious new products and services.

Empirical studies show that integrating customers into the innovation process is an applied method seeing increasing use that seeks to reduce the risk of failure in investment.

At the top of each management agenda, discontinuous innovations pose a specific risk because they involve more uncertainty than incremental innovations Factbox. The nature of the product itself, the organization's capacity to effectively and efficiently produce the product, its market acceptance and, ultimately, profitability are all at stake. At the same time, traditional product-development best practices associated with incremental innovation also present a challenge, as both the product attributes and the breakthrough innovation's future environments are not yet known. The results of traditional approaches in forecasting customer needs and market potential, whether they are quantitative techniques or qualitative methods, are limited to mere insights with respect to product improvements. Early customer integration, including the integration of other customers with similar needs as well as potential future customers, helps shed light on the previously unknown demands of the target market and on customers' future needs and can therefore lead to disruptive innovation Factbox.

Companies have, in fact, often tried to leverage the advantages of customer integration into their new product development process. Customers can be incorporated in different ways into the R&D environment with their contribution varying according to the phase of involvement. 1 provides a summary of how customer integration can differ at each stage of the innovation process, and which customers are best suited to achieve the expected input 3.

Early customer integration helps shed light on the previously unknown demands of the target market.

Requesting customers provide ideas for new products that follow from their needs. A requesting customer's contribution depends on the company's capability to capture customer knowledge, which is often expressed in the form of complaints and suggestions. As complaints are mostly anchored to current product uses and characteristics, they are a rather limited source of new product information. Conversely the *launching customer* is integrated right from the development phase to simulate or design, or to participate in development activities. The reference customer, on the other hand, supplies application experience. The highly productive role that *reference customers* can play in product and prototype testing has been revealed in numerous empirical studies. The *first buyer*, however, plays a more passive role in development. As described in models for the diffusion of innovation, a precursor that strongly influences market penetration may support market success. Customers who can cover all stages of the R&D process clearly are the preferred choice for cooperation – they are the *lead users*.

Several empirical studies have emphasized that the novelty of innovation, the expected turnover, market share and strategic importance for innovation projects based on lead-user methods are significantly higher than for projects based on traditional approaches. The lead-user method's multi-stage approach not only seeks to generate new, innovative product concepts, but also to improve and enhance the effectiveness of cross-functional product development teams.

Customer knowledge can help significantly to generate ideas, identify opportunities and define concepts for future products, processes or services.

Lead users differ greatly from ordinary users. They face new needs significantly earlier than the majority of customers in the market and they benefit from innovations that meet those needs. Lead users can contribute to different sub-phases in the early innovation process, sometimes called the "fuzzy front end." As 2 illustrates, customer knowledge can help significant-

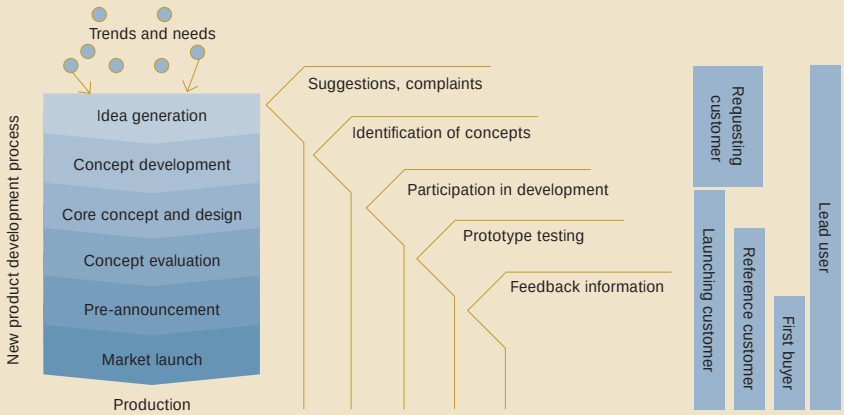
Factbox Innovation glossary

Discontinuous or disruptive innovation: a technological product or system that overtakes the current dominant technology or status quo product and creates a new market.

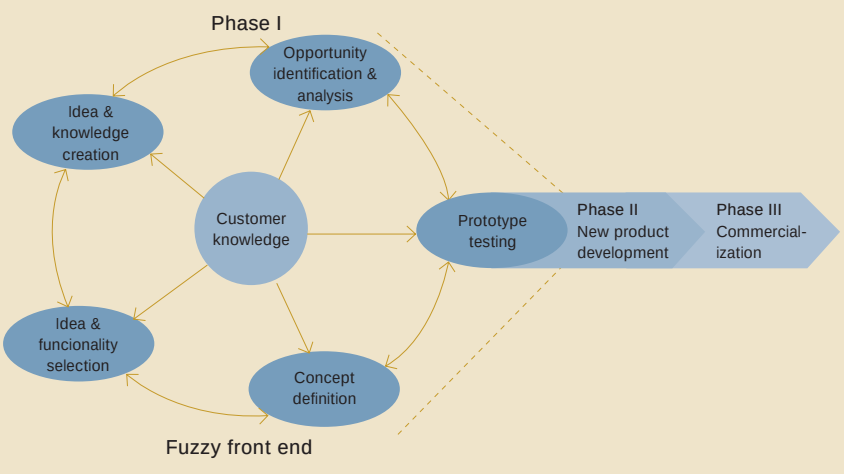
Incremental innovation: a small improvement upon an existing technology that satisfies short-term goals and sustains a company's growth.

Open innovation: the buying or licensing of processes or technologies from other companies; methods and procedures for the field of open innovation have been developed in the last five years [5].

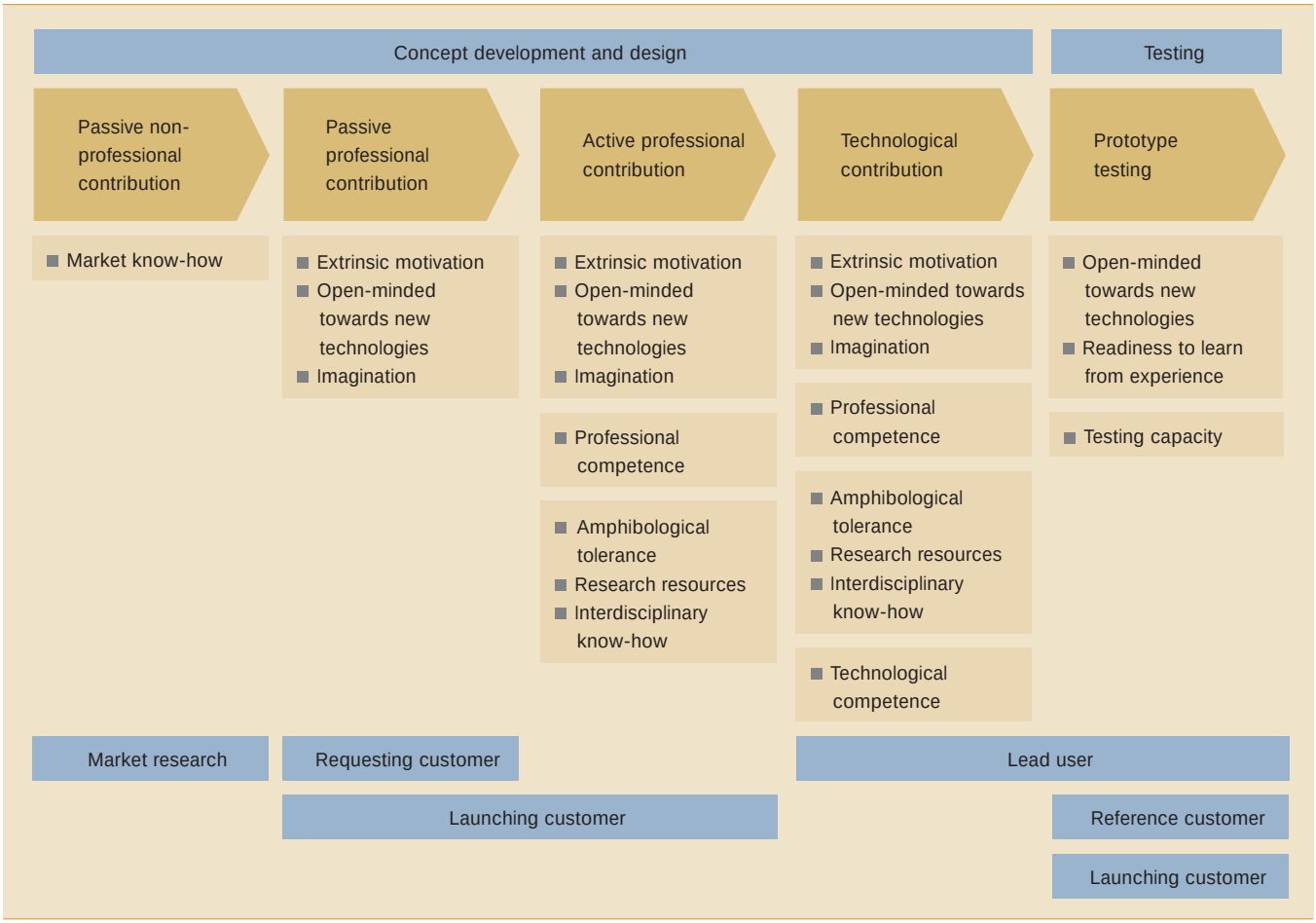
1 Customer types and their contribution to the process of new product development [1]



2 The "fuzzy front end" with regard to integrating customer knowledge



3 Required customer profiles for participation in the new product development process [1]

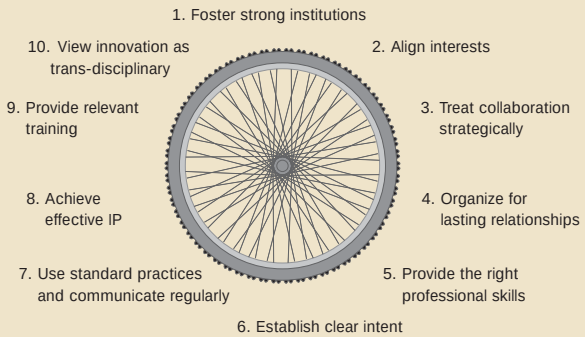


ly to generate ideas, identify opportunities and define concepts for future products, processes or services.

Integrating external knowledge not only from customers, but also universities and public research institutes, into the innovation process has created the promising new field of *open innovation* Factbox [5]. The practical aspects and guidelines developed under the framework of open innovation also can be applied to the customer relations 4 [2].

Collaboration with partners, when not properly managed, can also be risky. It can lead to a loss of proprietary competence, dependence on customer views, a limitation to mere incremental innovation or it may serve only niche markets [3, 4]. However, by following the above and other advice from best practice, the inherent risks of customer collaboration can become insignificant and the opportunities great.

4 Ten guidelines to maximize the success of cooperation in R&D



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Staying power on two legs

Industrial research as the link between market and technology

Friedrich Pinnekamp

Today, there are more scientists at work around the world than ever before. These scientists are better informed and more up-to-date, with new ideas and innovations being generated at an exponential rate. Fostering collaborative partnerships in scientific research has emerged as a critical imperative to sustain this innovation process and to transfer great ideas into great inventions for the good of society. That is why industrial research organizations should not only stand with one foot on the customers' premises but equally as important, the other must stand on the university campus.

The ultimate goal of university and industry co-operation is to advance the frontiers of knowledge and incorporate that knowledge into new products, processes, and services. With many of the challenges facing modern society, more scientific and technologically driven innovations are needed to provide the tools required to help ensure a better future for all [1].

Reaping the benefits of knowledge and turning them into jobs and prosperity, however, is not just a question of research and research policy. It is about the conditions for creating enterprises and how to promote contact between researchers and entrepreneurs.

In the long run, only more scientific and technologically driven innovations will enable enterprises to compete successfully on international markets. Therefore companies should strive to integrate university research collaborations into their product and service development process.

During the last decade, this principle has become more attractive for researchers in industry and ABB is proud to be among the forerunners. Indeed ABB's co-operation with universities all over the world has a long tradition. The company has working contacts with more than 50 universities in the US, Europe and Asia, many of which are internationally renowned as the best in their fields of research. A brief summary of six of these universities is given in the Factbox.

ABB has working contacts with more than 50 universities in the US, Europe and Asia, many of which are internationally renowned as the best in their fields of research.

By actively promoting the path to "open innovation" ABB is not only adding cut-

Factbox Some of the universities with which ABB has working contracts

Carnegie Mellon University, Pittsburgh
Carnegie Mellon is world renowned for its programs in computer science. Together with IBM, it pioneered the famous "Andrew File System". Michael "Fuzzy" Mauldin developed the revolutionary search engine "Lycos". In addition, Carnegie Mellon faculty and Sony are working with the company's AIBO robots and other initiatives to bring robots to life in the human environment as companions, helpers, and assistants. The College of Engineering, in particular the Department of Electrical and Computer Engineering, is consistently ranked among the best in the world.

RWTH Aachen University
RWTH Aachen in Germany is perceived as a leading university in energy research, power system and engineering processing, materials science research and production technology, to mention a few areas only. Because of these competencies, RWTH is working together with industry to develop, for example, physical models and simulation tools, and long-term studies related to the future power system structure in Germany.

Chalmers University of Technology
Chalmers has a broad expertise in many fields, among them the areas of combustion and catalysis, vehicle electronics and automotive safety, and design and dynamics. The Alliance for Global Sustainability (AGS) is a unique, international partnership between industry and four of the world's leading science and technology universities. The research teams have acquired new information about critical sustainability issues in the areas of energy and climate, mobility, urban systems, water and agriculture, cleaner technologies and communications.

ETH, Zürich
Ongoing material research is conducted together with major Swiss and international companies from the following industries: pharmaceuticals; engineering; computer-hardware; energy; materials; specialty chemicals; food; biomedical implants; and diagnostics sectors. Research in energy related questions as well as on automation technologies is also part of the spectrum.

Imperial College (IC), London
IC is noted for its expertise in information processing and management; systems research; aeronautics; structures and materials. Scientists working in energy research collaborate with many companies, for example, with Shell in exploration, production and processing with the aspect of sustainability in focus.

Tsinghua University, Beijing
Tsinghua plays an important role in the Chinese ambition of technology innovation. Over the past number of years, the university has been working hard to engage itself in international R&D collaborations with leading companies and leverage its limited resources to conduct leading-edge R&D, for example in in the areas of generation, transmission and distribution. Tsinghua is working together with ABB on interconnectivity issues related to China's regional networks.

ting edge technology to its products, but it is also attracting the best talents from the universities to its own R&D organization. At the same time this helps the universities find research areas that are beneficial for society. Such intense co-operation between industry and academia can only speed up the innovation process and contribute to growth in all parts of the world.

Partner universities in the US, Europe and Asia work closely with ABB's research centers around the world to develop, for example, new manufacturing processes, and to carry out power systems and advanced materials research. These collaborations also cover wireless networking, control systems, man-machine interfaces and much more.

For ABB the development of relationships with leading universities is a key element in its global R&D strategy. This mutual exchange of ideas and information gives ABB access to the latest developments in emerging technologies, helping it to develop competitive solutions for the benefit of its customers and society at large.

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No step without the customer

How customers are instrumental in product development

Peter Lindgren, Jari Suntila, Ilpo Ruohonen

The development of new products is a well structured process within ABB. For a variable speed drive, for example, it can take up to two and a half years from the definition of the initial concept to market introduction.

During that time the ongoing issue for the developers is to find out what customers actually expect from the new drive.

This investigation is an art in itself because customers favor their own application-specific details and would like the perfect drive designed specifically to meet their own precise needs.

Product development as well as technology development and research at ABB follow a structured process based on a sequence of well defined gates. Progression to the next gate is prohibited until all tasks relating to the previous gate have been completed.

There are eight gates or project phases 1 that are referred to as "go/no go" decision points:

- Gate 0: Project kick off
- Gate 1: Project planning finalized
- Gate 2: Project execution starts
- Gate 3: Confirm execution
- Gate 4: Start product introduction
- Gate 5: Product market launch
- Gate 6: Close project
- Gate 7: Retrospective investigation of project

A business based decision point determines whether or not to continue or terminate a project based on benefits, status, resources, technology and risks. Customer involvement is required at each step and is instrumental in ensuring a successful product launch. In some steps they are especially integrated to answer crucial gate questions. For example:

- *Gate 1:* Is it clear which kind of product we want to create from the customer and competition perspective and is the project scope clear?
- *Gate 4:* Do we want to start the product introduction activities at full scale? What feedback has been received from Alpha-pilot customers[1)] and selected applications?
- *Gate 5:* Is the product ready for general release? What feedback has been received from Beta-pilot sites[2)]?

Do customers "need" what they "want"?

ABB attempts to acquire feedback at various stages of the Gate Model from a broad selection of customer types including end-users, OEMs, system integrators and channel partners. However, overall development is directly influenced by feedback between Gates 0 and 1. It is here where it is essential to clearly distinguish between the "needs" and the "wants" of a customer. It may be that the designers can then satisfy these needs in a novel way.

Finding out what customers actually expect from a new drive is an art in itself because they would like the perfect drive designed specifically to meet their own precise needs.

For example, one customer demand was for a small size ABB industrial drive unit. Recent technology developments have seen the inverter modules dramatically decrease in size thereby reducing the average length of the MultiDrive to half its previous size. However, to further economize on space, engineers designed these small modules so that they could be tilted inside the drive cabinet.

In another development, current-carrying copper cables could not be made any smaller and so ABB designers created an innovative pedestal construction that now allows the power unit to slide out of the drive so the cabling can be reached.

Developing a high performance drive

Recently, ABB launched a new generation of high performance machinery drives, referred to as ACSM1 and aimed at demanding motion control applications 2.

The concept should open up a new era in drive technology with its ability to control several different motor types. Rather than being just a drive for special servo motors, it can control standard induction motors, synchronous and asynchronous servo and high torque motors with various feedback devices.

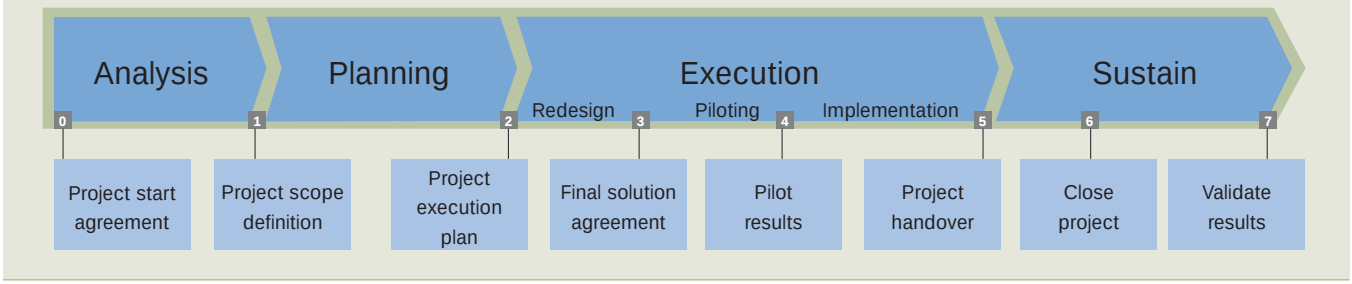
But aiming for such a powerful platform also runs the risk of offering the customer too many features. After all, if a drive with servo-like performance could control all motor types, then almost all applications could be served, a risk in itself as the focus of the development could easily get lost. In any case, no customer wants to pay for features they will never use.

To avoid this trap in product development ABB uses two different approaches: selecting lead customers and consulting reference groups.

Factbox 1 UniLift Control Technologies Ltd

UniLift Control Technologies Ltd is part of the Pickerings Lifts Group, an independently owned organisation specialising in lift design, manufacture, installation and service in the UK and Europe. The group employs over 500 people, including 150 at its UK manufacturing site.

1 The ABB Gate model for product and technology development



Working with lead customers

One application of ABB's high performance drive system is elevators. To ensure the right features were further developed, ABB solicited the help of one of the world's leading elevator manufacturers, Italy's UniLift Control Technologies Ltd Factbox 1 in Milan, and its system integrator, Starlift.

Beginning at Gate 1, ABB needed to know precisely what features UniLift was seeking; what their priorities were, and what was and wasn't available on the market. Equally as important for ABB was a true understanding of elevator technology which encompassed lift manufacturing and the industry's own culture and processes.

ABB's new generation of high performance machinery drives, ACSM1, is aimed at demanding motion control applications.

It is important to have a clear picture about the entire system and how it relates to the elevator application before tackling the drive and shaft level details. At a system level, for example, there are many possible combinations of solutions and each can influence the performance of the elevator system.

What became apparent early on in the discussions was that many basic features of the ABB high performance drive were already suitable for elevators. These included:

- The ability to control synchronous motors, which are gaining in popularity within elevators
- Two control variants, speed and torque or motion control for different control philosophies
- Wide range of feedback interfaces giving freedom to select the best speed or position control setup
- Different communication options
- Integrated braking chopper

Additional features needed were also identified:

- *Battery supply support* – needed to allow the elevator cabin to move to the next level after a loss of mains power
- *Safe torque off functions* – is a cost efficient way of stopping the elevator cabin according to industry standard EN 81-1.

Along with an enhanced customer relationship, the venture between ABB and UniLift has created fertile ground for future visionary ideas and open-minded innovations. These include four to six different set points for speed, a specific s-curve (jerk) control for some speed settings, and the handling of gear and roping ratios with the possibility of a direct set-up of cabin movement parameters.

The value of reference groups

Apart from external customers, ABB also runs reference groups made up of a cross section of internal representatives who are at the heart of daily customer activity in various industries. These reference groups therefore bring a good mix of direct customer feedback to the product development process.

Such a group, made up of ABB personnel from eight countries was used during the development of the liquid cooled ABB industrial drive. Each team member represented an industry in which liquid cooled drives could be applied. The industries represented included marine, wind power, offshore production platforms, and pulp and paper.

The use of reference groups and lead customers throughout the development process helps to both increase the focus and broaden the base of applications

Among the findings from the group was the need for a much smaller drive footprint. This demand is driven by several industries where space is a premium. Offshore applications, on board ships, cranes and the nacelle of wind turbines would certainly benefit from smaller devices.

Alongside this requirement is the need for a smaller, yet high powered brak-

2 The new ABB ACSM1 drive unit

Footnotes

1) Alpha-pilots are functional prototypes based on fast prototype tooling.

2) Beta-pilots are functional prototypes based on final mechanical tooling and are manufactured on an actual production line.

3) A braking chopper is used for dissipating braking power away from the direct-current rails of an AC drive system.

ing chopper[3]. The braking chopper of previous drive generations was too large to fit into the required smaller footprint. At the same time the market was waiting for one with a power range that extended up to 5,600 kW.

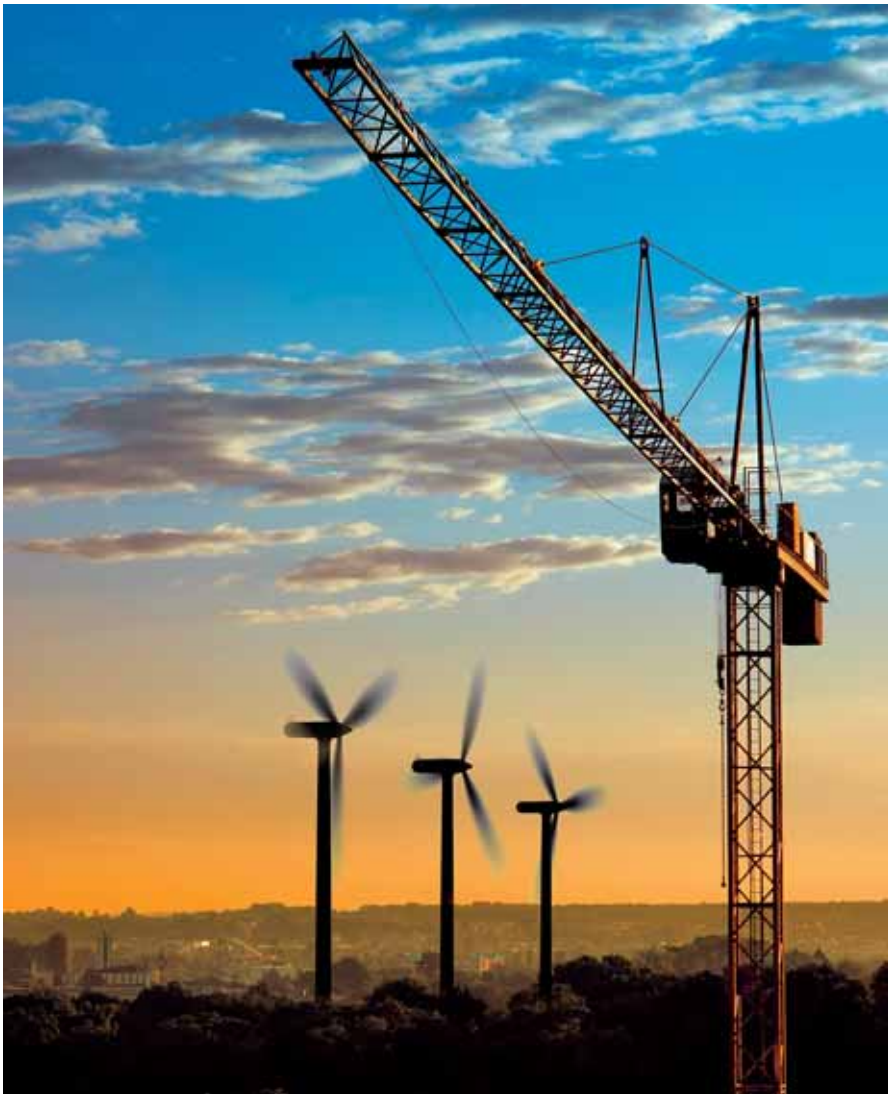
Recent technology developments have seen the inverter modules dramatically decrease in size thereby reducing the average length of the MultiDrive to half its previous size.

Customers play their part

Basic performance and promised features of new products have to be extensively tested: a win-win opportunity for the customer and ABB.

For the ABB high performance machinery drive, UniLift benefited by being able to influence product specification and by getting direct and real experience with lift features.

For the larger liquid cooled ABB industrial drive, the German vertical drilling machine manufacturer, Herrenknecht Vertical GmbH Factbox 2, agreed to act as a pilot customer. They reckoned the potential of the liquid cooled drive to meet the unusual needs of the company's "Terra Invader 350" vertical drilling machine (designed for geothermal drilling to depths of 6,000 meters) was good. What particularly interested the company was the small drive size combined with its high power output, and Herrenknecht Vertical GmbH needed a drive system with one MW power in a container of less than one cubic meter.



Factbox 2 Herrenknecht Vertical

Founded in 2005, Herrenknecht Vertical is an ISO 9001 certified company of the Herrenknecht group, specializing in the manufacture of deep drilling rigs. The custom-manufactured rigs, which are silent, safe and particularly efficient, allow for the development of geothermal energy sources and oil, gas or water at a depth of 3,500 to 6,000 meters. The competence team of Herrenknecht Vertical is supported by partners from industry and science, independent consultants and the Herrenknecht group, which is the leading solution provider in the field of mechanized tunneling systems and services.

www.herrenknecht-vertical.de (June 2007)

The fringe benefits of collaboration

By using reference groups and lead customers throughout the whole development process it is possible to both increase the focus and broaden the base of applications.

Customer involvement not only provides valuable insight on the subject but also helps to bring more discipline into the internal process. Engineers and researchers are always confronted with the customer needs and with that they have a tighter grip on the development.

The fact that ABB is the world's leading supplier of drives reflects its close links to customers already in the R&D phase.

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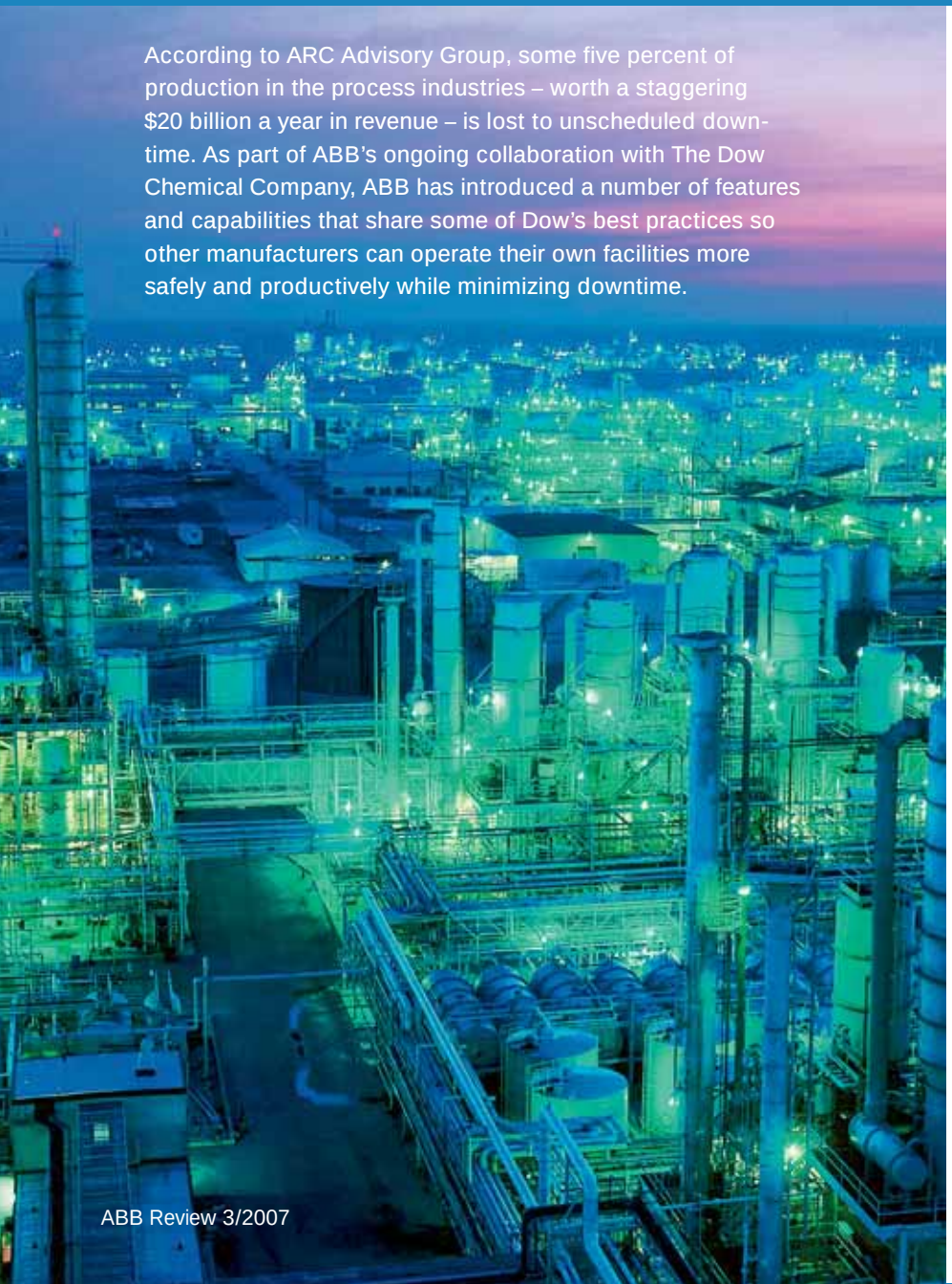
Collaborating for success

Innovative Dow/ABB relationship provides mutual benefits for manufacturers in all industries

Laura M. Patrick

According to ARC Advisory Group, some five percent of production in the process industries – worth a staggering $20 billion a year in revenue – is lost to unscheduled downtime. As part of ABB's ongoing collaboration with The Dow Chemical Company, ABB has introduced a number of features and capabilities that share some of Dow's best practices so other manufacturers can operate their own facilities more safely and productively while minimizing downtime.



The Dow Chemical Company Factbox is a leader in science and technology, providing innovative chemical, plastic and agricultural products and services to many essential consumer markets. Consistency and sustainability have always been key elements of the Dow's operating discipline. As a global company, it is important to be able to operate diverse facilities the same way, every time, to achieve high quality, as well as process reliability and repeatability of best practices [1]. In the 1960s, a number of technology development activities throughout Dow converged to ultimately become a standardized, redeployable process control strategy that supported their goals of overall consistency, productivity improvements, global operating discipline and innovation, all while maintaining high safety performance. In fact it can be said that Dow was striving for true "operational excellence" many years before the term was coined by industry analysts. "Operational excellence includes safety performance, which was and is a key focus for Dow. We're passionate about it. Protecting people, the community and the environment are non-negotiable priorities in our corporate culture. We must operate our plants safely, and in the same way, every time." [1]

At that time, however, a commercially available solution to help Dow realize its operating discipline did not exist. The Dow team then developed several

proprietary solutions, including a process control system that came to be known as MOD (Manufacturing Operating Discipline).

Seeking a new development approach

Over the years, the MOD System series delivered tremendous productivity benefits to the company. However, in early 2000, Dow realized it was no longer cost-effective to continue to invest in proprietary hardware and software systems. Instead, the company needed to focus on its core manufacturing business and therefore decided to seek a commercial solution.

The new commercial system had to satisfy essential requirements that addressed their need for sustainability going forward; these criteria included long-term commercial availability, cutting-edge technology, and forward-looking solutions. Dow needed a process control system that would take the company successfully into the future, be deployable on a global scale, leverage commercial standards as they became available, and be on a platform that could be used as a standard at any plant. Additionally, the system needed to be as sustainable as other plant assets which are expected to run for 40-50 years. A commercial system would also be required to meet Dow's increasing need for knowledge management, while remaining true to its process engineering culture [2].

Of a detailed list of 400 requirements, 32 high-level criteria were identified and affectionately coined "The Crown Jewels." A short list of candidates who could help fulfil these requirements was proposed, and ABB was one of them.

"After numerous presentations and discussions, ABB showed us its Industrial^{IT} technology – the heart of its Extended Automation System 800xA – and at that point we knew that we had found the commercial solution that would take us forward. The alignment with ABB's direction and ours meshed nicely. We had found the commercial technology that could accomplish our goals moving forward and meet our "Crown Jewels" criteria. We could use this platform to leverage our experiences and lessons with the MOD System services and take them forward. But while the technology is a necessary ingredient to make conversations happen, much more was needed to take relationships forward." [2]

"Today our relationship is much more than supplier and customer. It is difficult to determine at times who is customer and who is supplier – perhaps the very definition of collaboration." – Dow Chemical Company.

"In subsequent meetings with ABB, we mutually discovered that we had a shared vision of automation – its vision was completely compatible with our ongoing quest to practice our operating discipline. ABB was very open with us on the topic of system strategy and very willing to capture our safety control philosophy and incorporate it into its commercial offering. It also had the dedicated resources for system and technology development that we could not possibly have as manufacturer, as well as centers of excellence for safety, bench strength in systems engineering capability and the willingness to adapt its development program to accommodate our desired capabilities." [3] Together, ABB and Dow laid the foundation for a true collaborative relationship and provided the innovative environment needed to successfully develop the solution.

Forging a collaborative relationship

Beyond the formal development agreement that was signed in 2001, Dow and ABB forged a true collaborative relationship that nurtured ongoing development activities. The relationship consisted of four key elements:

- Shared vision
- Trust in each other
- Open communication
- Willingness to confront each other and use conflict constructively.

"The relationship has become stronger with the passage of time. When we began, each company had their own and separate view of the world of automation. The Dow MOD 5 with its FORTRAN-like language and ABB with its object-oriented programming – it was the collision of two different automation suppliers' philosophies. This collision began the long process of actually integrating the ABB System 800xA product in a standardized way into the Dow Chemical Company – this required a high degree of trust and collaboration. Trust and collaboration evolved as each company learned more of the capabilities of the other and thus began the process of listening and acknowledging the possibilities of the others ideas. Today our relationship is much more than supplier and customer. It is difficult to determine at times who is customer and who is supplier – perhaps the very definition of collaboration." [4]

The fruit of their labor

The latest version of ABB's Industrial IT Extended Automation System 800xA was launched in November 2006. Version 5.0 of System 800xA is equipped with new engineering functions that let customers make application changes without interrupting production and without incurring downtime – a common and costly occurrence whenever system modifications are made. These new engineering functions include Multi-User and Distributed Engineering as well as tools such as Load-Evaluate-GO. According to ARC, most unscheduled downtime could be readily avoided through improved automation capabilities such as these [5].

Load-Evaluate-GO was developed in collaboration with Dow. It lets customers add programs, modify configurations and implement software upgrades while production is running, and then simulates and evaluates the impact these changes will have on the production process. Once the application changes have been evaluated, the customer can choose to execute, modify or discard them. This capability significantly reduces the risks associated with making application changes in the running process, and improves overall efficiency by avoiding production stops, missed or delayed product deliveries, and costly downtime.

Dow specifically identified this capability as one of the high-level criteria that was essential when they decided to make the shift from their MOD 5 Basic Process Control system to a commercially available one.

Andre Schepens, Control System Architect, Engineering Solutions, Dow Benelux BV, explains the value case for this capability: "LEG (Load, Evaluate and GO) allows for online modifications to a plant control system and doing a last-minute integrity check against the running version of the control application. Because the system warns about any abrupt change that can have an impact on field devices at the moment of activating the new version of the control application, this will detect any hidden problems that surface only at the split second of the transition of the old version to the new version of the control application. Even the best dynamic process simulation cannot provide the exact data of the dynamics of a transition between old and new versions of a control program. Because the 'Evaluate' feature flags this while the output is in a passive status (not controlling the field device), the user has the ability to either back out or make a last-minute correction to resolve the delta prior to activating. The added value is translated into less risk (equipment damage, production loss...) and faster turn-around and payback of application changes."

Load-Evaluate-GO complements other jointly developed elements of System 800xA, including the innovative System 800xA High Integrity combined control and safety option. With embedded safety and control within the same flexible architecture, it offers customers the option of combining control and safety functions within the same controller or keeping control and safety functions separate within the same system. This improves process availability while reducing risk to the overall plant operation by providing a common high integrity system environment for production control, safety supervision, and production monitoring.

As the collaborative development relationship between ABB and Dow continues to move forward, process industries stand to benefit from the commercial availability of even more capabilities. Key elements of Dow's operating discipline have been "productized" and are available to other process manufacturers so they can operate their own facilities more safely and productively. This innovative relationship and collaborative business and development effort provides a win-win scenario not only for Dow and ABB, but also customers in all process industries.

This article contains references to the Dow/ABB article series as published in Control magazine. The entire series of articles can be found at www.controlglobal.com

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Factbox The Dow Chemical Company

The Dow Chemical Company is a diversified chemical company founded in 1897 in Midland, Michigan (USA) to manufacture and sell bleach commercially. The company has annual sales of $49 billion and employs 43,000 people worldwide. It operates under a „Vision of Zero": zero incidents, injuries, illnesses, accidents and zero environmental harm. Dow offers a broad range of products and services to customers in more than 175 countries, helping them to provide everything from fresh water, food and pharmaceuticals to paints, packaging and personal care products [6].

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Thinking ahead

Ensuring stable and more beneficial operation of a cement plant with Expert Optimizer

Konrad S. Stadler, Eduardo Gallestey

What can be done when the quality of the fuel burnt in a cement plant varies, but those tolerances may not be reflected in the final product? This is exactly the challenge faced when the goal is to use waste-based and other alternative fuels in such a process. The answer lies in adopting a predictive control strategy – a strategy that emulates that of a chess player by always thinking several moves ahead.

The cement production industry is a regional business in which the plants are owned by globally operating companies. Regional markets and differing legislation lead to diverse requirements within the production process: The production costs of cement depend strongly on the costs of fuel. The cement industry makes use of alternative or waste fuels to reduce these costs. These fuels range from used tires and carcass meal to the daily waste every single one of us produces. Hence, replacing fossil fuels with waste fuels significantly reduces the production costs. But this replacement also has its disadvantages. The variability of the quality of the waste fuels destabilizes the combustion process. Additionally, legislation regarding emissions is much stricter when the fuel in question is waste rather than coal. This leads to new challenges for the automation system to ensure that the quality of the cement can be sustained and to guarantee the legal operating limits.

ABB joined forces with a lead customer, the Lägerdorf plant of "Holcim Germany", in order to mitigate the negative effects of the AFRs (Alternative Fuels and Raw materials) in their calciner with the help of the most modern control technology available. The results were most satisfactory and stand as a showcase of a technical competence and customer orientation.

The process

The kiln process is schematically represented in 1.

Many different plant setups are common. The newer and more energy efficient of these have a preheater tower 1a with several cyclone stages 1c-f. The preheater extracts heat from the exhaust gas of the combustion downstream of the process. In the precalciner 1m, the decarbonization of the raw meal takes place ($CaCO_3 \rightarrow CaO + CO_2$). The heat used to drive the endothermic reaction is taken from the hot exhaust gases of the rotary kiln 1n and from the fuels burnt in the precalciner. From here, the decarbonized hot meal enters the rotary kiln 1n where the actual sintering of the clinker takes place.

The high variability of the alternative fuels used on the Holcim plant in Lägerdorf causes instabilities within the clinker burning process [1]. In this plant any changes in the degree of decarbonation of the meal entering the kiln will affect the quality of the clinker. Most notably, dips in the degree of decarbonation cannot be compensated by the rotary kiln due to its short length. Decarbonation of the hot meal is largely determined by the temperature in the precalciner. The relation between meal temperature and degree of decarbonation is shown in 2. In the described plant, up to 70 percent of the heat used within the clinker production process is generated by the combustion of fuels within the calciner.

As fuels transported by conveyor belts have a trasport delay of up to many minutes, they are not suitable for use as manipulated variables.

The nonlinear characteristic of the temperature versus degree of decarbonation shows that with increasing temperature, the benefit to the decarbonation is reduced and the process is therefore less energy efficient. In Lägerdorf, the kiln operators essentially try to keep the precalciner temperature high to ensure the required quality and therefore to stabilize the process [1]. At high precalciner temperatures, many additional problems occur. The high temperatures accelerate the wear of the refractory lining in the cyclones, increasing maintenance and repair activities. Additionally the meal grows more "sticky" and the risk of capital cyclone blockages increases considerably.

The R&D project

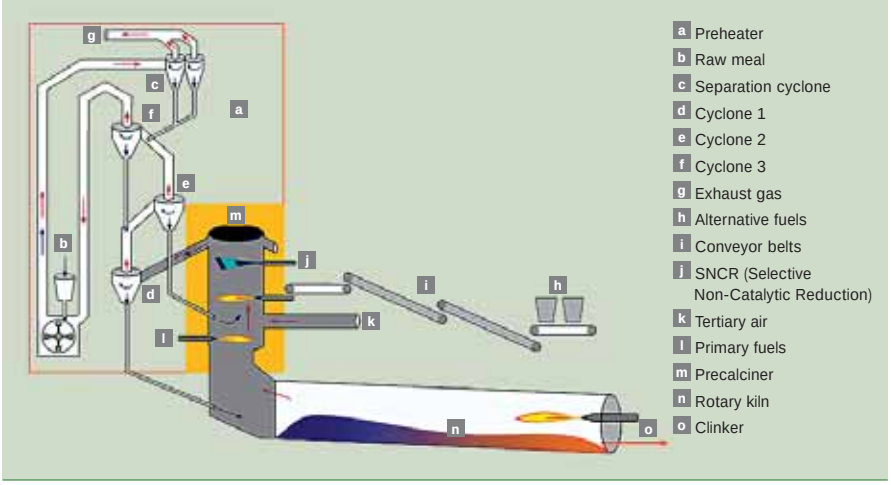
During the last two years, ABB has designed and deployed advanced process automation solutions and applications in different plants around the world. ABB is in constant contact with customers, seeking ways to improve current products to better meet their requirements. These automation systems are deployed using ABB's advanced process control system Expert Optimizer – a comprehensive engineering tool 3 that facilitates the development of generic control solutions for highly complex problems within the process automation industry [2]. Most installations have been implemented in blending, kilns, and grinding operations. Notably, 45 blending systems, 195 rotary kilns and 90 mills have been commissioned by the ABB team during the last 10 years.

The "precalciner control problem" had been a desired extension to ABB's control system portfolio for a long time, both on Holcim's and ABB's side. The necessary cooperation could therefore be swiftly established.

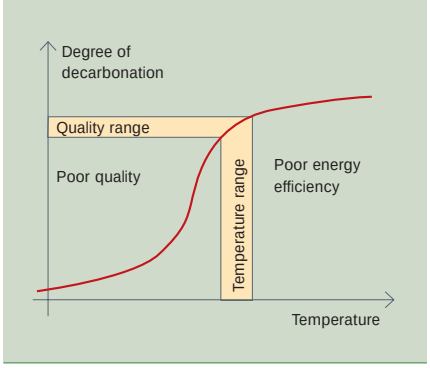
MPC as enabling technology

MPC (Model Predictive Control) is based on the "receding horizon" approach. A sequence of optimum actions extending into the future is calculated while incorporating the dynamics of the process 5. The first element of the optimal action se-

1 Schematic representation of the clinker production process at the Holcim plant in Lägerdorf, Germany



2 Relation between temperature and degree of decarbonation; the desired temperature and quality range are highlighted



quence is transferred to the control system as the new actuator setpoint. If new measurements are available, the algorithm is repeated and a new sequence is calculated. Typically, this approach is comparable to the strategy of a chess player:

(i) The situation on the chess board is evaluated, ie the state of the process is measured and assessed

(ii) Future moves are considered, ie a mathematical algorithm calculates the optimal sequence of actions

(iii) The first move of the selected sequence is applied, ie a new setpoint is sent to the actuators.

This sequence is repeated after the opponent has made his move. An important advantage of such a system is that the mathematical algorithm can take limits and constraints into account when deriving the optimal control sequence. Analogously, the chess player has a restricted area in which to make his moves (the board) and has a limited range of moves (depending on the chessmen).

Expert Optimizer supports many different control technologies including MPC. However, it has not previously been used to control a calciner combustion process in the cement industry.

The control problem

The temperature in the precalciner is the main continuous indicator for the quality of the hot meal. It is therefore used as the main controlled variable. Furthermore combustion of the fuel must be guaranteed and therefore oxygen levels need to be maintained above predefined limits. Carbon monoxide exhaustion is legally regulated and may cause the system to trip if the limits are violated.

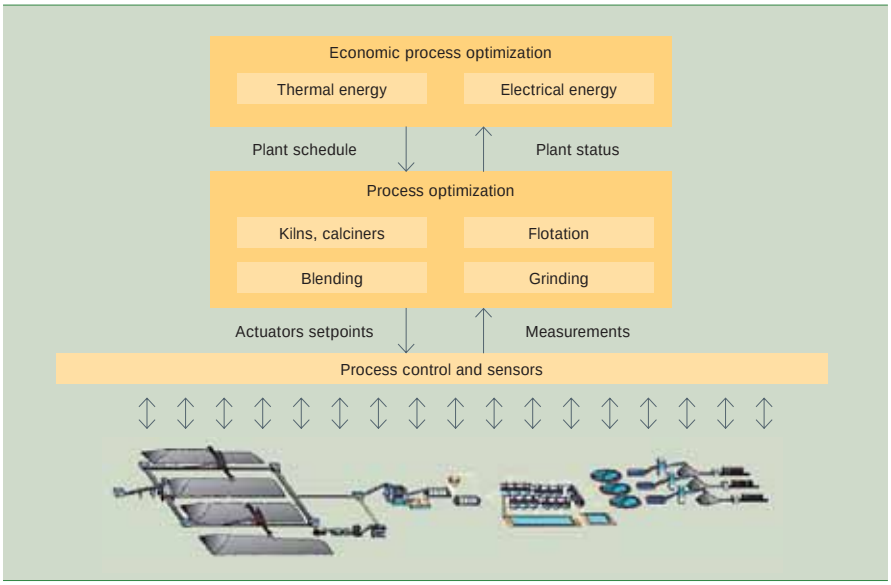
The primary fuels are used as manipulated variables. These are mainly coal, but in the specific case discussed here, a high quality waste fuel is used. In both cases this is transported pneumatically to the precalciner and forms the fastest available actuator of the system. Up to five other alternative fuels are used; these are transported to the precalciner by conveyor belts. As the transport delay of these fuels is up to many minutes, they are not suitable for use as manipulated variables.

The mathematical model

Part of the success of model predictive control in the process industry is related to the mathematical model being directly part of the control strategy. In general, the better this model describes the real process, the higher the expectations that can be placed on the performance of the controller. However, it is often also true that the more accurate the model is, the more sensitive the controller will be in reacting to uncertainty in the process. The uncertainty and variability of the process in this specific case is significant. For example, the calorific values of the alternative fuels change constantly depending on the composition of the originating waste, but the associated model parameters are updated only once a month.

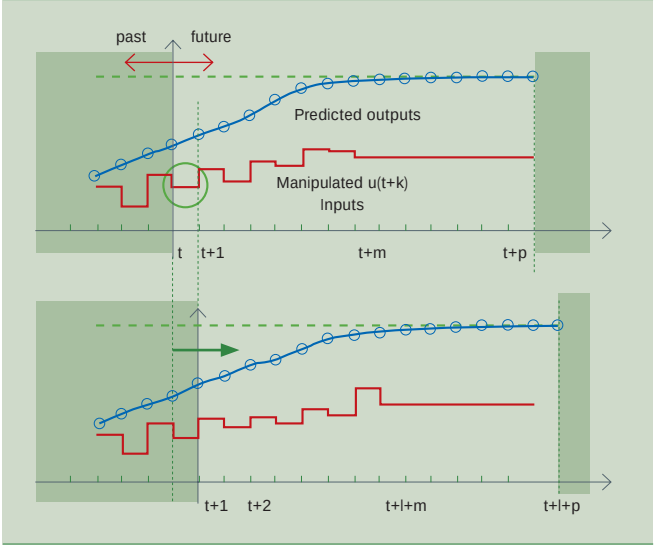
The model essentially comprises two separate parts: the transport model

3 Expert Optimizer applications scope

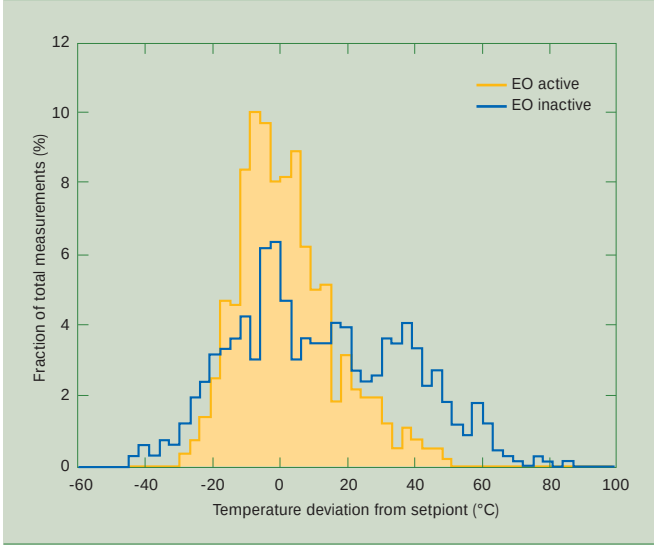


4 Recordings of plant operations; temperature and target temperature a, input heat flow from combustion of alternative fuels b, coal feed rate c.

5 The main principle of MPC is based on the receding horizon. After each sampling instance, the considered future in the optimization algorithm is modified accordingly



6 Distribution of the temperature error for periods in automatic (Expert Optimizer, EO, active) and in manual control (EO inactive)



and a combustion model. The transport model is a series of unit time delays corresponding to the different transport delays of each of the fuel feeders. The combustion model consists of two parts:
i) a heat balance and
ii) an oxygen balance.

The heat balance considers any heat which is added or drawn from the precalciner. This includes fuel input, gas and air flows, meal feed rates and the decarbonation reaction (which consumes considerable heat). Varying meal composition also introduces a significant variation of the heat used for decarbonation. Usually these composition variations are considerably slower in relation to the thermal reaction and therefore can be captured in an adaptive bias term.

Similar ideas are used to formulate the oxygen balance.

Results

A recording of plant operations is shown in 4. Subplot 4a shows the temperature and the target temperature. 4b shows the input heat flow to the combustion model related to all of the alternative fuels. 4c shows the main manipulated variable, the coal feed rate.

To compare the performance of the controller with the performance of the operators, several periods were evaluated where comparable conditions were present. 6 shows the distribution of the temperature error.

The performance of the control system outperforms the operators. The temperature targets are better maintained and the variations from set-point are less. Obviously this does not imply the operator is superfluous; instead this person is occupied by other and more important tasks. This shows that a control system can support the overall task of the operator.

Conclusion

The controller successfully stabilizes the temperature at a given target and reduces the variability of the deviation from the target. This allows the system to be operated closer to the quality limit, which is more energy efficient and decreases the risk of downtime. By using the control system, less stable operating points with lower temperature targets can be achieved without risking insufficient product quality. The generally lower temperature reduces the risk of capital blockages of cyclones. Hence, the controller protects the equipment and increases uptime.

This project's success was strongly conditioned by the close collaboration between the teams of ABB and the customer's. Both groups contributed with their technical competence and goodwill, thereby guaranteeing the success of this project.

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Hydrofluoric acid alkylation

ABB and ConocoPhillips develop a critical new process analysis tool

Michael B. Simpson, Michael Kester

The ABB Process Fourier Transform Infrared (FTIR) Analyzer for HF (Hydrofluoric Acid) Alkylation Refinery Process Unit Optimization, jointly developed with ConocoPhillips, helps petroleum refineries to operate their HF alkylation units more efficiently and safely, while making a significant contribution to operational and environmental risk mitigation.

In the early days of petroleum refining, back in the 1920's and 30's, most of the pool of gasoline blending components was made up of straight-run material taken directly from the crude oil distillation unit. Refineries were essentially rather simple oil boilers. The first conversion units were uncomplicated and aimed at thermal reforming of straight-run naphthas to yield higher octane blending components for improved product quality.

The situation was given a significant boost during World War II when there arose, for obvious reasons, a desperate need for high-octane aviation gasoline (military aircraft at that time were mainly equipped with reciprocating piston engines fuelled by high-octane gasoline, rather than jet engines fed on kerosene).

One of the responses to this need for high-octane gasoline was the development of a refinery conversion unit – the hydrofluoric acid (HF) alkylation unit.

Iso-octanes (alkylates) are the gold-standard of gasoline blending feedstocks in today's context of clean fuels and environmental concerns.

The HF alkylation unit (HFU) remains of key importance to this day. It plays a critical role in providing one of the most important feeds to the final product gasoline blending pool. Its significance has grown side by side with the increasing number of fluid catalytic cracking (FCC) units in refineries. The FCC adds value to the heavy end of crude distillation by catalytically cracking heavy feeds into lighter products such as light cycle oil and FCC gasoline, which can be used either directly or after hydrotreating in final product blending operations. The downside of this process is that light olefins, typically butene and propene, are also produced in FCC operations. These are essentially worthless as feedstock. Similarly, in any crude distillation process an excess of light end products such as butane tend to be produced that are of limited use. N-butane can easily be converted to iso-butane, and in this form it joins the FCC c3 or c4 olefins (butene or propene) as the combined feeds to the HF alkylation unit.

The HF alkylation unit performs the important role of upgrading these byproducts to high-value alkylate, which is used as a gasoline blending component. This economically invaluable task of sweeping up the c4 olefins from the FCC and the c4 isoalkanes from the crude oil distillation unit and converting them, through the catalytic HF alkylation process (a modified Friedel-Crafts reaction), to iso-octanes, continues to be of major importance in petroleum refining.

Iso-octanes (alkylates) are the gold-standard of gasoline blending feedstocks in today's context of clean fuels and environmental concerns. They have high RON and MON (Research and Motor Octane Numbers), low-sulfur, low Reid Vapour Pressure (RVP) and near zero aromatics. They are the perfect gasoline component.

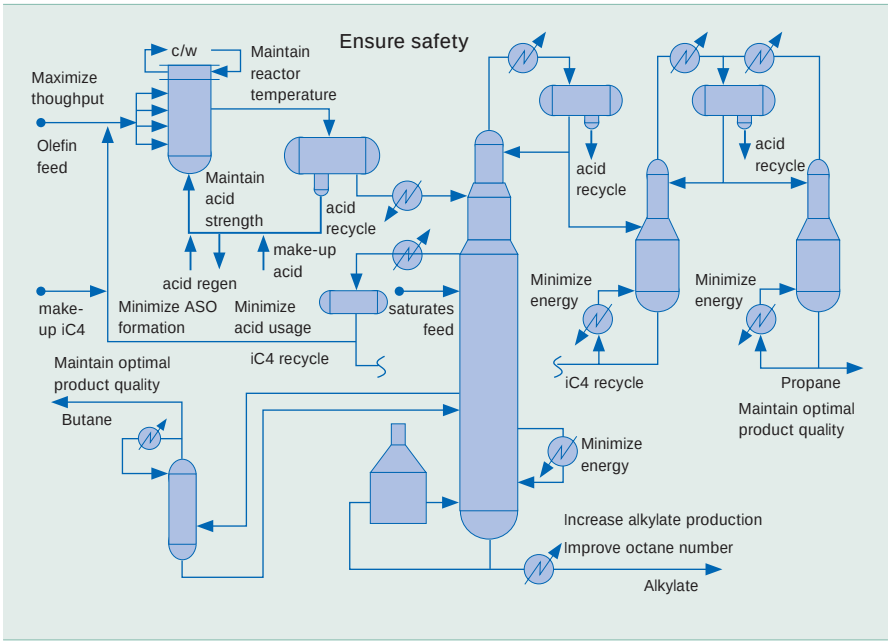
Over the past 15 years, gasoline formulation requirements, as driven by government environmental agencies in most regions of the world (but led by the European Union and the United States), have been significantly sharpened. Requirements for lower sulfur, lower benzene, lower aromatics, lower RVP and lower Driveability Index (a combination of fuel distillation properties) severely restrict the options for refiners in their final product gasoline blending operations.

The two most recent changes that have probably had the biggest impact on the gasoline pool are the removal of MTBE (methyl tertiary-butyl ether), because of its contaminating impact on groundwater, and the addition of bio-ethanol for its carbon-neutral status. MTBE is a lower vapor pressure high-octane blending component for gasoline. Although ethanol is equally high-octane it makes a substantial contribution to RVP, which essentially prevents straight butane from being used to any large extent in the same blend recipe. Thus, alkylate produced by the HFU is of exceptional value to refineries in their struggle to meet environmental and other legal constraints on their operations 1.

HF alkylation operating issues

Consequently, refiners operating HF alkylation units are under increasing pressure to maximize unit throughput, improve product quality and yields while operating safely and with low environmental impact. Ever tightening legislation on gasoline quality and increasing public and regulatory scruti-

1 The HF alkylation unit operational objectives



ny of the use of hydrofluoric acid combine to make reliable and efficient operation of HFUs of critical importance to the overall reputation and profitability of petroleum refineries.

The efficient operation of an HFU is a difficult task and subject to the most testing of operating regimes. This is due to a number of industry-specific constraints and operating issues that stretch the processing capability of the plant.

Operating issues

- HFUs must be able to deal with feedstocks that routinely vary in contaminant levels, hydrocarbon composition and volume due to upstream operating complexities.
- Operators have the difficult challenge of minimizing iC4 recycling and associated utility costs while producing alkylate of the desired quality with minimum acid consumption.
- The units must be operated in a safe manner despite the ever-present potential for acid runaway, accelerated equipment corrosion and associated HF release.

The demands on HF alkylation units are further increased by ongoing trends within the petroleum refining industry.

Industry trends

- The ongoing expansion of FCC units and the introduction of new cracking catalysts to satisfy gasoline growth also result in the production of more alkylation feedstock.
- The continuing trend of increased residue cracking and upgrading capacity produces more complex and problematic alkylation feedstock.
- There is an increasing interest in C5 olefin processing as a means to return volatile components to the gasoline pool while increasing product volumes.
- The continual tightening of legislation concerning gasoline quality further restricts the use of some current blend components.

Each of the above requires the HF alkylation unit to be more flexible in handling increased and varying feedstocks while maintaining unit efficiency and alkylate quality. The ideal blending characteristics of alkylate make it a critical element in meeting refinery profit targets and complying with fuel quality legislation.

Operational targets

- Alkylate quality optimization: the RON, RVP and distillation properties of the alkylate product of the HFU are critical for its use in downstream gasoline blending. These parameters are influenced by HF catalyst purity, and specifically by water content, which must be optimized within a suitable operating window. The water content of the HF acid recycle stream is vulnerable to feed contamination events, and these must be picked up and acted upon promptly.
- Corrosion mitigation: corrosion mitigation places severe lower limits on HF acid purity and upper limits on water content. Keeping within defined operational windows extends HFU turnaround times, significantly reduces maintenance costs and limits the risk of HF release into the environment.
- HF acid consumption: correct operation of the HFU depends on the successful separation of hydrocarbon product from the acid catalyst in the acid settler. If there is a build up of acid soluble oil (ASO) byproduct and HF acid is consumed (thereby reducing acid strength), the process can fail, with the resulting rapid consumption of the remaining acid – a so-called acid runaway event. Such an event is extremely costly, but is an inevitable risk of HFU operation. A close watch on acid strength and the percentage of ASO byproduct can significantly reduce the likelihood of this happening.

The ABB-ConocoPhillips partnership

Recognizing the need for improved online HFU process monitoring and control in the mid-1990's, Phillips Petroleum (now ConocoPhillips) sought a process analytical instrumentation partner to jointly develop a solution that would improve the monitoring and optimization of these complex process units. ABB was an established supplier of online process FTIR analytical solutions in gasoline blending and downstream petrochemical applications, and a productive partnership between ABB and ConocoPhillips Factbox was formed to jointly develop an analytical solution.

At the time, monitoring the key process parameters of HF alkylation units was not straightforward. It relied on expensive, slow and potentially hazardous manual sampling of the recirculating hydrofluoric acid catalyst for laboratory assessment of its strength and the level of critical contaminants such as water and fluorination byproducts (known as acid soluble oils).

HF acid purity determination is the key control parameter for HFU control and optimization, provided it can be delivered quickly enough to detect process unit upsets, such as transient shifts in acid strength and contamination events caused by upstream disturbances in, for example, FCC operation.

As of December 2006, the online acid analysis system is installed in almost 20 HF alkylation units worldwide and has a combined operating history of more than 40 years.

ABB began working with the ConocoPhillips R&D laboratory at Bartlesville, Oklahoma in 1996 to develop an online acid analysis system. Two years of testing and development followed on HF alkylation pilot scale units. This included sample system design, metallurgy considerations and model development. The analyzer was then installed at the Phillips Petroleum refinery in Sweeny, Texas in May 1998. Two more years of successful onsite testing ensured the technology was ready for industry-wide implementation. The online acid analyzer was then launched for the HF alkylation market at the 2000 Phillips licensee symposium.

As of December 2006, the online acid analysis system is installed in almost 20 HF alkylation units worldwide and has a combined operating history of

more than 40 years. The systems are installed in both ConocoPhillips and UOP licensed units in North and South America, Europe and the Middle East, and in sites operated by other major refining companies.

The ABB–ConocoPhillips solution

The key breakthrough in the creation of a robust and useful process FTIR analytical solution for HFU monitoring and optimization came with the development of an accurate and precise pre-calibrated chemometric model for the required process variables (HF acid strength, water % and ASO %) 2.

The traditional laboratory reference techniques for these measurements are poor, and in contrast to the usual methods of analyzer calibration, do not provide a reliable basis for the development of a precise calibration model. Fortunately, the HF acid recycle stream is of relatively simple composition. This allowed ConocoPhillips to develop the required universal calibration model on the basis of a gravimetrically prepared calibration standard and run it in a laboratory scale pilot alkylation reactor under real-life process conditions – but without any olefin feed in order to maintain exact acid composition during the run.

The successful development and market introduction of the ABB process FTIR HF acid analyzer is the result of a very fruitful cooperation between ABB and ConocoPhillips.

The data obtained were essential and subsequently formed the basis for a successful patent registration under which ABB offers the HF process FTIR alkylation analyzer solution under license.

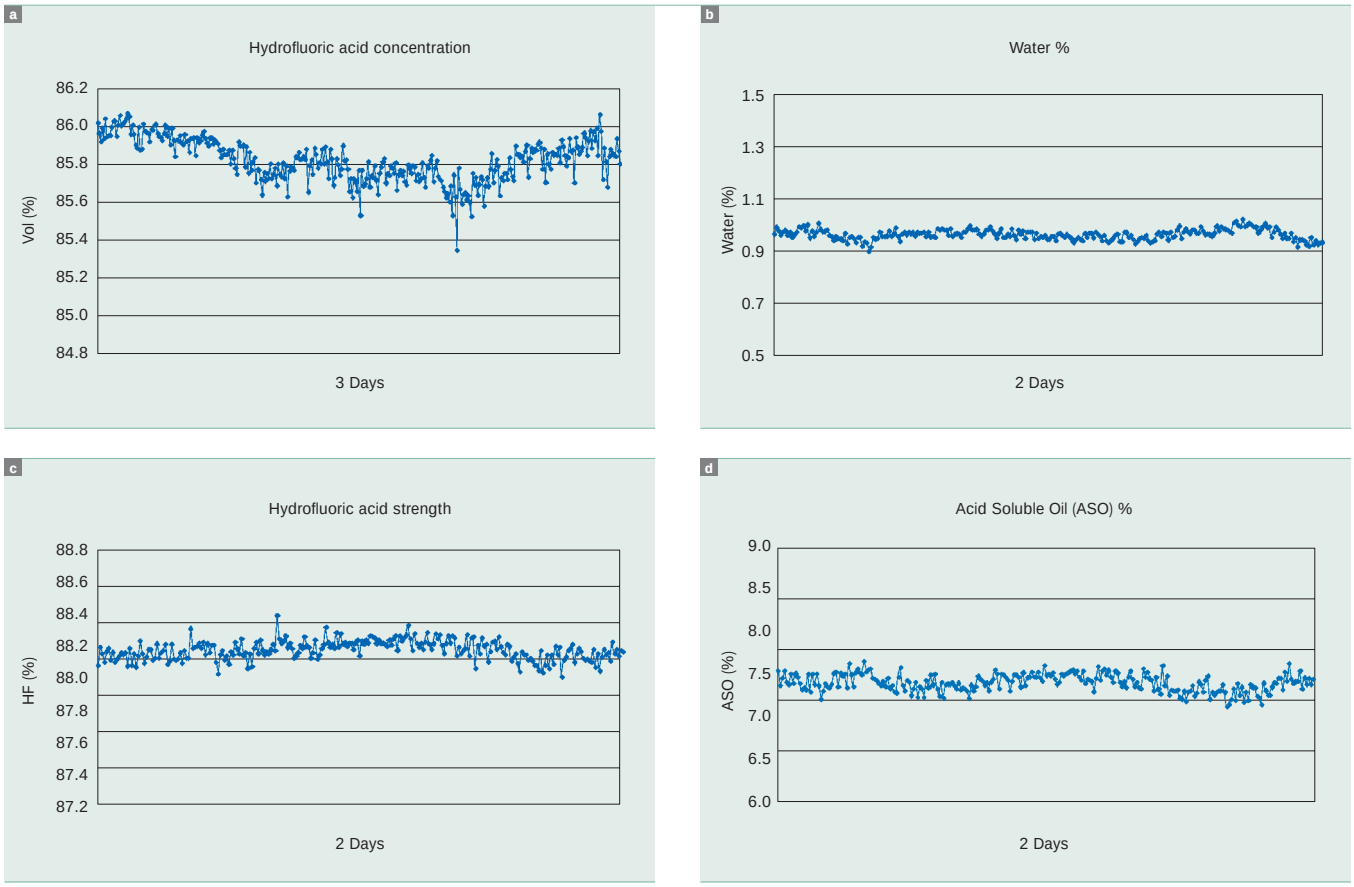
A major part of ABB's contribution to the project was the development of a safety-engineered field sample panel that is low maintenance and requires minimal field intervention inside the acid area (which in an HFU requires full C-suit personal safety equipment).

FTIR analyzer technology

ABB's fiber-optic-based multichannel process FTIR analyzer is ideally suited for this type of application. It allows a remote field-based acid-area sample flow cell and associated safety and sample conditioning system to be physically separate from the analyzer optics station (which is normally located in a control room or similar safe area). This arrangement is essential when dealing with the online analysis of an exceptionally hazardous process stream such as HF acid.

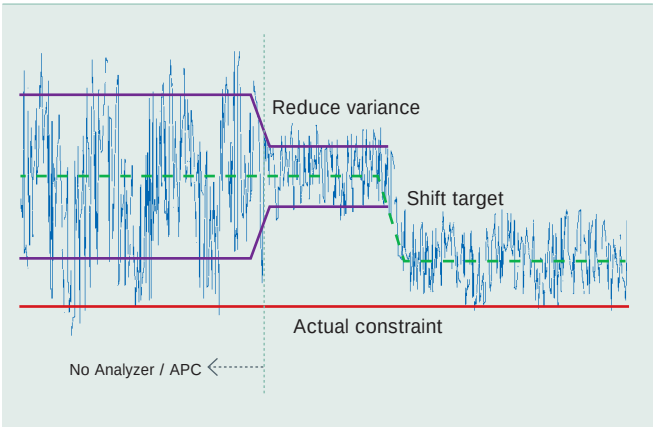
An additional benefit of ABB's FTIR technology is its ability to monitor multiple process streams with a single analyzer. In HFUs this enables two acid streams to be monitored (for example, the main acid recycle and the acid regeneration overhead) in real time, which significantly improves HF acid purity control and regeneration efficiency 3.

2 Run-time data from ABB's Process FTIR HF Acid Analyzer



In addition to these benefits there are other exciting process control options for the HFU process FTIR analyzer. Besides the HF acid catalyst monitoring role, there are many important hydrocarbon streams in the HFU that benefit from reliable, low-maintenance and rapid compositional analysis. The olefin feed stream and the iC4 recycle stream from the iso-stripper are the most important. Together, these two streams directly influence the feed purity to the HFU, which in turn has a direct impact on HF acid consumption. Real-time process data on these streams, along with the HF acid purity measurement, provide a significant improvement in unit operational stability.

3 Real-time process monitoring with APC



ConocoPhillips brought a key understanding of real-life process monitoring requirements and critical process variables to the partnership.

In summary, the ABB–ConocoPhillips solution for HFU reactor optimization offers ABB multivariable control technology underpinned by a unique capability for rapid online characterization of HF acid, recycle iC4, olefin/iC4 makeup feeds and alkylate. The solution delivers the following significant operating improvements to HF alkylation reactors:

- Feed rates, alkylate yield, and alkylate octane are maximized to an economic optimum, subject to operating constraints
- Isobutane:olefin (I:O) ratio and energy consumption can be reduced while meeting alkylate quality and yield targets with minimum acid consumption.
- Isobutane makeup rate can be optimized while respecting iC4 inventory constraints
- Acid quality is maintained in the optimum operating range for HF, ASO and water content. This leads to:
- Less frequent approaches to runaway conditions
- Lower acid inventory, as acid makeup requirements are reduced
- Alkylate octane enhancements are possible as the water content of the catalyst can be increased in a controlled manner. One of the major licensors reports that an increase in water content from 1.0 – 2.0 wt% can deliver more than $1 million in benefits for a 10,000 bpd unit operating at the typical I:O ratio of 10
- Less aggressive regenerator operation and lower acid losses
- Higher quality alkylate and yields
- Acid:hydrocarbon ratios and reactor temperature are controlled to improve product quality and suppress ASO production
- Reactor conditions are optimized to manage variations in fresh feed compositions.

Factbox ConocoPhillips

Headquartered in Houston, Texas, ConocoPhillips is the third-largest integrated energy company in the United States – based on market capitalization, oil and gas proved reserves and production – and the second-largest refiner in the United States. The company operates in more than 40 countries, has 38,700 employees and is known worldwide for its technological expertise in deepwater exploration and production, reservoir management and exploitation, 3-D seismic technology, high-grade petroleum coke upgrading and sulfur removal. For more information, please refer to www.conocophillips.com

An extended portfolio

The successful development and market introduction of the ABB process FTIR HF acid analyzer is the result of a very fruitful cooperation between ABB and ConocoPhillips.

As one of the principal HF process licensors, ConocoPhillips brought to the partnership a key understanding of real-life process monitoring requirements and critical process variables. Through their R&D department they also brought the capability to develop the crucial universal analyzer pre-calibration necessary for successful commercial exploitation.

ABB was able to contribute state-of-the-art process FTIR technology and expert field sample system design engineering. Together, these inputs have produced a result of significant benefit to both parties. ConocoPhillips is able to offer a key process analytical tool to its many HF process licensees, as well as benefiting from the direct implementation of the technology in its own refining operations. ABB has been able to add a significant and unique building block to its portfolio of refinery process FTIR analytical solutions.

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Tapping technology

Optimizing the water supply for the city of Basel

Daniel Moll, Thomas von Hoff, Marc Antoine

Tap water is not guaranteed to everyone on the globe. But in places with guaranteed access, tap water is a normal part of households. Its average consumption lies at around 120–160 litres per person and per day (trend decreasing).

In the western world, tap water is expected to be of drinking quality and permanently available. However, the quality of water collected from sources or ground water rarely meets the strict demands of water authorities.

To make the production and supply of high-quality water economical, a process of production and distribution is required that is well controlled and supervised.

Automation permits operation and maintenance costs to be reduced and simplifies cooperation between water supply installations over larger areas.

Natural drinking water is collected from springs and from the ground water. In most cases the amount of natural drinking water collected is insufficient and additional water must be procured from other sources. During its production, this water passes several treatment stages in which its quality is improved until it reaches drinking quality. After having passed the filters to eliminate rough particles, the water is drained into forest areas to enrich the ground water. The water is biologically and physically treated during this draining process. By using low-pressure pumps the water is carefully extracted from the ground. Some chemical post-processing is performed – if required – before the water is pumped into the pipe distribution system. The topology of the pipe system and the area to be supplied with water determine the pump strategy.

Powerful diagnostic tools help identify performance deviations permitting corrective actions to be taken early.

Plant optimization solutions

In order to be cost-efficient, utilities are constantly striving to optimize plant operation and to reduce life-cycle costs. Powerful diagnostic tools help identify performance deviations permitting corrective actions to be taken early.

The ABB OPTIMAX® Plant Optimization range offers a variety of products and solutions to address these requirements in the power generation and water business [1]. These systems may offer utilities complex generation portfolios which are seeking to optimize the costs and energy generation, whether they relate only to electrical energy or to a combination of electrical energy and other forms of energy (heat, water, waste, etc.).

Modernization of the water supply automation at IWB

The municipal utility of Basel (IWB) Factbox currently operates a water supply system consisting of:

- 12 high pressure pumps
- One internal ground water drainage and collection area, including 12 wells (with low pressure pumps)
- One external supplier
- Three double chamber reservoirs
- Roughly 26 million m3 of annual delivery

Apart from wishing to modernize the automation system for water production, IWB also required a solution for optimizing its operation and maintenance activities. The IWB concept is called “optimized unattended operation” and is characterized by its ability to function without the presence of an operator at the remote pumping (or reservoir) stations; permitting this to fulfil other important tasks in the overall operations and maintenance activities.

Factbox IWB

IWB (Industrielle Werke Basel) provides the canton of Basel and the location of Binningen with high quality drinking water. Since the 1st January 2007 the drinking water from IWB has its own designation: bâlAqua.

One thing that is special in Basel is the so-called biological treatment after the fast filtering plant. This means that woodland areas with groundwater are flooded from time to time with Rhine water for a mechanical and biological purification. This biological purification process is unique in the world and has potential for adaptation for the needs of other locations.

For further information see www.iwb.ch

Control systems in large municipal utilities or power plants usually involve an investment of several millions of dollars for hardware and engineering.

As part of this concept, IWB requested an optimized solution that can take a given load demand (water consumption) and determine the best operating schedule of pumps and wells, taking into account a set of infrastructure-defined constraints. Such a task can be formulated as a load scheduling problem. The operations and maintenance staff expected the new solution to be at least as good as their previous practice.

In unattended operation, an intelligent controller has to deliver schedules for the set points of pumps and wells that were previously defined by the operators. The optimization criteria are:

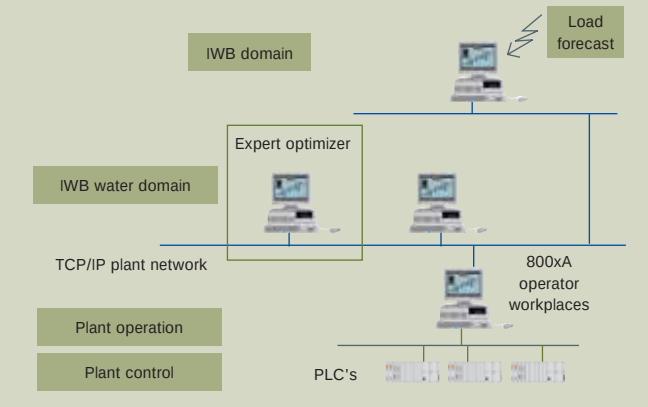
- the water supply itself
- achieving the required water quality
- keeping the costs for operation and maintenance as low as possible

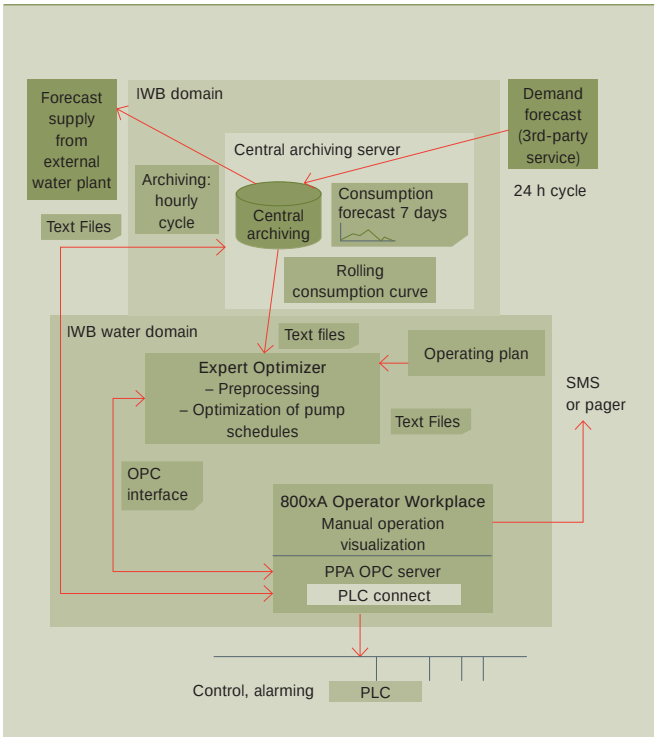
In other words – and this time in mathematical terms – the optimizer solves a hybrid problem consisting of continuous variables (eg, flows, levels, energy etc.) and discrete variables (as for example switching the plant equipment on/off). By using Model Predictive Control (MPC) and more recent developments, such as Mixed Logical Dynamic (MLD) Systems [2], this solution can be implemented as part of the ABB OPTIMAX® software applications.

Close cooperation between IWB and ABB

When the plant is operated in unattended mode, it must fulfil the same performance criteria as a manually operated plant. To define the design concepts and guarantee that the necessary intelli-

1 System architecture





gence is implemented in the optimizer software, IWB and ABB cooperated closely from the launch of the project. While ABB mainly contributed the automation and optimization know-how, IWB provided the specific plant knowledge and operational experience.

A customized solution

The underlying automation system

ABB's System 800xA includes functionalities of common operator consoles and provides access to any customer's hardware, allowing the integration of all equipment already installed in a typical plant.

Control systems in large municipal utilities or power plants usually involve an investment of several millions of dollars for hardware and engineering. Rather than calling for total replacement, ABB's system safeguards this investment. By selecting ABB's system 800xA, IWB opted for a process control system with a broad range of new functions while maintaining a uniform user interface over different underlying controller families.

The developed solution: optimizer

The solution is based on 800xA and the ABB Expert Optimizer 1. From an operator workplace the plant's past and predicted trends can be monitored. If desired, the operator can switch the optimizer from closed loop to open loop, which means switching to manual control mode.

Deviations from the schedule are continuously monitored and schedules are adapted where necessary.

The unattended operation is influenced by the operating plan which may contain some given pump set points or constraints (for example: restricted pump or reservoir availabilities due to maintenance work). The water demand forecast is received every day with an hourly resolution. This forecast is determined by prognosis software which considers the SwissMeteo weather forecast for the next 7 days. These data are provided to IWB through an online email service. Based on these data and constraints, the Expert Optimizer calculates the optimal operation schedules for pumps and wells.

The communication from the data archive and the operating plan to the Expert Optimizer is via text files, and the data exchange between the Expert Optimizer and the 800xA workplace goes via OPC[2]. The pumps and wells set point schedules are sent to the PLC[1] well in advance for safety reasons.

Since the water demand forecast is subject to some uncertainty – and since wells and pumps may potentially trip – the levels of reservoirs and wells are supervised and checked against alarm limits by the PLC. An alarm triggers a recalculation of the optimization and generates new scheduled set points, which take into account the changed conditions. In parallel, the operating personnel is informed by SMS or alarmed by pager in case their action or approval is required.

After detailed design specifications, jointly discussed between IWB and ABB during regular review meetings, the basic software functions were tested at ABB works during the factory acceptance test and were then installed on site. The system was extensively tested by the customer in the open

Footnote
[1] PLC: Programmable Logic Controller
[2] OPC: OLE for Process Control

2 Status of water wells. In this example, the flows from the different wells (blue, green and yellow) are equal

3 Filling the virtual reservoir: the actual level (green) follows the optimal set-point (yellow) and stays within the tolerance limits (orange)

loop mode, the optimizer's recommendations were checked and adaptations were made, if required. After having successfully finalized this trial period, the optimizer will be switched to closed loop operation.

2 and 3 show examples of the optimizer's displays.

Summary
The municipal utility of Basel (IWB) required a solution to significantly increase the degree of automation and optimization of water production – optimized "unattended operation". Based on an online water consumption forecast, the ABB solution determines the optimized schedule and set points for the pumping stations and groundwater wells. Deviations from the schedule are continuously monitored and schedules are adapted where necessary. The system runs in closed loop and automatically pages service personnel in case they temporarily need to intervene. Solution concepts were jointly developed with the customer. The main customer benefit is the reduction of operation and maintenance costs while maintaining the water quality and supply guarantee.

Operating personnel is informed by SMS or alarmed by pager in case their action is required.

The successful cooperation between IWB and ABB in the water supply optimization project is a good example of a pilot project in terms of a new operational concept introduced by the customer.

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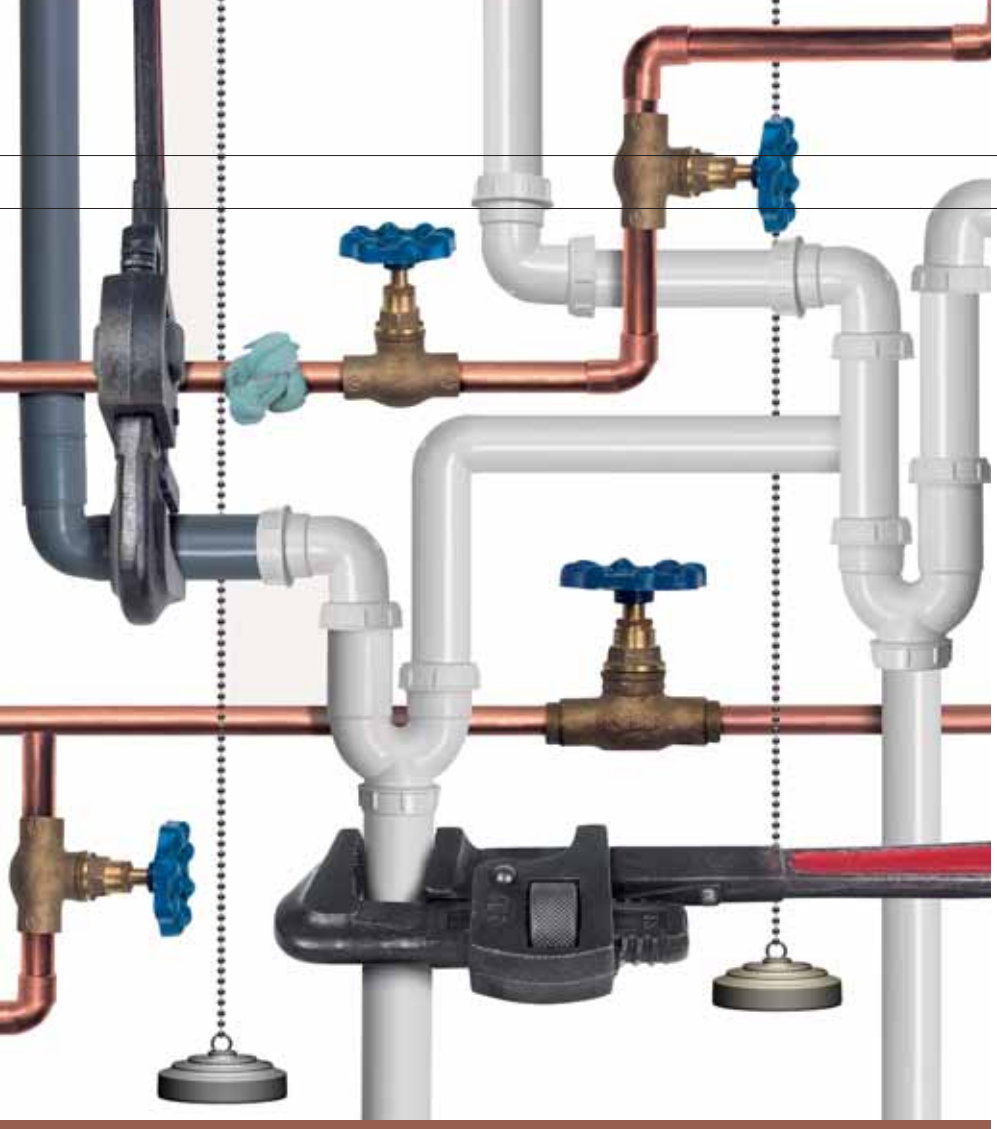


A smooth shutdown

ABB softstarters now come equipped with a new torque control algorithm to prevent hammering in water pipes

Jesper Kristensson, Sören Kling

If the motor that runs a pump is suddenly stopped, the abrupt change in the water flow that follows will cause pressure waves and water hammering in valves and pipes. Water hammering is often present in pumping systems with long pipes and in systems with a high pump head, and will, over time, cause wear and tear to the equipment. The use of softstarters generally reduces the effects of hammering by providing smooth motor deceleration. Now thanks to a successful collaboration with ITT Flygt, ABB has built on its softstarter concept by designing an innovative solution that completely eliminates hammering by controlling the optimum, time dependent motor torque.

The majority of pumps are still started with conventional electro-mechanical starting methods, such as direct-on-line start and star-delta start, and this means the risk of water hammering is ever present. However, various mechanical solutions, such as hydraulic valves or pressure tanks, are in place to prevent this effect. Although well-known, these solutions are costly, require high maintenance and, in the case of the pressure tanks, they need a lot of space.

Hammering in a water supply system can dramatically reduce the lifetime of pipes, valves and gaskets, cause unwanted interruptions and incur higher maintenance costs. The use of softstarters Factbox 1 generally reduces the severity of the hammering effect but cannot prevent it under all circumstances.

Because they help minimize mechanical wear and tear, softstarters are commonly used to start and stop motors in almost any AC motor application [1]. ABB, for example, developed softstarters that can control motors and pumps up to 1000 kW, and over 40 percent of ABB's softstarters are used to start and stop AC motors in pump applications. As well as their application in pumping systems, softstarters can be found in various other applications ranging from bow thrusters on ships to compressors in filling stations for natural gas to snow making machines, as well as more common industrial applications such as fans, compressors and conveyor belts. The former design, however, with its linear voltage ramps to start the motor, is not the most optimal one and needs to be improved if water hammering is to be totally eliminated.

Looking for an intelligent solution

In conventional softstarters the voltage supplied to the motor is linearly increased during a start phase (meaning the starting current is low) or decreased during a stop phase. For most applications this provides the basis for good motor acceleration and deceleration.

While water hammering is not an issue during a start phase, the situation is somewhat different during the stop

phase. In a distributed water supply system with many valves and corresponding motors, the effect of closing one of these valves depends on the actual system configuration. System dynamics may differ from one start and stop to another since the water flow or number of pumps running in the system may vary. So even if the modification of parameter settings in one case prevents water hammering, it doesn't mean this is true for other system parameters.

Factbox 1 Softstarters

A softstarter uses thyristors (SCR = Silicon Controlled Rectifiers) to control the voltage supplied to the motor during start and stop. This in turn reduces the current, and less mechanical stress is put on the motor application compared to using full voltage starting, or other electro-mechanical starting methods.

Without the use of softstarters electrical, mechanical and operational problems can be expected:

- The voltage and current transients may overload the local supply network and cause voltage variations resulting in flickering lights and interference with other electrical equipment.
- Broken belts, cracked couplings, grinding gears and wear to motors can occur.
- Pressure surges in pipelines, damage to products on conveyor belts and uncomfortable escalator rides may be the result.

A more adequate solution is to take the dynamics of the water system into account when the softstarter thyristors are used to control the voltage to the motor 1. With more measurements available inside the softstarter, the water flow may be better controlled. At the same time it is possible to determine to what extent the voltage to the motor affects the water flow. By controlling the voltage it is possible to control the torque which in turn controls the motor speed and hence the water flow 2.

Hammering in a water supply system can reduce the lifetime of pipes, valves and gaskets, cause unwanted interruptions and incur higher maintenance costs.

Various measurements will allow a torque control loop algorithm to be established whose function is to control the deceleration of the water in the pipes to prevent water hammering when the pumps are stopped.

This is a typical example of control loop technology but with the added requirement that the same solution must work for all types of pumps and pipe configurations, as well as all motors between 15 kW and 1000 kW. An ideal scenario is a solution that requires no fine tuning of the settings. In order to better understand these varying requirements ABB contacted ITT Flygt Factbox 2 in Sweden.

Cooperation with ITT Flygt

ITT Flygt and ABB had previously worked together on variable speed drives and other starting equipment. ITT Flygt's experience in water supply systems, together with its sophisticated simulation tools convinced ABB it was an ideal partner with whom the water hammering problem could be solved

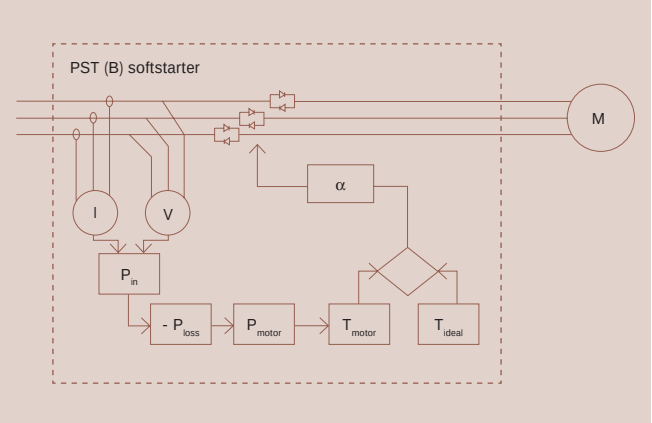
From an ABB point of view, getting to know the simulation tools gave valuable insight into the optimal way of decreasing motor torque and hence the water flow in the pump during a stop phase to prevent water hammering.

Judging whether or not hammering will occur is dependent on a number of parameters including the main pipe

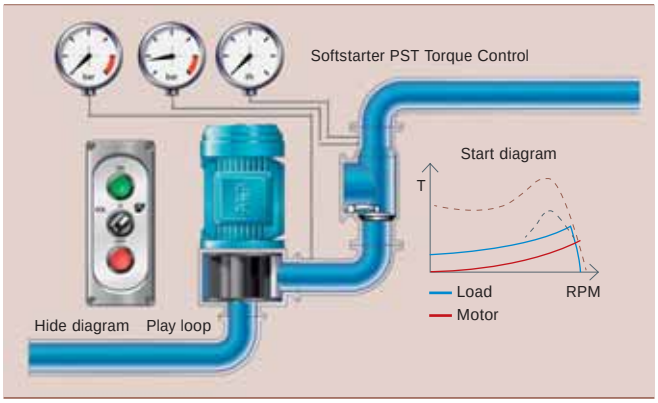
Factbox 2 ITT Flygt

ITT Flygt was founded in 1901, and with its headquarters on the outskirts of Stockholm in Sweden, ITT Flygt is the world leader in submersible pumps and mixers. ITT Flygt is involved in a broad spectrum of activities aimed at helping governments, municipalities and companies to improve sewage handling, flood control, energy conservation, land reclamation and tunnel construction. Their products are also used in mining, industrial processes, agriculture and aquaculture.

1 Motor control using feedback from a water flow system



2 Softstarters to control pumps – a demo showing the positive effects on current, torque and water flow when using ABB's PST softstarter with torque control



system and its components, and the type of pipes used, the pump head, length and the water flow. A number of other parameters must also be considered including the pipe work of the internal pump station. Slamming check valves is very common since the dynamic behaviour of the valves is too slow.

At shutdown the problem is much more acute. The most critical parameter during this phase is the change in flow speed. This, as well as the actual number of pumps on duty will affect the ramp down demands of individual pumps. To deal with these changes ITT Flygt already had a detailed analysis tool/method in place. For difficult cases this tool, which can perform a transient analysis of the system, is utilized when designing specific pipe configurations. During the project it provided ABB with valuable information concerning critical water flow parameters during pump shutdown.

3 The new ABB softstarter for pump applications

Softstarters have to cover a wide range of applications, from home equipment to pipelines

With clear specifications from ITT Flygt on how a torque control solution needs to perform to prevent water hammering and increase the lifetime and up-time of their pumps, ABB's team of researchers concentrated on designing the desired solution. ITT Flygt proved to be an excellent discussion partner by taking a wider approach to the question of how the use of softstarters can increase the reliability of pumping stations, or which intelligent functions are required in the starting equipment to facilitate the softstarter's use in pump applications.

The solution designed by ABB in collaboration with ITT Flygt to eliminate water hammering in pumps focuses on controlling the optimum, time dependent torque in the motor.

The solution designed by ABB to eliminate water hammering focuses on controlling the optimum, time dependent torque in the motor. To determine the required torque, it is necessary to carry out measurements and advanced calculations. The calculated torque is then compared to an ideal torque curve both during start and stop. If the torque is too low the voltage supply to the motor is increased using the thyristors. In the same way the voltage supply is decreased when the measured torque is too high. During the start and stop sequence both measuring and control are carried out in real time, and are fast and accurate enough for the torque to be controlled for all possible pumps and motors in all pipe configurations.

The available prototypes were first subject to ABB in-house testing followed by further testing at ITT Flygt's research facilities in Stockholm. Field tests were then carried out at several pump stations where ITT Flygt was already running tests on new pump models and prototypes. The tests in real systems helped validate both the simulation results and the torque control algorithm. The test stations were also used as demonstrators for end customers, thus enabling them to see the positive effects of torque control when stopping pumps.

The close cooperation between ABB and ITT Flygt during the initial design period enabled control algorithm modifications to be implemented at an early stage, thus reducing the product development phase significantly. Building on this successful cooperation, both companies will demonstrate a joint pump system at various fairs to show the advantages of using a submersible pump from ITT Flygt together with ABB's PST softstarter with the newly implemented torque control algorithm 3.

Towards wider applications

The selection of a leading customer as a collaboration partner to cover the general market requirements turned out to be instrumental for both parties. Among others, the open exchange of crucial design data and ideas not only led to an innovative solution to eliminate water hammering but it also provided invaluable expertise that can be used to address similar challenges in other applications where the starting currents and mechanical stresses in compressors, fans, bow thrusters or conveyor belts, for example are to be minimized.

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Combining forces to provide stability

Statnett, Sintef and ABB act together to tame the large Norwegian electric grid

Petr Korba, Ernst Scholtz, Albert Leirbukt, Kjetil Uhlen

Electric grids like the one in Norway can extend over thousands of kilometers, connecting generators and end users of electrical energy via countless substations and a wide network of cables and overhead lines. In a well managed grid, disturbances are damped out smoothly and a collapse of the system can be avoided. With increasing utilization of the grids, due to the growing need of electric power everywhere, the limit of stable operation is almost reached.

In this regime of operation the grid as a whole has to be balanced and wide area monitoring and control is required. This sounds easy but due to the nature of a complex, oscillating system like an electric grid, it turns out to be a major technical challenge. Statnett, the Norwegian system operator, SINTEF, the scientific and industrial research group in Norway and ABB, the supplier of technical solutions to the problem have joined forces to keep a tighter rein on the grid.

A typical case for a grid with large geographic extension is Norway. The Norwegian system is subjected to large quantities of power transfer on its transmission network because the large capacity hydro power generation units are located in the western part of the country while the bulk of consumers are situated in the east 1. The large distances between power generation and consumption is one reason the grid system is under stress [1]. For the Norwegian transmission system operator Statnett, it is vital to identify critical operating conditions and to take corrective action before disturbances or local instabilities develop into wide spread blackouts. Besides a net of measuring devices, algorithms to determine unstable situations, mitigation strategies and decision support for the operators must be available.

Research collaboration between ABB, Statnett and SINTEF dates back many decades and has resulted in the introduction of new technologies into the Norwegian system.

What is possible in theory

An extended grid with thousands of substation knots, generating units and wide spread consumers is a highly complex system that requires a wide area view of the manifold oscillations. Various solutions for the stability issue have been proposed and described in the literature, and a number of functions related to monitoring, control and protection have been studied.

So far, such automatic control explorations have mainly been academic in nature. However, ABB Corporate Research and SINTEF, the Foundation for Scientific and Industrial Research in Norway, have acquired a deep insight into this area.

Linking needs and technology options

Research collaboration between ABB, Statnett Factbox 1 and SINTEF Factbox 2 dates back many decades. There are

Factbox 1 Statnett

Statnett is the national Transmission System Operator (TSO) in Norway, responsible for a balanced amount of power generated in Norway and its consumption. Statnett also has the nationwide responsibility to create conditions conducive to an efficient electricity market, providing reliable transmission of electricity through cost-effective development of the electricity grid infrastructure. Statnett owns approximately 85 percent of the facilities in the Main Grid. In 2005 the number of employees was 630 with operating revenues of 5244 million NOK.

www.statnett.no (May 2007)

Factbox 2 The SINTEF Group

The SINTEF Group is the largest independent research organization in Scandinavia. The abbreviation stands for *The Foundation for Scientific and Industrial Research* and employs 1800 researchers located mainly in Trondheim and Oslo. The partner in this project has been *SINTEF Energy* Research Ltd., a division of SINTEF located in Trondheim and acting as a recognized consulting company having the required deep expertise on the Scandinavian power system, and the challenges and limitations associated with large power exports.

www.sintef.no (May 2007)

1 The Nordic transmission grid and installed PMUs, indicated with red circles

many examples where, as a result of such a collaboration, new technologies were successfully introduced into the Norwegian system. Perhaps one of the more well-known ones is the HVDC (High Voltage Direct Current) installations from the 1970s. Since 1999, ABB has been cooperating with Statnett and SINTEF in several R&D projects focused on using Wide Area Monitoring Systems (WAMS) and control to raise the energy transfer limits of the Norwegian 420 kV transmission grid. The work was structured in two main phases:

1999 to 2004

"Norwegian Intellectric" project with the mission to increase transmission system utilization and operational security by intelligent monitoring applications and control concepts based on new measurement and communication technologies.

2005 to present

"Secure transmission" project to deploy a WAMS in the 420 kV grid and demonstrate new concepts for secure operation of the power network.

ABB's Voltage Instability Predictor (VIP), which provides a transmission system operator with a local measure of the power margin before voltage collapse at a particular substation is encountered, was one of the first monitoring concepts relying on new measurement technologies to be tested [2]. The phasor measurement was developed later. Phasor Measurement Units (PMU) provide time-synchronized values of the local magnitudes and angles of sinusoidal signals with high resolution in time domain [3]. The PMU signals are then evaluated by an adequate processing algorithm, thus enhancing the functionality of the operator's Energy Management System. A threatening instability can then be quickly assessed by a direct connection to FACTS (Flexible AC Transmission Systems).

A significant benefit of a WAMS is its ability to detect dynamic wide-area phenomena in real-time, thereby allowing for direct counter measures.

Further cooperation

Every large grid has its characteristic inter-area oscillations. In the Scandinavian power system the main oscillatory modes are between 0.3 and 0.5 Hz. Such oscillations are known to the planning departments of system operators from off-line studies. Oscillations can be quantitatively characterized by several parameters in the frequency- and time-domain, such as modal frequency and damping, amplitude and phase. One of the significant benefits of a WAMS is the possibility to detect dynamic wide-area phenomena such as electromechanical oscillations in real-time, allowing for direct countermeasures.

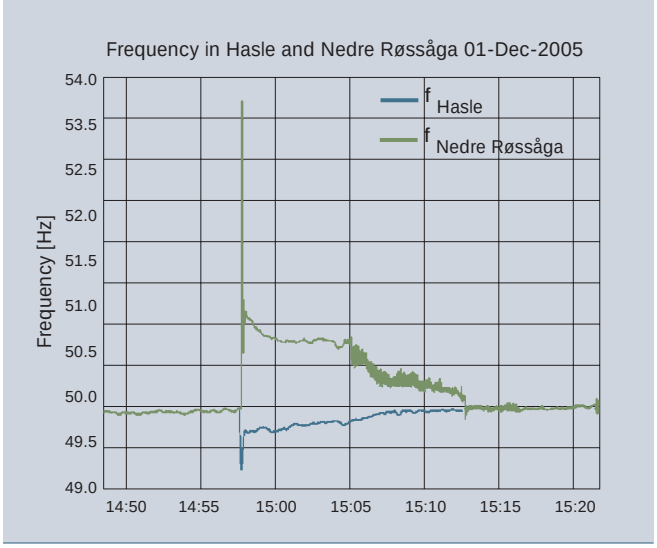
To get a comprehensive overview of the oscillations with as few measuring sites as possible, the first step was the selection of appropriate sites for those few PMU installations. To successfully do this, the following had to be considered:

- The possibility of detecting the characteristic swing modes
- Access to line voltage and current measurements from metering devices
- Access to existing Ethernet communication links to rapidly disseminate the rich information from a PMU to a data processing unit

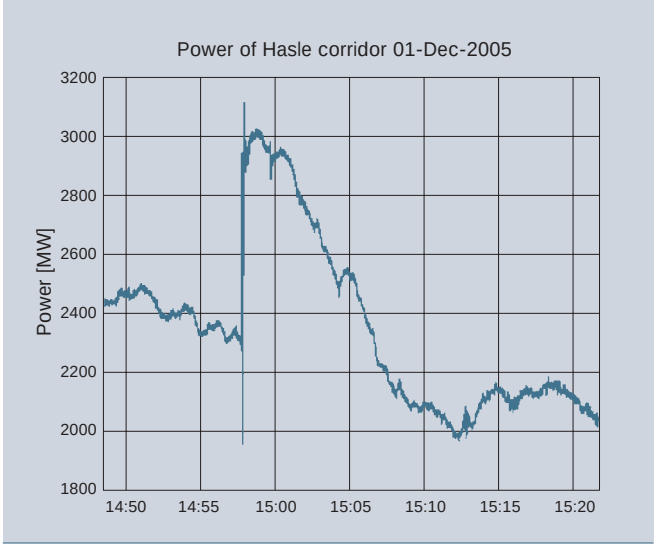
A detailed analysis together with the customer and his profound knowledge of the system led to the selection of four sites: Hasle, Fardal, Kristiansand, and Nedre Røssåga substations 1.

Countless measurements were collected at these four PMU stations and analyzed in order to demonstrate system information in normal operating conditions, and the dynamic response during more critical system disturbances. For example, on December 1

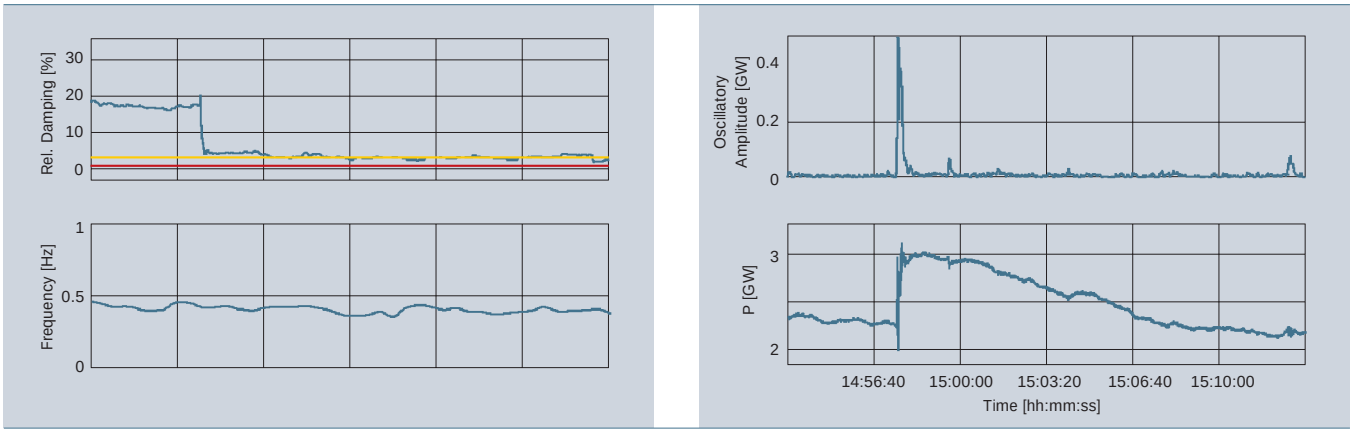
2 Captured system frequencies in Southern Norway (Hasle) and Mid Norway (Nedre Røssåga)



3 Power flow on 420 kV lines from Hasle towards Sweden



4 Monitoring results: the relative damping, frequency, and oscillatory amplitude are the real-time estimates of the most dominant oscillatory mode contained in the measured response P



2005 a large disturbance occurred in the Nordic power system. The disturbance was initiated by a fault in Northern Sweden. Transfer trip schemes, which should have shed generation in Norway, failed, leading to surplus generation and subsequent overloading of remaining power transmission lines in Northern Norway. This led to an uncontrolled collapse and the formation of several islands in Northern Norway.

The wide area impact of this local disturbance is clearly seen – in real time thanks to the time synchronized recording – in the PMU measurements shown in 2 and 3[1]. 2 shows the system frequency as derived from voltage phasor measurements in Hasle (Southern Norway) and Nedre Røssåga (Northern Norway), respectively. The time of network separation and resynchronization are easily detected. The system imbalance due to a cut-off of a significant generation surplus area in the north of Scandinavia led to the activation of primary reserves in the rest of the system. The sudden increase in power flow on the Hasle corridor (power flow towards Sweden indicates that a large amount of the power deficit is compensated by generation in Southern Norway.

To estimate the stability of the complete, widely extended grid in real-time, carefully selected PMU signals are run through an analysis which employs a model-based approach[2]: An autoregressive model with time-varying coefficients and Kalman filtering techniques optimally identifies the best suited model parameters [4]. This method, for the on-line detection of oscillations, was applied to the measured response of power transfer

5 Controller tuning for 0.33 Hz mode regulating the SVC in Sylling using angle measurements from Nedre Røssåga and Kristiansand

Footnotes

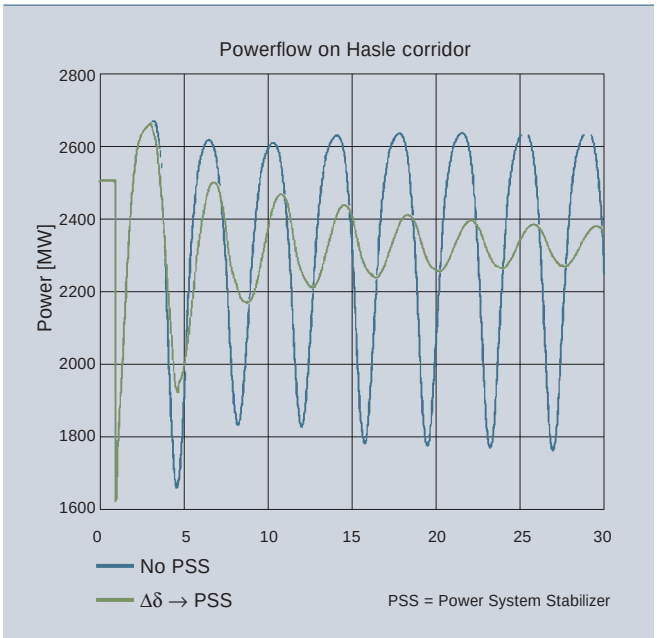
[1] In the past, such a wide-area dynamical view would have been difficult and time-consuming to assemble and would only have been possible after the event had occurred.

[2] Its extension to a model-based controller design is possible in the future.

across the Hasle interface 3 during the December 2005 disturbance.

The resulting estimate of the dominant oscillatory mode is shown in 4. The step-like change in relative damping from approximately 15 percent before the initiating event to between 4 and 7 percent during the period after the disturbance can be clearly seen. The modal frequency, which is a function of the network topology and connected elements, remains more or less unchanged; it hovers around its mean value, changing only slightly after the disturbance from 0.39 to 0.42 Hz. Similarly, the estimated oscillatory amplitude increased temporarily in the first 15 seconds after the event. By appropriately choosing alarm thresholds, this type of information can easily be used to automatically trigger operator warnings.

6 Power flow on Hasle corridor with and without damping controller



Close cooperation such as that between ABB and Statnett is the only feasible way to develop solutions for the challenges of a complex system like a power grid.

Once these warnings are received, the operators have to take corrective action to stabilize the system. At present, several SVC units (Static Var Compensator – a FACTS device) in the Norwegian system are equipped with Power-Oscillation Damping (POD) functionality, using local measurements (eg, bus voltage or power) which contribute to the damping of inter-area electromechanical oscillations as input. While this works well, local measurements may not in all cases provide adequate mitigation of critical inter-area modes.

The aim of the current common project between Statnett, SINTEF and ABB is therefore to investigate how remote measurements from PMUs can best provide input signals to damp the critical modes in the extended grid using the existing SVC actuators.

As a first step towards this objective, a computer simulation study was conducted on the PMU measurements at Hasle, Kristiansand, Nedre Røssåga, and Fardal. To obtain the optimal damping controller parameters, several existing automatic control approaches (lead-lags, robust H∞ design, and adaptive methods) were tested. of the 5 and 6 show how the SVC unit in Sylling, close to Oslo, can be tuned to damp oscillations around 0.33 Hz using voltage angles from PMUs in Kristiansand and Nedre Røssåga.

The resulting damping of the low frequency mode clearly demonstrates the benefit of WAMS technology in that it is possible to take informed as well as timely control and protection actions based on high resolution PMU measurements.

Lessons learned

The close cooperation of technology providers such as ABB, and technology users like Statnett is the only feasible way to develop solutions for the challenges of a complex system like a power grid. The technical problems addressed here are very similar for many other energy systems and operators. The unique experience ABB gained in this joint R&D collaboration provides critical feedback and direction for development of new products, which in turn leads to improved utilization of existing grids in a reliable manner.

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Control and protection

Creating a control and protection relay for medium voltage distribution feeders

Mohamed Y. Haj-Maharsi, Deia Bayoumi, Thomas G. Sosinski, Doug Voda

To be able to provide a level of safety and productivity that goes beyond the ordinary, a company may often require installations whose specifications go beyond those that are available “off the shelf”. This was the challenge that faced Hydro-Québec in procuring medium voltage feeder-protection units – a challenge that was met through close cooperation between the company and ABB.

As a leader in the fields of power system and apparatus protection, Hydro-Québec is continuing to develop protection applications that place strong emphasis on the safety of its employees. To increase the protection and reliability of its medium voltage feeders, Hydro-Québec has developed specifications for the upgrade of its feeder protection relays using the latest generation of microprocessor controlled protection relays. Compared to standard protection products, this solution permits multiple benefits to be reaped in terms of protection, serviceability and performance. The key lies in a solution using a single enclosure with redundant power supplies and combining primary and back-up protection elements.

Advantages include improvements in product performance, the reliability of electronic device operation, and installed relay life, while reducing retrofit, training, and maintenance costs. Emphasis on application and product design by Hydro-Québec significantly eases the replacement of legacy equipment with new generation protection systems.

It was ABB’s record of providing solutions that integrate multifunction capa-

bilities within a single unit and with versatile communication capabilities and innovative solutions for protection functionality – Engineered for Safety™ – that convinced Hydro-Québec to select ABB as a prime supplier for its medium voltage feeder protection, control, and automation solution.

Hydro-Québec's specifications combined advanced application and analysis requirements with high reliability demands and the need for an easy-to-use interface. Fulfilling this was only possible through significant cooperation and communication between the personnel of the two companies in all phases of product planning, development, material selection, and product validation and manufacturing certification. These interactions broke new ground in development techniques, material selection and the testing process of the final product. The result reflects world-class product function and performance.

Protection beyond the ordinary

Hydro-Québec, the world's largest producer of hydroelectric power, serves Québec, Canada, and areas of the north-eastern United States. Hydro-Québec's distribution division is responsible for maintaining the reliability of distribution network apparatus and the continuous delivery of electric power to its customers.

To strengthen its feeder protection system, Hydro-Québec issued a call for tender in April 2005 to build a protection unit featuring primary and redundant protection systems enclosed in a single case. The relay was needed for retrofitting existing equipment. Design emphasis was on advanced protection, control, system reliability and reduced maintenance. The new relay provides automatic transfer from main to redundant protection as well as a failsafe mechanism for apparatus protection in critical fault situations.

In July 2005, ABB was selected to build the new protection relay. A series of meetings between ABB and Hydro-Québec laid the framework of a valuable collaborative process and led to the creation of a protection relay tailored to Hydro-Québec's needs.

The product name selected by Hydro-Québec was CEPA, "Control Et Protection des Artères" (French for control and protection of distribution feeders).

Hydro-Québec, the world's largest producer of hydroelectric power, serves Québec, Canada, and areas of the north-eastern United States.

The protection unit

CEPA is an advanced microprocessor-based feeder protection system incorporating the latest innovations in protection, control and automation features. Due to its redundant protection functionality, it is the ideal solution for providing highly reliable protection and control of distribution and sub-transmission line applications.

CEPA offers a complete package of protection functionality, including the features listed in Factbox 1. This protection allows the relay to be used in most distribution and sub-transmission applications.

All protection schemes provide parallel fault detection and are autonomous in terms of power supply, measurement and processing of analog signals, A/D converters, binary inputs and outputs, in accordance with specifications and descriptions defined in the standardized technical specifications of Hydro-Québec.

CEPA's user interface encompasses signal lamps, control push buttons, an operator control interface (OCI) on the front featuring dual displays and keypads, dual front panel EIA232 ports for communication with a PC connected locally to the relay, a rear panel EIA232 port and an Ethernet port for network communications Factbox 2.

User interface

Relay settings, metering, events, and control are accessible through the OCI and an external PC-based program, WinECP.

Operator Control Interface (OCI)

The OCI design is temperature compensated, permitting the display to be viewed clearly throughout the entire operating temperature range (–40 ° to +85 °C). The OCI continually displays magnitudes for current and voltage quantities. The OCI displays the number of fast trips allowed, the reclose counter, and the total number of reclosures allowed.

Windows External Communications Program (WinECP)

WinECP provides users with an easy method of communicating with the relay.

A user friendly menudriven application permits users to:

- Show or change settings
- Save settings to a file

CEPA unit

Factbox 1 CEPA protection functionality

CEPA protection functionality features include:
- Phase and ground instantaneous and time overcurrent protection
- Multi-shot reclosing
- Breaker failure check

Factbox 2 CEPA features at a glance

CEPA provides these major features:
- Advanced 32-bit microprocessor technology plus Digital Signal Processor (DSP)
- Enhanced Operator Control Interface (OCI) with dual LCD display, one for primary and one for backup protection
- Isolated Communication ports for superior remote communications
- Front and rear communication ports for simultaneous local and remote access
- Multiple Communication Protocols:
  - DNP 3.0 Level 2+ (Standard)
  - Modbus, Modbus TCP/IP
  - IRIG-B time synchronization; Battery backed-up clock keeps time even during power-down

Standard features include:
- Digital Fault Records (DFR)
- Complete multifunction protection
  - phase/ground overcurrent
  - under/over voltage
  - breaker failure
- Complete metering and control
- WinECP user interface software

- Display various records stored in the CEPA relay (summary fault report and sequence of events)
- Monitor metering values, physical I/O and status points
- Save digital fault record and time sequence data
- Control of the breakers and I/O signals

The new relay provides automatic transfer from main to redundant protection as well as a failsafe mechanism for apparatus protection in critical fault situations.

WinECP can be used off-line to explore the capabilities and functionality of the relay. During off-line operation, the settings and configurations displayed are the factory default values. The relay settings can be edited, saved to a file, and retrieved for downloading to a CEPA unit at later time.

Digital fault recorder

The CEPA relay includes a digital fault recorder to analyze faults and disturbances. Settings of triggering sources and selectable cycles of recorded pre-trigger data are stored in the unit. The data collected is held in nonvolatile memory and can be downloaded to a PC. A separate program is used to display the records for post mortem analysis and system planning.

Working with the customer

In developing the CEPA relay, ABB had to ensure customer requirements were completely fulfilled. Some of Hydro-Québec's requirements constituted standard protection features, whereas others were customized for specific environmental and performance needs. ABB and Hydro-Québec were in constant dialog throughout the specification development, product creation, component selection, system verification and production phases.

While electrical safety standards specified the minimum requirements for application performance, Hydro-Québec had functional expectations that exceeded general standard recommendations. To meet these requirements, ABB defined and tested its product for conditions and stresses beyond typical utility application requirements.
ABB will use the knowledge gained through this process to improve its standard products while continuing to provide engineering applications and expertise to Hydro-Québec for existing and future apparatus and protection products.

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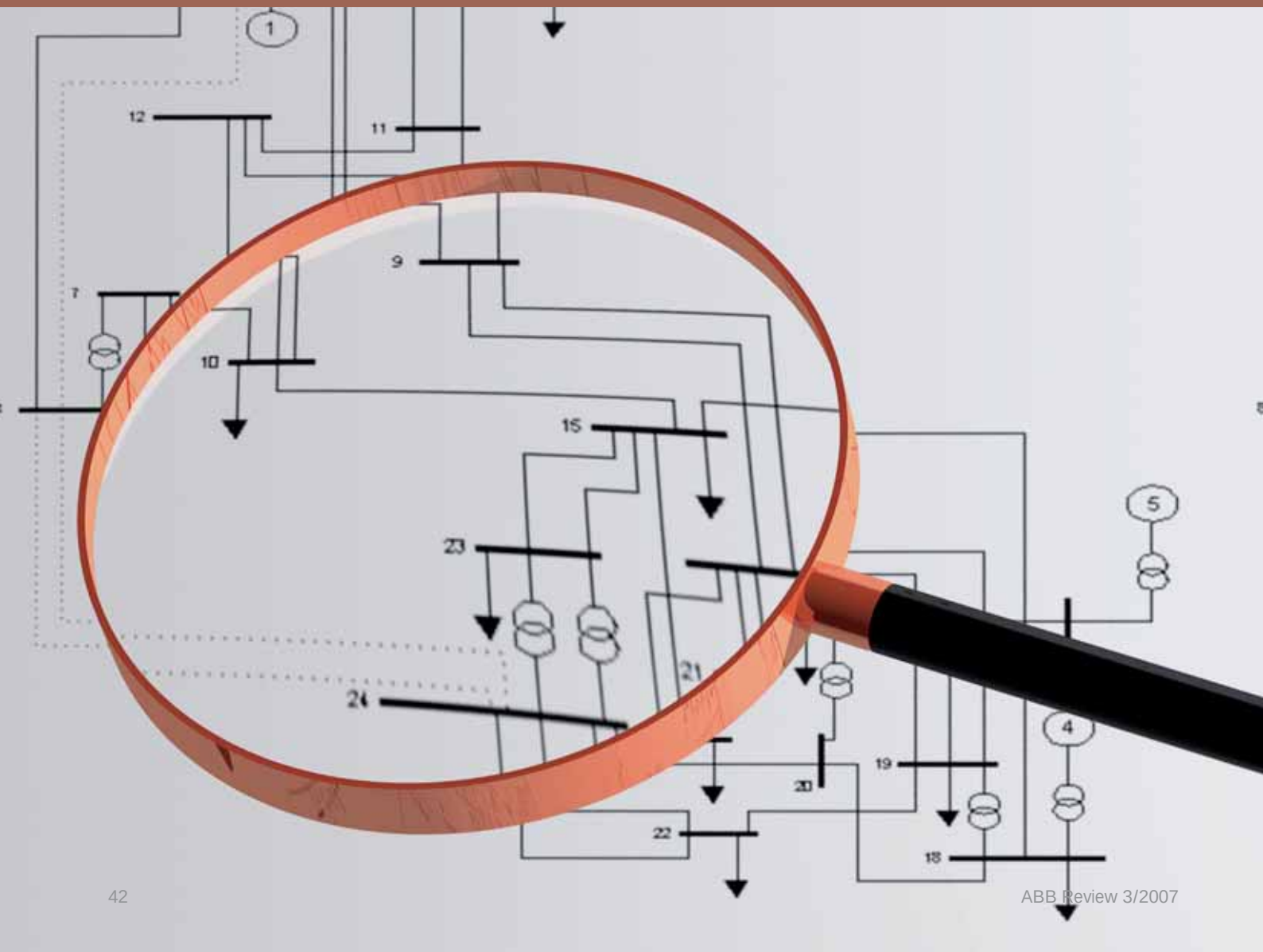
Detected!

A vote of confidence for ABB's high impedance fault detection system

Ratan Das, Deia Bayoumi, Mohamed Y. Haj-Maharsi

They are practically invisible to conventional fault detection methods, are dangerous to the unsuspecting public and have created unique challenges for many a protection engineer. However, the days where high-impedance faults evaded complete detection are now numbered or are even over thanks to an innovative high-impedance fault detection system from ABB. Known as *HIF Detect*™, it uses a multi-algorithm approach to identify downed conductors on soil, gravel, concrete, sand and other surfaces. Not only does it increase overall electrical system safety, but it also offers improved system reliability through better outage management control.



Most of the faults on power systems result in a substantial increase in current flow towards the fault point and conventional overcurrent protection schemes are used to detect and protect against these "low impedance" faults. High impedance faults (HIFs), on the other hand, do not produce enough detectable fault current to trigger conventional overcurrent relays or fuses 1. A high impedance ground fault results when a primary conductor makes unwanted electrical contact with a non-conducting foreign object, for example overgrown vegetation, a road surface or a sidewalk, to name a few. In general, HIFs do not threaten power system equipment, but an energized conductor on the ground surface is a serious public safety hazard. Non-conducting objects present high electrical impedances therefore allowing only small amounts of current through them. So, as far as conventional protection schemes are concerned, there isn't a problem.

High impedance faults (HIFs) do not produce enough detectable fault current to trigger conventional overcurrent relays or fuses.

Two characteristics of HIFs are the low fault currents and arcing. Typical HIF currents on a distribution system can range anywhere from zero amperes for contact with asphalt and dry sand to 50 A for contact with wet grass or 75 A for contact with reinforced concrete [1]. Arcing is the result of air gaps due to the poor contact made with the ground or a grounded object and can start fires. Also, there may be air gaps in the ground (soil) or grounded object (concrete, tree, etc.). These air gaps create a high potential over a short distance, and arcing is produced when the air gap breaks down. The sustainable current level in the arc is not sufficient to be reliably detected by conventional means [2].

ABB, under the *Engineered for Safety*™ program, has come up with a HIF detection solution that is now an integral part of its power protection devices, an example of which is shown in 2. This economical and reliable innovation, known as *HIF Detect*™, is the result of years of research and development. Utilities around the globe are enthusiastic about this solution and some have already partnered ABB to test it in a live power system network.

Field tests provided utilities with a welcome opportunity to participate in the testing of a new and innovative technology.

HIF Detect™ system – an overview

A schematic diagram of an electrical power system equipped with ABB's *HIF Detect*™ system is shown in 3.

HIF Detect™ is based on patented advanced signal processing techniques and includes a multi-algorithm ap-

1 a No-fault voltage and current waveforms and b High Impedance Fault (HIF) voltage and current waveforms

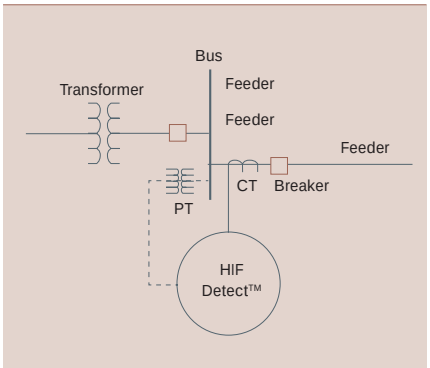
proach. Each algorithm uses various features of ground currents to detect a high-impedance fault. In other words, ground current signatures can be non stationary, temporally volatile, and of various burst durations.

With reference to 4, power system signals are acquired, filtered, and then processed by individual high impedance fault detection algorithms. The individual algorithm outputs are further processed by decision logic[1)] to provide the detection decision, ie, whether or not a HIF has occurred.

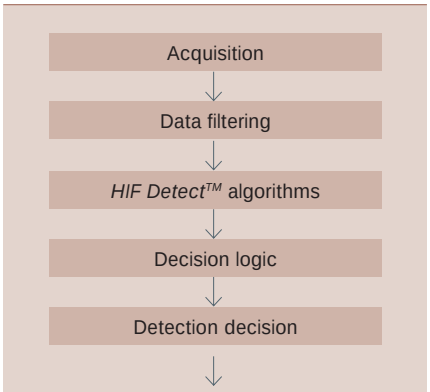
All harmonic and non-harmonic components within the available filter data window can play a vital role in HIF detection. A major challenge is to develop a data model which acknowledges that HIFs could take place at any time within the observation window of the signal, and which could be delayed randomly and attenuated substantially. Such a model is motivated by extensive research, actual experimental observations in the laboratory, field testing, and what traditionally represents an accurate depiction of a non stationary signal with a time dependent spectrum.

2 ABB's REF550 feeder protection device

3 An electrical power system equipped with ABB's *HIF Detect™* system



4 Signal processing in *HIF Detect™*



5 IEDs equipped with *HIF Detect™* and data collection system

As well as being hazardous to the public, HIFs result in service interruptions which reduce system reliability, dependability and continuity.

The proof is in the pudding

ABB's *HIF Detect™* system has undergone extensive and successful laboratory testing (between 1998 and 2000) producing correct detection rates of around 80 percent while false detection rates remained close to zero. Having completed these tests, the technology was implemented in an embedded platform so that HIF detection could be integrated into Intelligent Electronic Devices (IEDs) used for the protection and control of feeders. In 2002, additional HIF field data was obtained from an independent research laboratory after it conducted its own set of tests in a distribution system. To perform satisfactorily with the laboratory and acquired field data, the implemented *HIF Detect™* system was successfully adapted and modified.

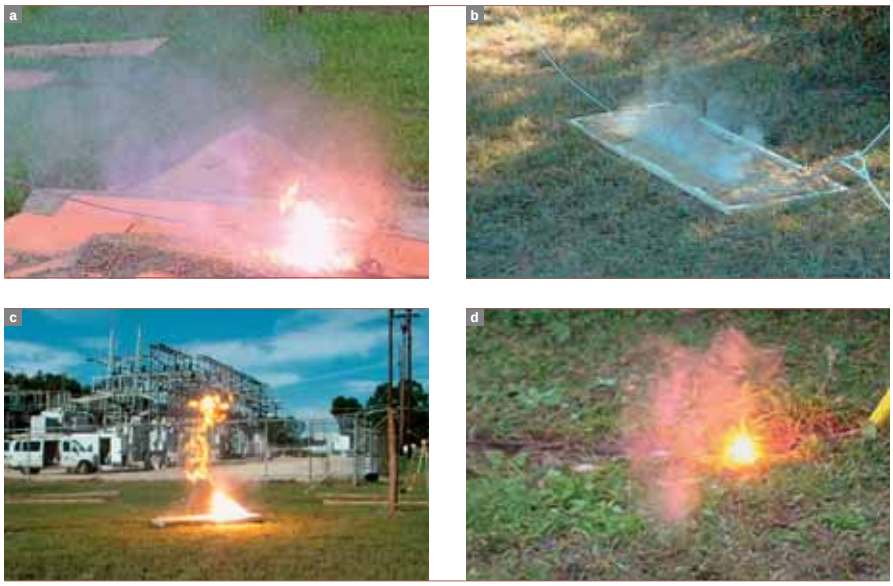
In addition to the IEDs equipped with ABB's *HIF Detect™*, a separate Data Acquisition System (DAS) for HIF field testing was also developed 5. This DAS is independent of the HIF detection units[2)] and is based on LabVIEW software from National Instruments.

Footnotes

[1)] The decision logic can be modified depending on the application requirement.

[2)] The HIF detection units are subject to continuous development and further enhancements.

6 Validation of *HIF Detect*™ on gravel a, sand b, concrete c and grass d



DAS assembly and system software development was carried out by ABB.

Field testing of the IEDs was done while collecting data from staged HIF testing, and was conducted together with utilities in North America, Latin America and the Middle East. Using active feeders, the tests were completed without any interruption to the utility concerned or its customers. Testing on various surfaces is shown in 6. *HIF Detect*™ successfully detected HIFs on gravel, sand, concrete, soil and grass, and it proved to be very secure when presented with various load conditions that resemble HIF situations. From a utility point of view, these field tests provided a welcome opportunity to participate in the testing of a new and innovative technology that is destined to become the most reliable HIF detection method available.

ABB's High Impedance Fault (HIF) detection solution is now an integral part of its power protection devices.

ABB has implemented *HIF Detect*™ as a standard feature in one of its feeder protection devices, the REF550[3]. One of the hallmarks of ABB's solution is its user-friendly design. There are only two settings, the first being the level of security in the HIF detection system. A very intuitive setting, called HIF level, can be set anywhere between 1 (least secure) and 10 (most secure) in steps of 1, with a default setting of 5. The second setting is related to the grounding system; the user can select between a grounded and ungrounded system, with a choice to disable the feature.

Currently field testing of the commercially available unit is continuing.

Safety is the reason

For electric utilities, public safety must always take top priority. However, as well as being hazardous to the public, HIFs result in service interruptions which reduce system reliability, dependability and continuity. Arcing faults result in energy waste and can damage property. Because they have proved evasive in the past, utilities need an economic solution that not only reliably detects them, but also ensures against false detection. Reliable detection can also prevent fires and minimize property damage.

Innovative technology for HIF detection has been developed and proven by ABB with its *HIF Detect*™ system and backed up by outstanding results from many field tests.

HIF detection requires a different approach than that for conventional low impedance faults. Innovative technology for HIF detection has been developed and proven by ABB with its *HIF Detect*™ system and backed up by the outstanding results from many field tests.

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Footnote

[3] REF550 was released onto the market in January 2005. More information about this device can be found at www.abb.com (May 2007).

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Safety in speed

ABB's Fast Protective Device scheme for series capacitors is in a league of its own

Rolf Grünbaum, Joacim Redlund, Louis P. Rollin

Many over-voltage protection schemes for series capacitors are limited in terms of size and performance, and are easily affected by environmental conditions. While the need for more compact and environmentally robust equipment is recognized, so too is the necessity for a new type of general series capacitor protection scheme that would improve performance, reduce total costs and increase flexibility, as well as enhance the series capacitor concept.

Thanks to modern technology and recent developments, ABB has developed such a scheme and called it Fast Protective Device. It is intended to operate in combination with a primary metal oxide varistor in high voltage and extra high voltage series capacitor applications. The scheme has already been tested in high voltage and high power laboratories, and in a pilot installation in the Hydro-Québec 315 kV network in Canada.

Reactive power compensation by means of series capacitors is an efficient way of improving power transfer in high voltage systems with long transmission lines [1]. Series capacitors basically consist of capacitor banks connected in series with the transmission lines, thereby effectively reducing the inductive impedance of the lines. They also increase power transfer and dynamic system stability. Due to the nature of this connection, a series capacitor installation must be able to provide full system insulation to ground. This is achieved by locating the main circuit hardware on single-phase platforms which are then insulated to line voltage level. Unfortunately, equipment at this location is exposed to environmental conditions such as snow, ice and air pollution.

As well as full system insulation to ground, the capacitor bank must also withstand all line currents. However for practical and economical reasons this may not always be possible. The solution then is to bypass harmful currents (thereby limiting the voltage across the capacitor bank). The equipment to do this has to handle very high power and must be stable with respect to protection performance regarding both speed of control and capacitor protection level. It also has to provide qualified dynamic performance for quick capacitor reinstatement after a line fault clearance. Control and protective equipment is normally located at ground potential and signal communication is required from ground to line voltage level.

With so many conditions, it is no wonder the industry has long felt the need for a new type of general series capacitor protection scheme. And this need has been satisfied by ABB with its *Fast Protective Device (FPD)* scheme.

Fast protective device scheme

Many utilities use the *Metal oxide varistor (MOV)* scheme which was introduced around 1980. Although its basic performance is excellent, the number of MOV elements required in many practical applications makes it quite costly. When high fault currents occur, MOV has to absorb large amounts of energy during the fault duty cycle. To reduce the amount of MOV elements needed, the scheme can be combined with a *forced triggered spark gap*. Unfortunately environmental conditions limit the performance and reliability of the spark gap and therefore that of the complete scheme. Furthermore, a protective scheme combining MOV and forced triggered spark gap requires a lot of platform space.

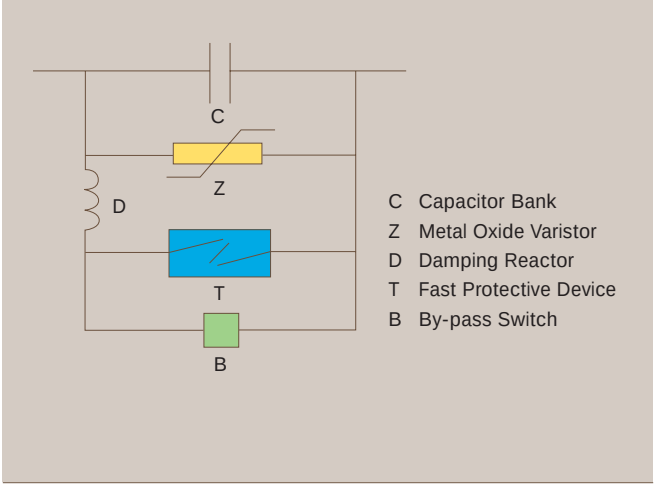
The FPD scheme is a new approach to the protection of high voltage equipment. It has been especially adapted to series capacitor applications but may also be used for the protection of other types of equipment located at high voltage levels. Its design gives it the potential to enhance the series capacitor concept by adding new features. A single line diagram of an FPD scheme is shown in 1 and a schematic overview is illustrated in 2. Included in the scheme are two newly developed key components: the hermetically sealed and very fast high power switch that replaces conventional spark gaps, *CapThor*, and the *Operation and Supervision Unit (OSU)* for control, supervision and power supply from ground to any line voltage. Both are described in greater detail in this article.

ABB's Fast Protective Device (FPD) scheme is a new approach to the protection of high voltage equipment and has been especially adapted to series capacitor applications.

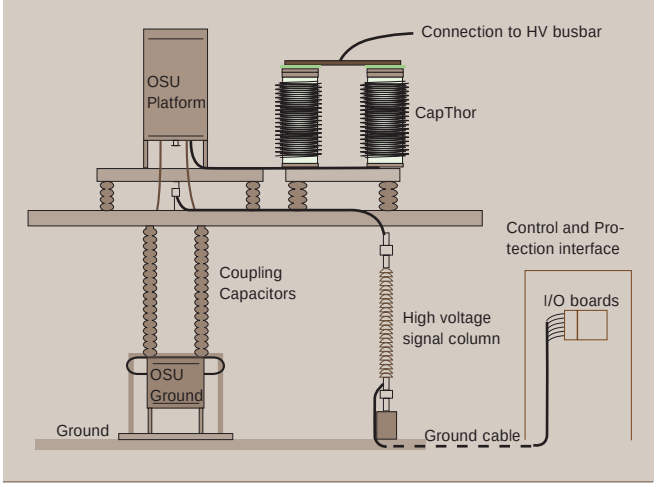
The FPD scheme works in combination with an MOV, and allows bypassing in a very controlled way in order to reduce energy dissipation in the MOV. CapThor can be operated a number of times during a fault cycle so that the series capacitor can be bypassed and reinstated without problems.

The OSU consists of a power supply unit at ground potential; a power supply transmission link to platform

1 Single line diagram of the Fast Protective Device (FPD) scheme



2 Schematic overview of one phase of the Fast Protective Device (FPD)



potential; a cabinet on the platform with energy storage capacitors; and control for activating and supervising the switch.

The FPD operates in combination with a damping reactor that limits the capacitor discharge current, and a fast bypass switch which is used for general switching as well as series capacitor bypassing. In accordance with common practice, FPD control signals are transmitted via a high-voltage optical link. Retrofitting most existing series capacitor installations with the FPD scheme (using standard components) is possible as the hardware is generally independent of the line current and the particular characteristics of the capacitor banks. In addition, the equipment is compact thus simplifying transportation and installation tasks. It is pre-tested before delivery, and with the exception of pressurization during installation, no on-site adjustment or maintenance is needed. Other advantages of ABB's FPD scheme over those that use spark gaps include:

- Capacitor by-passing is possible at low voltages
- It is not affected by environmental conditions
- FPD is flexible for future series capacitor upgrading
- It is self supervising

CapThor

An external and internal view of CapThor is shown in 3. It consists of a very fast-acting high power plasma switch connected in parallel with a fast mechanical switch 3b. The two switches are housed in two composite high-pressure insulator chambers which are filled with gas at an elevated pressure and placed side-by-side on the platform. These chambers, or tubes, are similar to those used for the breaker head housings of modern live tank circuit breakers.

Plasma switch

The plasma switch consists of a high power electrode arrangement into which a conducting electric arc or plasma can be injected, bridging the insulating distance between the main electrodes. In contrast to triggered spark gaps, the function of the plasma switch is essentially independent of the voltage between the electrodes. The time needed before the plasma switch is fully conducting after receipt of an external "close" signal is in the range 0.3 – 1 msec. The injected electric arc is powered by an external energy source, ie, a capacitor rated at 820 µF and charged to 2.4 kV. A trigger unit with very low ignition voltage initiates the arc. The injected electric arc current increases at a rate of about 100 A/µs, an amplitude of 10 kA and a duration of about one millisecond. It is directed into the main electrode gap by magnetic forces created by the current loop in the trigger unit.

The high power arc injection trigger method has been used for 10 years in medium voltage series capacitor applications. The plasma switch has a very high current making capability, and is static with no moving parts.

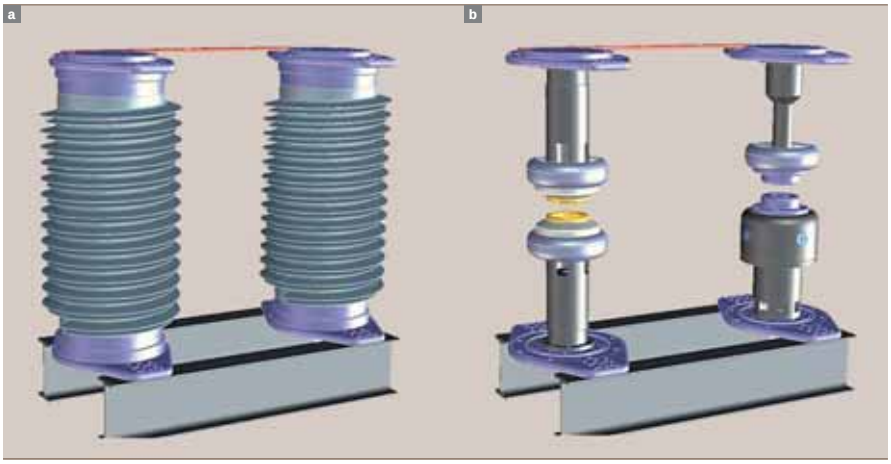
Fast mechanical switch

The mechanical switch consists of a contact which can be moved very quickly between the open and close positions, and is actuated by means of the Thompson magnetic mirror effect of repulsive forces. Like the plasma switch arc injection, it is powered by a similar external energy source but in this case the capacitors are rated at 4,785 µF and charged to 1.2 kV. The basic switch principle is the same as that applied to the high speed closing switches[1)] used in indoor medium voltage switchgear for paralleling ground fault currents to prevent severe damage and personnel danger. The fast mechanical switch has a very high current making capability at low voltages corresponding to the voltage drop in the plasma switch arc and in the local circuit impedances. Closing and opening times are both less than five milliseconds. The switch has only a small breaking capability, and in FPD series capacitor applications it can only be opened when the high voltage bypass switch is closed.

Operation and Supervision Unit

The OSU comprises one control module located at ground potential, a high voltage transfer link and a control module located at line voltage on the platform. In the grounded module, a DC voltage – from an uninterruptible DC supply – is converted to a high frequency AC voltage by an oscillator. The oscillator is connected to two high voltage coupling capacitors bridging the potential difference between ground and line potential. The capaci-

3 External a and internal b view of CapThor. The plasma switch to the left in b and the mechanical switch to the right



Factbox The Kamouraska installation

The Kamouraska installation consists of four series capacitors; each rated at 192 Mvar, and supporting transmission of power in four parallel 315 kV lines. The series capacitors, which compensate the line reactances by 60 percent, also increase the transient stability of the system. The transmission corridor is an important link for the export of power to New Brunswick, Canada. The capacitors were installed in 1987 and are equipped with protection schemes consisting of MOV in combination with triggered spark gaps.

tors are of the same type as those used for Capacitive Voltage Transformers and Power Line Carriers. The capacitance of the transfer links are matched with two connected compensating inductors to give zero circuit impedance for the actual frequency.

In the platform control module, the AC voltage is converted to 1.2 kV and 2.4 kV local DC supply voltages which are then used to continuously charge the energy capacitor bank needed by the CapThor plasma and mechanical switches. The required number of consecutive CapThor operations determines the number of energy capacitor units.

Customer collaboration

In October 2003, as part of the verification process, an FPD field demonstrator was added to the existing Kamouraska series capacitor Factbox located in the Hydro-Québec 315 kV grid in Canada 4. For the first eight months in service the FPD had no protective duty. Instead it was merely energized and exposed to real environmental conditions while various FPD functions were repeatedly tested and controlled by ABB and Hydro-Québec together. At a later stage, the FPD electrically replaced the original spark gap scheme and since then a combination of FPD and the original MOV have functioned as bank protection.

4 Close-up view of the FPD pilot installation: the power supply transfer link in the foreground, the optical transmission link to the right, and CapThor and the OSU cabinet on the platform

To communicate with the OSU platform module, a fiber communication system was installed between the platform and the control room[2]. In the control room, a control and protection interface (CPI) was fitted and this is coupled to the existing protection system and the existing sequence of event recordings with the OSU platform module. During a protective action, the protection system issues a "close" order to the CPI which then transmits it to the OSU platform module where, upon receipt, CapThor goes into action.

FPD testing is expected to end during 2007.

Potential for the FPD scheme

The development of a new protection scheme, characterized by its fast and controllable performance, has opened the way for engineers to focus on new protection strategies. For example, t he FPD has the potential to bypass a series capacitor as soon as an internal line fault is detected and before the protection level of the capacitor is reached. This in turn would reduce discharge current amplitude, MOV energy dissipation, and general stress on capacitors and other equipment. Given this important breakthrough it is now possible to relax the overall design criteria of the series capacitor concept which in turn reduces costs.

Another strategy is as a result of the fast closing and opening feature of the FPD. Because of this, it has the potential to bypass and reinsert the series capacitor for all types of line faults without affecting the system conditions. In other words, the FPD becomes the primary protection and the MOV acts as back-up. In such a set-up, the MOV design requirements can then be relaxed.

The foundation for the third strategy comes from the high closing speed of the FPD, and its ability to be triggered at low series capacitor voltages. A series capacitor in a transmission line can have an increasing effect on the amplitude of the transient voltage, which appears when a line circuit breaker opens to clear a fault. The voltage, which affects the breaking performance of the line circuit breaker, is referred to as the Transient Recovery Voltage (TRV). With the FPD's high closing speed and ability to be triggered at low series capacitor voltages, it is possible to bypass the series capacitor well in advance of the line circuit breaker opening. Given the speed of FPD operation, the line conditions and the TRV voltage across the breaker will be similar to switching the line without any series capacitor.

Everyone's a winner

For Hydro-Québec, the opportunity to work with ABB on a project involving a new product gives the company the chance to evaluate innovative equipment out of the normal supplier-buyer relation path. Both parties gain from the knowledge exchanged during the project in that the designer is made aware of the user's needs while the user becomes familiar with the new equipment.

In a world of growing demand for electric power, ABB's FPD scheme adds to grids' ability to increase power transmission in both a time and cost effective way. It can be expected that the scheme will find increased use in series capacitors all over of the world.

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References

[1] Grünbaum, R., Pinero, J. L., Series compensation goes the distance, Modern Power Systems, June 2001.

Footnotes

[1] These switches are only capable of closing and must be manually opened.

[2] The control room is located approximately 240 meters from the platform.

Partners in technology

A French utility giant and ABB work together to “transform” the distribution network

Pawel Klys, Marcin Blaszczyk, Alain Zagouri,
Peter Rehnstrom, Egil Stryken

Behind every successful product lies knowledge, innovation and team work. One such example is ABB’s TPC transformer, a three-phase distribution transformer with built-in protection. It was designed in response to EDF (Electricité De France) demands for extra functionality and safety, as well as increased distribution network reliability. This transformer meets stringent environmental regulations in that it is hermetically sealed. It is also an example of how effective cooperation can lead to unexpected gains for both sides.

EDF (Electricité De France) Factbox owns and operates one of the biggest distribution networks in Europe. In France alone, 700,000 oil filled distribution transformers, rated at between 50 and 1000 kVA, are installed. While the transformer is considered one of the most reliable components in a network, this reliability is threatened if adequate protection is missing. In particular the relatively small (usually 50 to 160 kVA) pole mounted transformers tend not to be protected by fuses and a load break switch, and this can have significant consequences for the rest of the local network especially during severe storms, and the one that hit France in December 1999[1)] serves as an excellent example to illustrate this. This storm exposed the vulnerability of sections of the network and so the EDF decided to bury part of the MV distribution network. Some of the now buried lines use small non walk-in compact secondary substations (CSS) which are equipped with small transformers (100 to 250 kVA). A switchgear is used to protect these transformers. Doing this also significantly impacts the total investment required.

In any case, long before the storm struck EDF had realized the need to secure the distribution network, and a program was launched in the 1990s to do just that. Beginning in 1996, EDF introduced their own technical specifications for a "self protected" range of transformer rated from 50 to 250 kVA. Known as the TPC transformer, it should be filled with oil and include a load break switch, fuses, and thermal and oil level protection in the tank. Some of the first companies to successfully meet these specifications included Areva (former Alstom), Schneider, Transfix and Pauwels. However back in 1993 ABB was one of the first companies to be involved in the development of self protected transformer technology.

EDF purchases 17,000 transformers per year of which 75 percent are of type TPC. In fact the group believes that "in the near future all new oil filled distribution transformers will be of type TPC to ensure better reliability of the distribution network". Unfortunately a significant part of these oil filled distribution transformers are PCB polluted, and in accordance with European and French regulations the group has launched an exchange campaign to clean up the network before 2010. In addition to this all CSS equipped with 400 and 630 kVA transformers will receive a TPC type transformer. These CSS, specific to the EDF market, will then be known as PUIE.

As an established and recognized supplier of world class transformers, ABB wanted to have its own TPC concept certified by EDF. Not only has this happened but the company is now a concrete part of the frame contract with EDF. This means ABB TPC transformers have access to one of the biggest European utility markets and are also in a strong marketing position in EDF influenced markets. The transformer concept is discussed in greater detail in the following paragraphs.

As an established and recognized supplier of world class transformers, ABB has had its own TPC concept certified by EDF.

TPC transformer concept description

ABB's TPC transformer, 1 and 2, adheres to the current transformer (CT) principles and standards but greatly extends the functionality provided by distribution transformers. This three-phase transformer is completely filled with mineral oil and are hermetically sealed[2]. With additional built-in protection, environmental and customer impact is minimized in the event of unforeseen disasters. The product fulfills the technical requirements as described by the EDF specification[3]. On top of this, ABB's TPC transformer also complies with the new IEC 60076-13 standard[4] for "Self protected liquid-filled transformers".

The built-in TPC transformer protection functionality is generally activated by high voltage wiring faults causing a "three-phase disconnection". The overall purpose of the internal protection is to then:

- Clear all internal faults without any external manifestation
- Protect the upstream network
- Clear the downstream faults without any external manifestation
- Clear the low voltage bushings and busbar faults that in turn cause fuse and overpressure protection tripping
- Protect maintenance crews against possible transformer faults

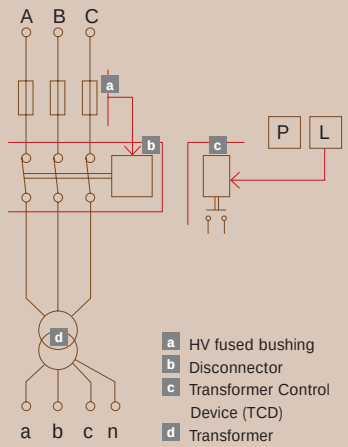
TPC transformer protection does not function when the fault is located on the supply network and when in

Factbox EDF (Electricité De France)

The EDF group is an integrated energy operator present in all sectors of the electricity industry and is a major player in the French electricity market. It also has solid positions in the United Kingdom, Germany and Italy. The group has the largest generation capacity in Europe. It has approximately 37 million* customers worldwide and a workforce of about 156,000 employees*. See www.edf.com for further information.

*2006 figures

1 TPC electrical connection diagram



2 TPC substation unit equipped with plug-in resin bushings

Footnotes

[1] On the 26th, 27th and 28th December 1999, France and Germany were hit by severe storms and rain. The storms caused extensive damage to property and trees as well as the French and German national power grids. For more information, please refer to http://www.absconsulting.com/resources/Catastrophe_Reports/Lothar-Martin%20Report.pdf (April 2007).

[2] Flexible corrugated tank walls enable sufficient cooling of the transformer and compensate for the changes in the oil volume during operation.

[3] The CDN, (Standards Centre) which is part of EDF R&D, publishes a catalogue of technical specifications. These specifications list a series of technical requirements that must be met by a product, a process or a service.

[4] IEC 60076-13 applies to high-voltage/low-voltage self-protected liquid-filled and naturally cooled transformers rated from 50 kVA to 1,000 kVA for indoor or outdoor use. http://www.iec.ch (April 2007).

operation, it doesn't cause a supply network outage.

The advantages of TPC transformers are numerous, with the most obvious being the environmental impact in times of failure. Additionally the quality of the energy delivered is improved by reducing shut-down times. Maintenance is simplified because the rules for the TPC transformer are equivalent to the standard hermetically sealed transformer maintenance rules. The use of pole mounted units 3 eliminates the need for the fuse/switch elements, and in substations, TPC transformers are considered a compact solution.

Even though the transformer was designed according to EDF requirements, the concept can be applied to three-phase oil immersed transformers from 50 to 250 kVA, with the possibility of extending it to 630 kVA in the future. The current equipment limits the voltage of the transformer to 24 kV.

Manufacturing

ABB's TPC transformer technology was initially developed in Finland. However in 2004 the project was transferred to Lodz, Poland mainly because it is the site of an ABB "focused factory" [1] which concentrates on the manufacture and testing of SDT oil transformers. The initial TPC concept has since been modified meaning that the cut off protection system concept has been redesigned and simplified to make the proposed solution more reliable and production friendly. This was mainly driven by feedback from EDF (in particular EDF R&D) and their in-depth understanding of specific customer needs. The TPC transformers have been subjected to numerous tests around Europe but the protection functionality has been verified at the experienced and specially equipped EDF laboratory in Les Reanadiers.

3 TPC pole mounted transformer type equipped with outdoor resin bushings

This new solution is currently being patented, something that may not have been possible were it not for the fruitful cooperation that existed between ABB and EDF.

The things that differentiate one transformer from another are the security features provided and/or additional functions that satisfy customer requirements and build added value.

TPC as a new marketing tool

The relationship between ABB and EDF is most certainly not over. Rather it looks set to continue for the foreseeable future. EDF is a natural partner and the main customer for TPC transformers and ABB's strategy will focus on continuously improving its business relationship with France's biggest utility. As a fully approved transformer supplier ABB is not only in a position to meet normal EDF demand, it will also help the group meet the requirements of the PCB oil transformer replacement program.

On the other hand, having a fully approved product means the search for potential customers is definitely more diversified. And the TPC solution is not limited to EDF and France. For example, to meet new regulations brought into force following the havoc caused by hurricane Gudrun in 2005, Sweden is currently working towards a specification which follows the IEC 60076-13 standard. In anticipation of this ABB has developed standard transformers with TPC features specifically for the Swedish market[5]. Successful marketing has already yielded an order from Jämtkraft, a utility company in the north of Sweden. The order was secured in cooperation with the CSS manufacturer Norrmontage. ABB in Lodz commenced production of the TPC transformer for the international market in the first half of 2007. ABB sales teams around the globe are now busy promoting this sophisticated and advanced TPC transformer concept as well as monitoring the markets for potential customers.

The basic principles or physics surrounding transformer operation will always remain the same. What differentiates one transformer from another however are the security features provided and/or the inclusion of functions that satisfy various customer requirements and build added value. ABB shows that it understands these requirements by promoting new and more effective solutions, and by leading the change process wherever it is needed.

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Footnote

[5] These solutions have been developed and introduced by ABB Sweden under the SafeGrid concept.

Reference

[1] Hegyi, S., The manufacturing beat, *ABB Review* 1/2006, pp. 12–15 (paragraph entitled Batch flow factories, p. 14).

Oiled and ready to go

Advanced application of ABB BIOTEMP® vegetable oil in a HV power transformer

J. C. Mendes, A. S. G. Reis, E. C.Nogawa, C. Ferra, A. J. A. L. Martins, A. C. Passos

Since it invention, the transformer has evolved in terms of added functionality and size to keep pace with rapidly changing and complex electric power systems. One thing that has remained virtually unchanged since it was first applied in Germany in 1890 is the use of mineral oil as an insulating and cooling media. However, the global crude oil crisis in the early 1970s and the ever increasing demand for environmentally friendly combustibles has seen the birth of several initiatives as well as extensive technology developments focused on finding alternative fuels, in particular for the automotive industry.

For their part, Brazilian electric power utilities have worked hard to develop insulating vegetable oil based on castor oil. However, an advanced high performance insulating vegetable oil for high voltage power transformers and apparatus, developed by ABB and known as BIOTEMP®, seemed just the solution these utilities were looking for. The first worldwide application of BIOTEMP® vegetable oil as an insulating and cooling fluid in a high voltage power transformer has been made by CEMIG, an electrical power utility based in the Southeastern region of Brazil and a key ABB customer.

Cost effective operation of electrical power generation, and transmission and distribution systems is related to reliability, availability, loading capability, extended useful life and reduced power transformer maintenance in connection with environmental preservation requirements. These factors have pushed many power utilities into searching for advanced technologies for both new and refurbished transformers.

In Brazil, for example, utilities and industries are increasingly interested in vegetable oil filled equipment not only for environmental reasons but also because of a government effort encouraging the use of vegetable related fuels[1]. In addition, there is a drive to replace as much imported mineral insulation oil as possible because of (a) the problem of corrosive sulfur from foreign oil imports and (b) economic reasons. And finally, the Brazilian Standards Committee has already published an insulating vegetable oil specification similar to the corresponding ASTM[2].

One utility in particular has never been wary of trying new technologies. On the contrary, CEMIG Factbox 1 has a long tradition of supporting the development and application of advanced ABB technologies. For example, in the 1970s it was the first utility in Brazil to introduce ABB's[3] 525 kV long transmission system, and in 1992 it was also the first to support ABB in the development and application of a project that focused on the on-site repair of large power transformers [1]. More recently, CEMIG has come up with a complete solution for a 525 kV shunt reactor diagnostic and complete refurbishment [2]. It should come as no surprise then that it was the first utility in the world to use BIOTEMP® [3] as an insulating and cooling fluid in its transformer type rated for a system voltage level of 145 kV.

BIOTEMP®, a superior performance renewable and biodegradable vegetable oil is compatible with solid insulating materials and is 97 percent biodegradable in 21 days.

Let's work together

Besides its continued support in the development and application of new technologies, other factors contributed to its inclusion in the project. For example, as a power utility, the company is constantly striving to increase power delivery reliability to its customers, and this means taking into account extreme and safe high transformer overload capability. Additionally, it is keen to be a lead supplier of environmentally clean and reliable energy and the use of a fully reprocessed, renewable and easily dispensable insulating oil is certainly a step in the right direction.

This joint project between ABB and CEMIG focused particularly on a transformer type delivered to CEMIG in 1974. Originally rated at 138/13.8 kV, 10/15 MVA, ONAN/ONAF, the application of advanced technologies involving hybrid solid insulation (DuPont Nomex® plus Cellulose) combined with ABB's BIOTEMP® vegetable oil as an insulating and cooling transformer fluid has increased the rated power to 25 MVA (ONAF). The refurbished transformer also includes:

- Up-to-date ABB TrafoStar™ technology
- An extremely high overload capability – up to 70 percent above the rated power – without any loss of useful life
- ABB's advanced TEC transformer electronic control and on-line monitoring system

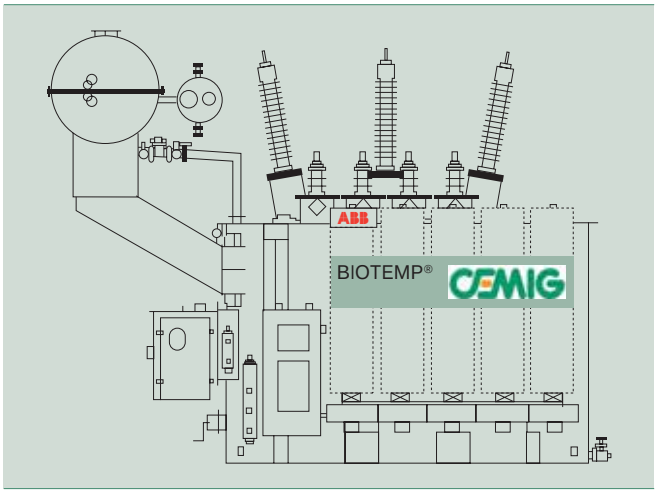
Factbox 1 CEMIG

CEMIG (Companhia Energética de Minas Gerais) is the electrical power utility of the State of Minas Gerais in the Southeastern region of Brazil. CEMIG has an installed capacity of 6113 MW, a transmission system comprising more than 21,000 km of lines (4,912 km of line are reserved for the extra-high voltage level from 230 kV to 500 kV) and a distribution system extending over more than 379,400 km. It supplies electricity to an area equivalent to a country the size of France (or roughly 568,000 km²). This area includes 774 cities and a population of about 17 million people.

Factbox 2 Typical transformer insulating fluid properties.
Note: H.T.H = High Temperature Hydrocarbon Fluid (ASTM D5222)

TYPICAL PROPERTIES OF INSULATING FLUIDS				
	BIOTEMP	Mineral Oil	H.T.H.	Silicone
Electrical				
Dielectric Strengh, kV (ASTM D877)	45	30	40	43
Physical				
Viscosity, cSt. 100°C	10	3	11.5	16
(ASTM D445) 40°C	45	12	110	38
0°C	300	76	2200	90
Flash pt. °C (ASTM D92)	330	145	285	300
Fire pt. °C (ASTM D92)	360	160	308	330
Specific Heat (cal/g/°C) (ASTM D2766)	0.47	0.43	0.45	0.36
Coefficient of Expansion (per °C) (ASTM D1903)	6.88×10^{-4}	7.55×10^{-4}	7.3×10^{-4}	1.04×10^{-3}
Pour pt. °C (ASTM D97)	-15 to -25	-40	-24	-55
Sp. Gravity (ASTM D1298)	0.91	0.91	0.87	0.96
Color (ASTM D1500)	<0.5	0.5	0.5 – 2.0	<0.5
Environmental				
Aquatic Biodegradation Rate (%) 21 day test using CEC-L-33-A-93/94	97.0	25.2	27.1	0.0

1 The new regulating transformer rated at 25MVA, 145kV and filled with ABB's BIOTEMP® vegetable oil



Factbox 3 Transformer data before and after the revamp

	Original	Refurbished
Serial Number	54381	
Manufacturer	ASEA	ABB
Year	1974	2006
Frequency, Hz	60	60
Phases	3	3
Voltages	138 ± 2 x 2.5% / 13.8 ± 16 x 0.625 kV	
Rated Power, MVA	15 (ONAF2)	25 (ONAF2)
Overload, MVA	-	37.5 (6h, 150%) 42 (4h, 170%)
OLTC	UZERN 250	UZF 250
Insulation	Cellulose	Hybrid (Nomex + Cellulose)
Oil Type	Mineral	BIOTEMP®

- Low voltage on-load regulation using ABB's UZ type on-load tap changer filled with BIOTEMP® vegetable oil
- High voltage ABB GOB type bushings also filled with BIOTEMP® vegetable oil

The benefits provided by such a transformer as seen by CEMIG include:
- High transformer reliability
- High transformer availability due to reduced maintenance needs
- Reduced installation costs
- The risk of an explosion and the consequent ground and underground water contamination is significantly reduced when compared to a mineral oil filled transformer. Even if an explosion were to happen, the vegetable oil would generate much less hazardous non-toxic by-products.

BIOTEMP®: a superior vegetable oil

BIOTEMP® is the brand name of an advanced biodegradable electrical insulating fluid made of high oleic vegetable oil and extracted from renewable natural agricultural sources. The fluid has excellent dielectric characteristics with high temperature stability and superior flash and fire resistance: 330 °C and 360 °C respectively while mineral oil has flash and fire temperatures of 145 °C and 160 °C. BIOTEMP® is very compatible with solid insulating materials and is 97 percent biodegradable in 21 days. It is an inhibited oil and has been approved according to both ASTM D2440 – which concerns the "Standard Test Method for Oxidation Stability for Mineral Insulating Oil" – and ASTM D3487 type II [4] – it does not contain any PCBs. A comparison of BIOTEMP® with other insulating fluids is given in Factbox 2.

The development of advanced new materials means utility services can upgrade old transformers, thus allowing increased safety, low maintenance and increased product lifetime.

BIOTEMP® vegetable oil can absorb water thus greatly increasing the life of the insulation paper immersed in it. In fact a study based on tensile strength and degree-of-polymerization measurements has shown that Kraft paper immersed in BIOTEMP® lasts twice as long as paper in transformer oil derived from petroleum sources. This property combined with BIOTEMP®'s superior thermal properties means a transformer can support a higher hot spot temperature in its winding. Because of these thermal properties, transformer installation requirements become a little less complicated in that:
- Fire walls in the substation bay are no longer required
- Fire liability and insurance costs are reduced
- Fire extinction system requirements in the substation bay can be effectively optimized
- The distance between the transformer and adjacent equipment and/or buildings becomes less critical

Putting it all together

The electrical and mechanical redesign of the transformer was fully developed by ABB Brazil. Engineering efforts concentrated in particular on:
- *Winding insulation dimensioning* using Nomex® paper and board insulation. The dielectric permissibility of these impregnated in insulating vegetable oil is very different to that of standard cellulose paper in insulating mineral oil. As a result, a specific electrical potential distribution exists based on the combined insulation structure formed by the cellulose or Nomex (paper and/or pressboard) impregnated in the insulating oil
- *Internal winding connections* using paper insulated cables for electrical

Footnotes

[1] Nowadays Brazilian cars use a flexible fuel automatic control system that allows cars to run on a natural gas, gasoline, sugarcane ethanol and a mixture of gasoline and ethanol in any percentage of each combustible. Additionally biodiesel is used in trucks.

[2] ASTM International is an international standards development organization that develops and publishes voluntary technical standards for a wide range of materials, products, systems, and services.

[3] In the 1970s, both BBC (Brown Boveri Corporation) and ASEA contributed – as separate companies – to CEMIG's 525 kV System

and thermal dimensioning for overload conditions
- *External cooling system dimensioning and temperature rise evaluations,* taking into account differences in the viscosity of the vegetable and mineral oils and the extreme high overload requirement

The revamped transformer is shown in 1 and the main data before and after redesign are given in Factbox 3. The transformer manufacturing process was carried out in accordance with the well-established TrafoStar™ regulations. A specially adapted vegetable oil filling process, comprising a separate temporary oil system and dedicated oil processing machines such as a thermo-vacuum plant, filters, heaters and hoses, was used. Other factors such as conditioning, vacuum time, oil filling under a vacuum process, oil circulation time and final standing time before tests have been defined and applied were also considered. Quality control was carried out during each stage of the process in accordance with internal ABB Six-Sigma procedures[4]. ABB high voltage GOB bushings were also filled with BIOTEMP® vegetable oil and rigorously tested.

A great performer

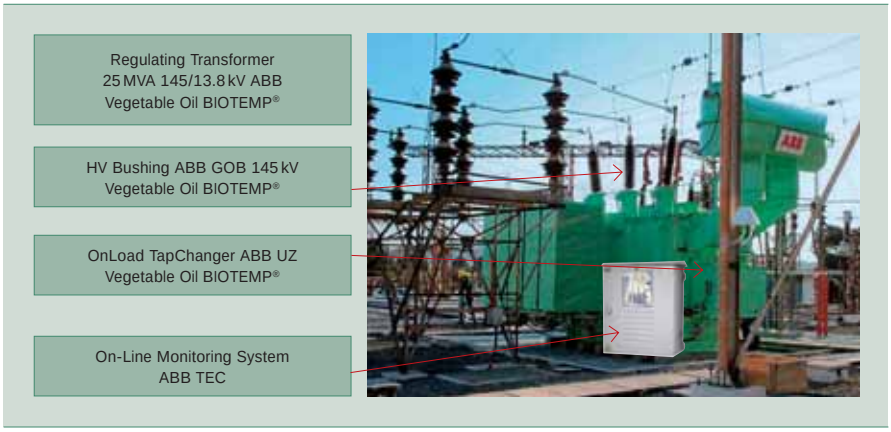
2 shows the assembled transformer sitting in the test bay of the ABB Brazil High Voltage Laboratory. All standard routine tests [5, 6], together with a set of specially designed ones were performed. Dielectric, thermal and operational tests included:
- Lightning (full and chopped waves) and switching impulse tests in all windings terminals
- Short duration AC applied tests
- Long duration induced voltage tests – including Partial Discharge measurements – before and after the heat run (where oil and winding temperature rise measurements were taken) as well as overload thermal tests
- No-load and load sound level measurements tests, including octave-band noise spectrum measurement
- A long duration overload test
- Power frequency long duration over-excitation tests
- A Frequency Response (FRA) test

All dielectric and thermal tests were monitored by oil dissolved gas analysis (DGA). The oil DGA test results showed there was no significant variation in gas concentration before and after the electrical and thermal tests, a clear demonstration of the transformer superiority and reliability [7].

In the long term, the utility can expect a reduced risk of explosions, less maintenance and extended transformer useful lifetime.

The use of BIOTEMP® vegetable oil also has its advantages when it comes to transportation. Because the transformer can be shipped filled with BIOTEMP®, costs and the amount of paperwork needed are reduced. This is in stark contrast to mineral oil

2 BIOTEMP® vegetable oil filled transformer at the HV laboratory test bay (ABB Brazil)

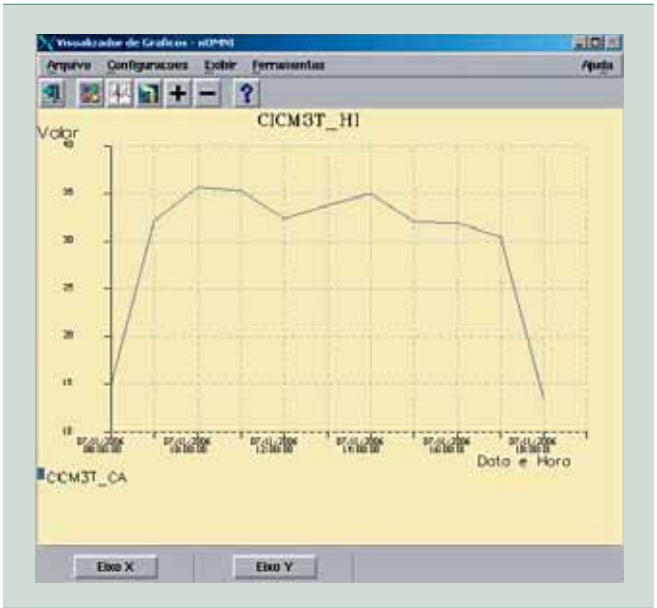


Footnote
[4] ABB Six-Sigma procedures are in compliance with ISO 9001 and ISO 14001 standards.

3 The newly revamped BIOTEMP® vegetable oil filled transformer in operation at a CEMIG substation bay

which must be shipped in a separate container to that of the transformer. Therefore transporting the transformer over 500 km from the ABB factory to the CEMIG Cidade Industrial substation was relatively straightforward. Once installation and commissioning were completed 3, the transformer began commercial operation at the end of July 2006. Since then it handles peak overloads of up to 42 MVA (170 percent) almost everyday 4.

4 An example of a typical daily loading cycle.



Transformer operation is monitored by ABB's TEC online monitoring system as well as by conventional oil tests, oil and winding temperature monitoring and periodic infrared scanning. The aim is to follow, as closely as possible, the performance of both the transformer and the BIOTEMP® vegetable oil. So far the results have shown very reliable transformer performance especially under severe overload conditions.

From here on

The development of advanced new materials is a significant step forward in transformer technology. This also means utility services can upgrade old transformers and reap the rewards of these developments such as increased safety, low maintenance and increased product lifetime. Well-established development cooperation projects, such as that between ABB and CEMIG, create ideal conditions for the application of new and advanced transformer technologies, resulting in benefits not only to both companies, but also to the power industry and society as a whole.

To explain this further using the ABB/CEMIG development project as a direct reference, the thermal properties of new materials, for example, enabled the rated power of the original transformer to be increased. Additionally, transformer reliable overload capacity was also increased from 150 to 170 percent of its rated power. The benefits of using BIOTEMP®, a superior performance renewable and biodegradable vegetable oil from ABB brought about increased safety and reduced costs during installation at CEMIG. In the long term, the utility can expect a reduced risk of explosions, less maintenance and extended transformer useful lifetime.

There remains, however, much to be done for the utility industry. Finding ways of further simplifying and optimizing future substation design will keep engineers busy for a long time. A first step towards this goal would be to review today's transformer installation standards and local legislations. In any case, the work of applying this new transformer technology at voltage levels greater than 145 kV is well and truly underway.

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Pressing challenge

ABB's DDC servo technology speeds up press lines

Sjoerd Bosga, Marc Segura

From Henry Ford's adoption of the moving assembly line more than a century ago, to the large scale deployment of robots today, the automotive industry has often been at the forefront of progress in manufacturing productivity. To achieve further optimization, manufacturers and their suppliers are continuously re-thinking their processes. One candidate with potential for improvement is the press shop – the most capital intensive area of the factory.

The body of a car is typically assembled from several hundred metal parts, most of which are made in presses. The throughput of such presses presents itself as an area with potential for optimization. Unfortunately, increasing the overall speed at which a press runs compromises quality. Time can however be gained by speeding up press actions in between actual pressing. This is the purpose of ABB's DDC (Dynamic Drive Chain) technology. The solution uses servo-motors to reduce cycle times. Furthermore, the technology can be added to existing lines, decreasing risk and protecting the customer's investment.

Significant increases in productivity of flexible tandem press lines at an acceptable cost – this is what the automotive industry is looking for when investing in press shops. Since the press shop is the most capital intensive area in a car factory, investments are not directed exclusively at new lines. The life time of a large press can stretch over several decades – hence operators' desire to be able to upgrade existing lines. ABB is continuously developing new technologies to deliver higher productivity in both new and existing lines.

A press shop produces parts such as car doors, roofs, etc., from flat metal coils. After the blanking operation (in which coils are cut to blanks), the parts pass through a sequence of three to five presses 1. In the most basic configuration of this process, a de-stacker at the beginning of the line takes the blank and loads it into the first press 2 3. Further robots transfer parts from one press to the next; and at the end of the line a robot or human operators place the parts into a rack.

From the aspect of line productivity, the first thing that matters is the duration of a single press cycle 4. This cycle time consists of two parts: One part is entirely determined by the robots (designated T1) and the other part entirely by the press (T2). T1 includes the unloading and loading of the press by two different robots. Typically, unloading starts as soon as the press has opened sufficiently for the unloader to enter it. Similarly, the press will typically start its motion downwards before loading is fully completed. In an ideal configuration, robot and press motions are optimally synchronized. ABB's Stampware software 5 provides this functionality in a standard package.

The basic purpose of servo technology is to permit the press to open and close faster, while maintaining the original speed for pressing.

The motion of the press itself (in the T2 part of the cycle) can be divided into three phases. In the first of these, the press closes, ie moves downwards until the so-called upper die touches the part to be pressed. From this impact point the actual pressing takes place (second phase). Pressing is completed when the press reaches the lowest point in its travel curve, the bottom dead center. From that point on, the press is opening (third phase).

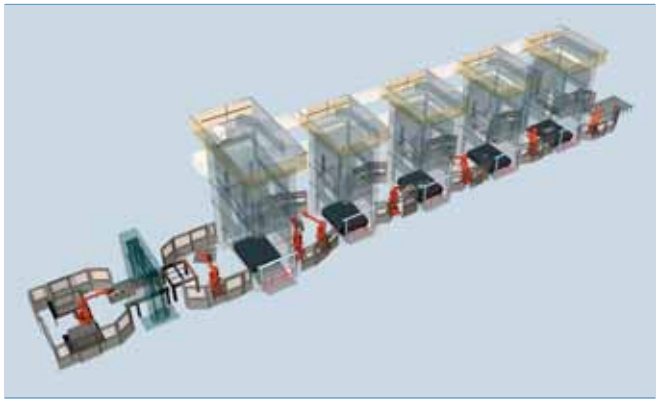
Traditionally, ABB's optimization efforts have focused on the T1 part of the cycle – the time needed by the robots. This attention has been rewarded with success: Innovations such as a special press automation robot, optimized robot placement, robot synchronization techniques and a special seventh axis for the robot have resulted in a reduction of T1 from more than six seconds five years ago to less than three seconds today – even for large parts. However, with T1 being so much reduced, T2 is increasingly becoming the bottleneck.

In a traditional mechanical press, there is no easy way to reduce T2: Speed is dictated by a large flywheel and limited by the requirements of the pressing process. So what means did ABB have to further reduce the cycle time? The addressing of this challenge led to the emergence of ABB's DDC (Dynamic Drive Chain) technology 6i. The development of this technology required intense collaboration between different groups within ABB: notably the global lead center for press automation in Spain and the electrical machines and intelligent motion group at the corporate research centre in Västerås, Sweden. Internal pooling of expertise alone was, however, not sufficient. Strong customer involvement was needed to optimize press line productivity.

Servo technology helps out

The basic purpose of servo technology in large presses is to permit the press to open and close faster, while maintaining the original speed for pressing. In fact, it is even possible to start the pressing at a lower speed than used today and still gain productivity. Slower pressing means improved part quality, the second ingredient to success after speed! Iñaki Zubiete (Robotics and new investments Manager at Gestamp – Estampaciones Bizkaia) explained to the ABB DDC team, that to be able to reach sufficient quality, presses are

1 A tandem press line: blanks are destacked, washed, centered and loaded into the draw press to pass though a series of cutting and punching operations



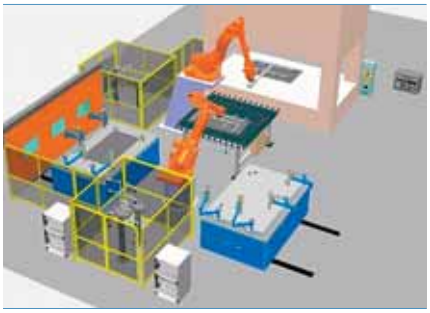
2 An ABB robotic destacker cell in PSA's Poissy factory feeding sheet metal blanks into a press line

often operated at only 80–85 percent of their highest speed, costing 7 to 15 percent of productivity. These figures were confirmed by Santiago Mínguez (Standard Equipment Engineering Manager for Renault Valladolid).

So how much productivity gain can servo technology deliver? Much depends on the dimensioning of the servo drive. To investigate the possibilities on existing press designs, collaboration was started with a press manufacturer: FAGOR. FAGOR is a medium size press manufacturer located in Northern Spain, with whom ABB has had strong cooperative ties for over 10 years. Simulations performed in collaboration with FAGOR showed that even with a rather small servo motor size, a productivity increase between 10 and 30 percent can be obtained using the servo technology alone. Combined with the latest robot automation developments, even higher increases can be obtained!

Limiting the size of the servo drive has been a core aspect in ABB's contributions to servo press development.

3 Robots transferring parts to the press line



While discussing the viability of servo presses with Gerard Lallouette (Structure and Stamping Manager at PSA Peugeot Citroën), ABB concurred that the proposed solution should take into account not only the cost of the press drive itself, but also the cost of the power network in the factory and the cost of energy and peak power. If a large servo press would require 5 MW instead of today's typical 500 kW, this would be a real concern.

A low peak power solution

ABB now offers a servo press drive with a peak power that in most cases does not require redimensioning of the factory's power grid. How is this possible? The secret lies in the control and the drive design, which both started from ideas learnt in previous research projects.

An important aspect of this design is related to the inertias of the moving masses in the press and the drive. While inertias are typically thought of as limiting the dynamical performance of a servo drive, they can in fact be used for energy storage, releasing power when the press drive needs it most.

In a first version of ABB's servo press drive, the traditional flywheel of the press 6f is maintained to give the peak power required during the pressing phase of the cycle. However, in contrast to a mechanical press, there is no mechanical braking, nor is a clutch used to bring the press up to speed. ABB's DDC technology ensures a smooth acceleration and deceleration of the press; and clutching 6g is used after the servo has controlled the press to synchronous speed. In a second version, the traditional clutch and flywheel are eliminated completely, and the servo is dimensioned differently.

A solution for existing press lines

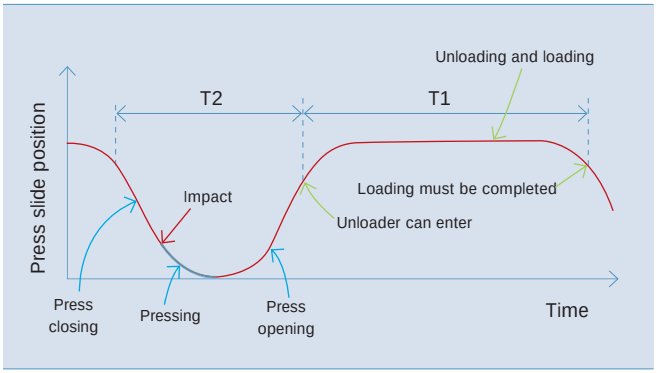
Early in the development of the servo press drive, ABB already discussed the proposed idea with customers such as Gestamp and PSA. The message from these customers was very clear: There should be a servo solution for existing press lines, and it should be possible to get acquainted with servo technology before installing a completely new servo press line. These requirements guided the main thrust of ABB's development efforts, focusing first on a solution that transforms existing presses into servo presses: the *Press Upgrade Kit*.

An important feature, strongly requested by Gestamp and other customers was that this upgrade should be easy to install – well within the time frame of a usual one-month summer shutdown. While such requirements can be considered a severe limitation, it stimulated ABB to design a solution that not only met these requirements, but also constituted a low-risk, reversible solution.

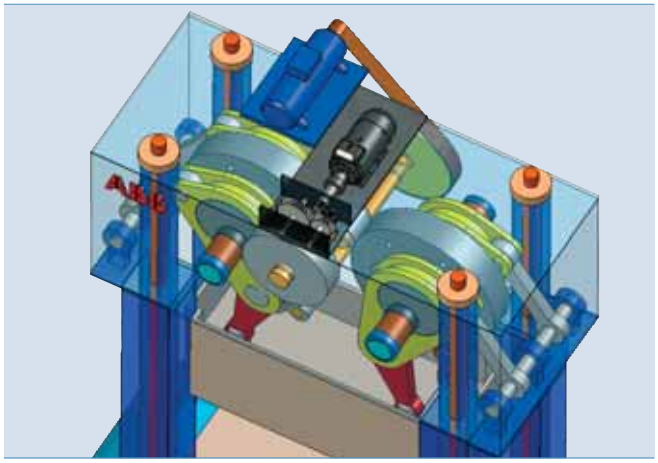
A low risk solution

A customer who is upgrading a press line is usually doing so for a good reason: It can be the production start of a new car model, or – for a Tier-1 – an important contract. So when FAGOR and ABB started to investigate

4 Typical position profile of a classical mechanical press, of which one part (T2) is determined entirely by the press (closing, pressing, opening) and the other part by the unloading and loading equipment (T1)



DDC mounted on a press

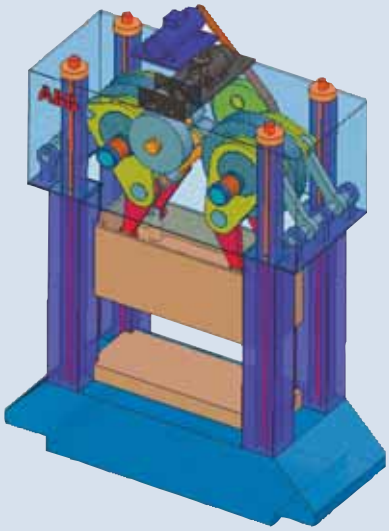


the construction of a first prototype, a main question was whether it could be installed within a very limited time schedule. The solution we designed – the Press Upgrade Kit – can not only be installed in a very short time. If anything unexpected would prevent completing the installation in time, the kit can simply be removed and production can start as planned, using the press in the traditional, mechanical way.

Meanwhile, ABB's discussions with Mr. He, (assistant manager of the No. 1 Pressing department of Honda, Guangzhou, China) led the company to go even one step further: the first DDC servo presses have been designed with a switch that can completely disable the new technology. When switched off, what remains is a classical mechanical press, which can be used in the same way as it has been in the last 50 years.

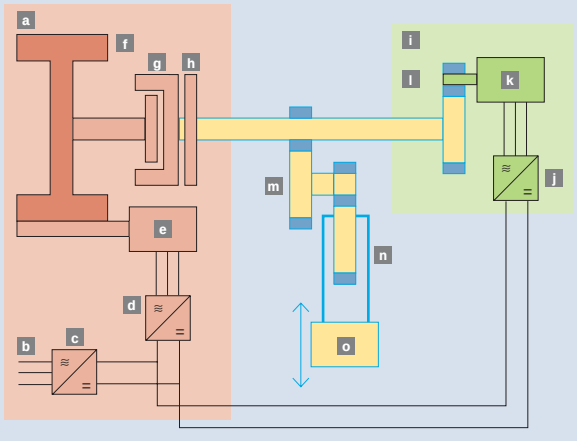
Although the DDC represents a technological leap (the R&D innovations involved go from the new press topologies to the advanced control software), it is built on existing ABB products such as the ACS800 drive and the IRC5 robot controller. This is of great value for the traditionally conservative automotive industry, which will enjoy the benefits of a cutting edge technology while relying on known and proven products that are well supported by local ABB units already serving the industry.

An important question that was raised by both Honda and Gestamp was how the servo speed and acceleration



5 ABB's Stampware is a dedicated software package for ABB IRC5 robot controllers in press shops

6 Schematic diagram of a servo press, showing both the classical mechanical press drive a and the press upgrade kit i



- a mechanical press drive
  - b grid
  - c rectifier
  - d inverter
  - e motor
  - f flywheel
  - g clutch
  - h brake
- i press upgrade kit
  - j inverter
  - k servo motor
  - l auxiliary gear
- m press gears
- n eccentric wheel
- o slide

Factbox 1 DDC (Dynamic Drive Chain)

Traditional automation and press drive systems constituted a typical "discrete" automation case. The different steps of the production process were interlinked by a sequence of "permission signals". The press clutch was engaged when the loading job was finished, and the unloading started when the pressing was done to enable the next loading cycle. This method of operation involved many gaps between the operations resulting in low efficiency. Also, the system failed to adapt itself to the changing conditions on the line, requiring continuous fine tuning to keep a good optimization level.

Some steps were taken to improve this situation, such as ABB's robot to press or robot to robot synchronization. However a total integrated motion control system including the presses has long been unachievable.

In response to this, ABB with its unique combination of robotics and motors and drives expertise, is introducing a revolutionary control and drive architecture that will transform the press lines into a continuous/adaptive manufacturing process: a real Dynamic Drive Chain.

Factbox 2 DDC for press automation

What exactly do ABB's customers expect when working with ABB to automate a press line? While the final goal if of course productivity, there are three key factors for the press shop profitability:

Speed

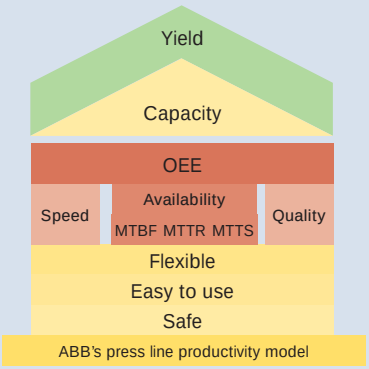
The higher the production rate that equipment can deliver, the lower the capital investment and the running cost needed to run the line (fewer press lines and operators are needed). *DDC brings 10–30 percent increase in production rate.*

Availability

Production equipment has to work without faults for the longest periods possible. *DDC eliminates the clutch and brake failures which are amongst the top 5 downtime sources.*

Quality

Scrapped parts represent a direct loss for operating companies. To minimize the number of rejected parts it is crucial to assure a smooth and slow stamping process. *DDC can bring up to 40 percent slower stamping speed while keeping the same cycle time.*



OEE: Overall Equipment Effectiveness
MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair
MTTS: Mean Time To Service

would affect the press mechanism. As Iñaki Martinez (Stamping Technical Manager, FAGOR) was quick to point out, ABB's servo solution involves much smoother acceleration and deceleration than the clutch and brake for which the current press mechanisms were designed – so the servo will actually increase the life time of the press! In fact, the highest acceleration forces affecting the press die do not occur while using servo control or during pressing, but as the press is starting from standstill using the clutch.

It should also be noted that in the DDC version in which the flywheel is maintained, pressing will be exactly as it always has been, ie, affected by press and flywheel dimensioning only. There are no unknown parameters or settings here – the only setting is flywheel speed. The Dynamic Drive Chain technology automatically and dynamically (hence the name) optimizes the rest of the motion.

Don't stop the presses!

The message ABB received from both Daniel Eguia (Corporate Equipment Manager at Gestamp) and Gerard Lallouette (Structure and Stamping Manager at PSA) was "don't stop the presses!" Today's press lines have intrinsic inefficiencies (start and stop movements, gaps and waits). These must be eliminated by achieving a continuous, optimal and adaptive motion system, a Dynamic Drive Chain. ABB's DDC does this by integrating the control of the press with the control of the robots.

While inertias are typically thought of as limiting the dynamical performance of a servo drive, they can in fact be used for energy storage, releasing power when the press drive needs it most.

Future

Recently ABB was told by Schuler, the world's largest press manufacturer that "in the near future, all new presses will be servo presses". ABB agrees but would like to add: "not just new presses…". The trend from mechanical to electrically driven systems in the pressing industry has just begun and will not be reversed. ABB is positioning itself as a major player in this new market with its DDC – while boosting its competitiveness in the automation systems and motors and drives businesses. The first DDC servo press drive will be installed on a 1200 T FAGOR press this fall. Both FAGOR and ABB are looking forward to demonstrating this servo press to their customers!

While the addition of servomotors to the existing mechanical presses is a first step, it is expected that in the mid to long term, totally electrical-driven presses will take over. In strong collaboration with customers such as Gestamp, Honda, Renault, PSA and Nissan, ABB is defining the parameters of the ideal servopress. Through collaboration with partners such as FAGOR, the company can design the drive to fit future servo press topologies of these companies and others. This development should bring even lower cost, simplicity (no clutch-flywheel) and more pressing controllability.

ABB will continue its close cooperation with both customers and press manufacturers to develop the next generations of automated press lines, anticipating customers' future needs and requirements and providing technology that brings more value to their stamping operations.

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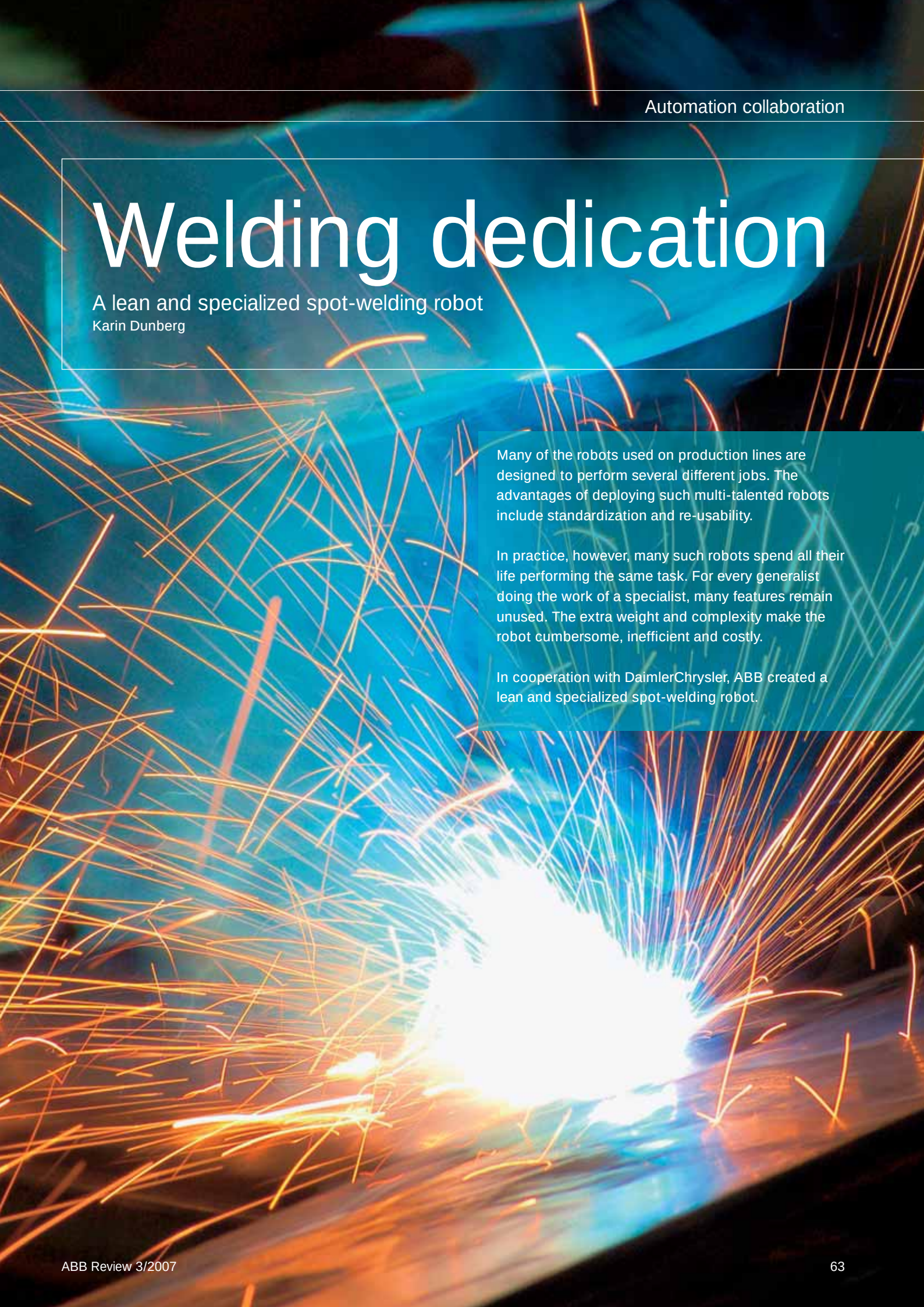
Welding dedication

A lean and specialized spot-welding robot

Karin Dunberg



Many of the robots used on production lines are designed to perform several different jobs. The advantages of deploying such multi-talented robots include standardization and re-usability.

In practice, however, many such robots spend all their life performing the same task. For every generalist doing the work of a specialist, many features remain unused. The extra weight and complexity make the robot cumbersome, inefficient and costly.

In cooperation with DaimlerChrysler, ABB created a lean and specialized spot-welding robot.

Automation collaboration

It all began when DaimlerChrysler contacted ABB in 2003: The company was searching for a new dedicated spot-welding robot.

They were seeking to jointly develop a lean standard robot. This robot should handle a payload of 150 kg to be able to master the majority of the company's spot welding applications. The six-axis robot should also be able to perform a series of spot welding tasks utilizing a single servo-controlled weld gun.

The so-called semi-shelf layout permits a second level of robots to be added to the line, with the robots on the upper level being able to weld upside down.

"We needed a workhorse for our main spot welding applications," said Anton Hirzle, Senior Manager at DaimlerChrysler. "Today we use standard robots for most of our applications. The same robots can weld, glue, handle parts, do whatever you want them to, but we had to pay for a lot of features that we never used in spot-welding applications. We wanted a dedicated robot for spot welding; cost-savings were the most important driver for the project."

DaimlerChrysler is a robot-intensive company with around 9,000 robots in its Mercedes plants and about 5,000 in its Chrysler plant in the United States.

Factbox The DaimlerChrysler Group

The DaimlerChrysler Group, which generated more than € 150 bn in revenues in 2006, can look back on a tradition stretching over more than a hundred years and marked by pioneering achievements. Today, the company is a leading supplier of up-market passenger cars, SUVs, sports and touring cars, minivans and pickups, as is also the world's largest manufacturer of commercial vehicles.

Anton Hirzle, Senior Manager at DaimlerChrysler: "We wanted a dedicated robot for spot welding"

The company consulted several robot suppliers, presenting their ideas on how to this goal could be achieved.

As a result of this, DaimlerChrysler and ABB embarked on a common R&D project in 2004. Instead of adding features, this project focused on removing features that were not needed for spot welding. The goal was to optimize through simplicity.

Almost three years later, the two companies had created a lightweight robot with a wide working range – the IRB 6620. No less than 800 kg of weight has been removed from the original robot! This not only lead to savings in the steelwork, but created a robot that is more agile and easier to handle.

This robot has a payload of 150 kg and a robust wrist-design capable of handling typical integrated-transformer spot-weld guns. The tool-mounting flange conforms to ISO standards for 200 kg and the robot comes with a dress package especially designed for spot welding.

The IRB 6620 is easier to install, has a lower investment cost and a wide working range. Especially the increase in the working range in the area below the robot's base presents an interesting approach for a redesign of spot-welding cells. The so-called semi-shelf layout permits a second level of robots to be added to the line, with the robots on the upper level being able to weld upside down. This approach saves space and provides more efficient integration of the robots in the working cell and hence greater productivity.

Instead of adding features, this project focused on removing features that were not needed for spot welding.

In the long run, ABB wishes to replace most of the multipurpose robots that are used for spot welding today with the lean and dedicated spot welder IRB 6620.

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Additional reading

Negre, B., Legeleux, F., FlexLean – Robots challenge low cost labor, *ABB Review* 4/2006, pp. 6–10, and especially the factbox on p. 8 of that article.

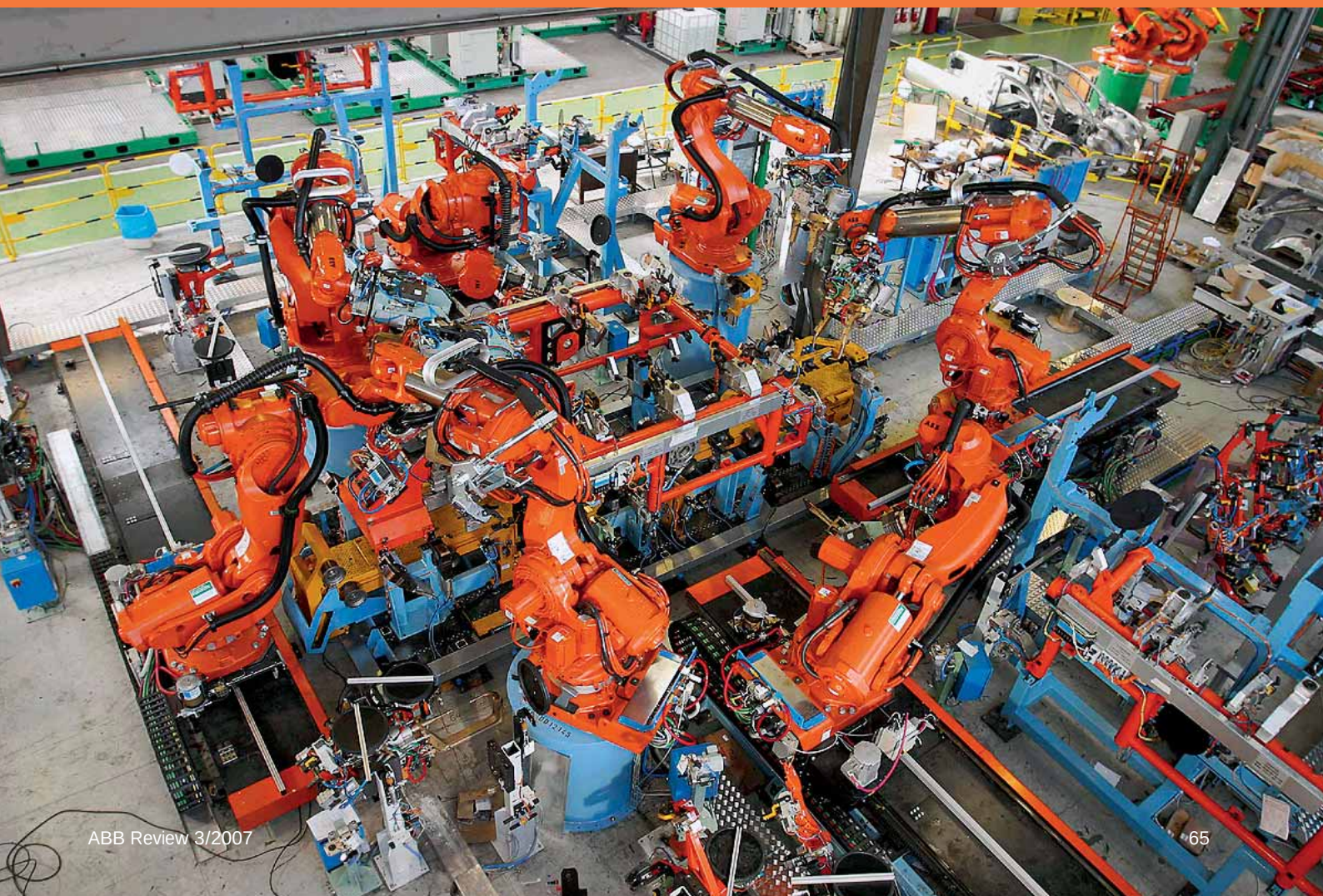
Robotic specialists

The lean IRB 6620 for dedicated spot-welding operations

Ola Svanström

Robots are multi-talents. They are built to perform a number of different tasks with high precision, high speed and heavy loads. When a specific task — and only this task — is required, it makes sense to use a customized version of the multi-functional robot.

ABB's FlexPicker is an example of this highly specialized expert robot, designed to sort different goods with very high speed. Spot welding in the automotive industry is another example where talented "professionals" are of high value.



Automation collaboration

Modern assembly lines for car manufacturing are filled with robots. Most of these robots look like the ones we are used to: they have a long arm with a "hand" that can bend forward and backward and turn around like a golfer in a full swing.

But there are also other mechanical movement systems in place that normally would not be called "robots," even though they work in a way similar their more prominent relatives. These robots can weld, grip, move, lift, sort, paint, grind or hold parts of a car together to help other robot colleagues perform different tasks in an optimal way.

For a car manufacturer, it makes sense to install multi-talented robot types because these can be used for so many different tasks without making major adjustments.

Ten years from now, thermal welding technology will likely still be dominant when compared to mechanical joining or chemical methods.

When we look at the automotive support robots that join parts, it turns out that the majority of them today are there for thermal welding 1. Thermal welding can be done with rather different technologies: conventional spot welding, laser welding, laser soldering or friction steer welding[1]. Regardless of the specific technology, the same robot can be used to operate the thermal joining mechanism.

Ten years from now, thermal welding technology will likely still be dominant when compared to mechanical joining or chemical methods. Given this trend, and the growing requests from the automotive industry for higher flexibility and lower cost, it makes sense to complete the portfolio of robots in an assembly line with specialized welders.

2a shows ABB's new specialist in welding, the IRB 6620, and the multi-talented IRB 6600 2b. The innovative IRB 6620 is a much lighter version of its "big brother," making it better suited for spot welding[2]. As it is more compact, it saves valuable space in the production line, which can now be filled with two welding specialists – one may be hanging from the ceiling or mounted on a second working level in relation to the moving car body. Due to its agility, the IRB 6620 also can reach under a car frame to perform less accessible welding operations.

ABB recently developed robot controllers that allow for coordinated movement of several robots and simultaneous working on the same piece Factbox 1. If the new agile welding robot is connected to such a system, other robots can position the workpiece for welding. This compensates for the slightly shorter reach of the IRB 6620 (as compared to the IRB 6600).

Due to the flexible mounting of the welding robots, several of them can handle a car body at the same time and even reach below or into the car

1 Spot-welding robot in car manufacturing

without disturbing each other. ABB's safe movement concepts ensure a collision-free operation at all times.

While the robot specialists dance around the car body and weld with high speed in all corners, the multitalented IRB 6600 can concentrate on the manifold other operations.

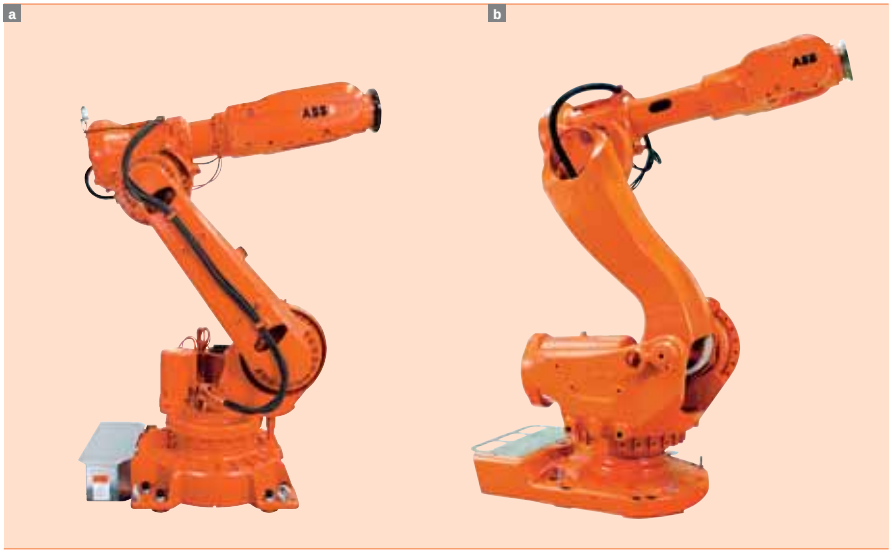
Factbox 1 MultiMove

MultiMove is a function built into ABB's IRC5 robot controller. It permits the synchronization of up to four different robots or positioners, which means it calculates the movements of up to 36 servo axes.

Without such synchronization, a positioner might first have to move a workpiece into position and then stop. A welding robot would then approach the piece, weld and withdraw. Only when the robot had come to a halt could the positioner turn the piece to permit the robot to work on the other side. Using MultiMove, considerable time is saved by allowing many of these movements to take place simultaneously. For example, the welding robot can move towards the workpiece as the positioner brings it to the robot, and the positioner can slowly rotate the workpiece while welding is in progress. The resulting continuous weld would enhance the quality of the final product. The functionality can also be used to permit several robots to weld simultaneously. The resulting time savings permits cycle times to be reduced and throughput augmented.

See also Bredin, C., Team-mates – ABB MultiMove functionality heralds a new era in robot applications, *ABB Review* 1/2005, pp. 26–29.

2 The IRB 6620 a and the larger IRB 6600 b.



3 A FlexPicker handling meat packaging

This combination of generalists and specialists opens up manufacturing to radically new concepts. Through this achievement, respot[3] lines get shorter and faster with eight robots working simultaneously.

The assembly of body sides and roofs becomes more flexible and faster when spot welders and power robots help each other. This increased flexibility is highly appreciated by the automotive industry. It supports the trend to manufacture more car models on the same line, which not only speeds up the process but also enables optimal use of the valuable assets in the production line. A modern assembly line cannot effectively work without specialists that support the multi-talented robots.

ABB has also developed specialists for quite different applications. The Flexpicker 3, for example, is a system with three very light arms and a gripper that can lift and transport light items such as chocolate pieces or pralines and sort them into boxes Factbox 2. The IRB 6600 would be too slow for this, even though it could perform more functions in the sorting process.

The concept of specialist robots is gaining ground in industry. Whenever mass production of parts is required, a specialist may very well be the more flexible and more economic solution.

Factbox 2 FlexPicker

ABB's FlexPicker is a so-called parallel kinematics robot: In contrast to conventional industrial robot designs, in which articulations are arranged serially along a single arm 2, a parallel kinematics robot has three or more parallel arms supporting a manipulator 3.

All of FlexPicker's motors and gears are installed in its base. This makes the moving parts very lightweight, contributing to the robot's agility – accelerations above 10 g can be achieved and handling rates can exceed 120 items per minute.

The robot was designed with hygiene in mind: It has no painted surfaces and can be washed with low-pressure water and without detergents, making Flexpicker suitable for handling food.

The conveyor-tracking functionality of the IRC5 controller permits Flexpicker to pick and place on a moving conveyor, eliminating the time-consuming need to start and stop the belt for every object. Furthermore, the PickMaster software permits the robot to identify and pick irregularly arranged and shaped objects, as frequently occur in food manufacturing.

See also Andersson, H. J., Picking pizza picker – ABB FlexPicker robots demonstrate their speed and agility packing pizzas, *ABB Review* Special Report Robotics (March 2005) pp. 31–34.

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Footnotes

1) Friction steer welding is a welding process in which the head of a rotating pin is moved along the welding seam. The frictional heat and clamping pressure cause the parts to be forged together without melting the metal. The method is primarily used for aluminum.

2) See also "Welding dedication" on page 63 of this edition of ABB Review.

3) Respot is the process providing the final weld after initial welds have been used to hold parts in position.

Customer driven

Fine-tuning an integrated drive monitoring system

Michal Orkisz, Jaroslaw Nowak, Maciej Wnek

When factory equipment unexpectedly breaks down, production grinds to a halt, resulting in costly downtime while the equipment is repaired. But with ABB's renowned Condition Monitoring Systems (CMSs) for continuous tracking of asset history (ie, operation, wear, damage and maintenance), these production hiccups can be prevented, thereby relieving a company of serious economic implications.

One such CMS is ABB's drive monitoring system. As large drives are often used to power critical equipment, their continued maintenance is also critical. Drive units, such as ABB's medium voltage (MV) drives, also serve as huge data banks, recording information related not only to the drive converter performance, but also to the driven equipment and the whole downstream production process. Because of their important role, a reliable and intelligent CMS is highly desirable. This requires detailed asset knowledge and analysis of the operational context, application requirements and reference data. But this information can only be gained through practical application – here, cooperation with ABB customers is vital. To develop its drive monitoring system, ABB collaborated with several customers to test the system in real industrial environments. This article highlights two of these successes.

One of the world's longest communication tunnels is being constructed through the Swiss Alps. The new railway route under the St. Gotthard Pass will be over 57 km long and comprise a total of 153.5 km of tunnels, shafts and passages. The project is expected to be completed in 2016.

To help excavate the tunnel, a 821 m deep shaft was dug near the mountain village of Sedrun. A large hoist machine lifts rubble out of the mine through this shaft. ABB's multi-megawatt ACS 6000 drive powering the hoist machine's motor is one of the first pilots for the drive monitoring system. While thoroughly tested in the laboratory, this CMS required verification under true industrial conditions – dust, vibration and temperature variation – and, perhaps most importantly, it required real data from a real application. The tunnel construction site provided these very conditions.

The pilot installation helped to optimize the hardware design, enabling evaluation of performance and data storage capacity to thermal and cooling issues of the monitoring unit. Only a real-world installation with its cyclic process could enable analysis of average data intake and processing speed, thereby minimizing CMS installation costs for future customers.

This pilot also provided a field test for the remote connection under realistic, albeit somehow unusual (underground) conditions. To ensure a stable remote connection and a secure VPN data access between the client site and ABB offices, the two groups had to work together closely.

The industrial environment also verified that the diagnostic procedures had been well defined: Is the system responding to the changes as anticipated? How could one improve the original design to add even more value, robustness and effectiveness? These basic questions could not be answered by the development team alone.

A customer pilot provides benefits for both ABB and the client. To test the drive monitoring system, ABB observed the state of the huge drive with great scrutiny while this was at the same time automatically monitored by the CMS. This provided ABB had the opportunity to test, debug, and fine-tune a new product that is being deployed in many applications.

While thoroughly tested in the laboratory, the ACS 6000 drive required verification under true industrial conditions.

A year of test experience in the tunnel excavation site confirmed the robustness and efficacy of the drive monitoring system. With no faults in the CMS, ABB could confidently move forward with a mature product.

Ventilation tunnel at Sedrun. © AlpTransit Gotthard Ltd

Smooth sailing

Imagine a double-acting tanker more than 250 m long, carrying 120,000 m^3 of crude oil and crashing through the ice with its propeller while sailing astern across the frozen waters of the Botnic Sea, or a luxurious cruise liner with more than 1,300 crew members, taking 2,500 passengers onboard for a dream vacation to exotic, tropical islands.

These starkly different vessels have at least one thing in common – they are operating examples of state-of-the-art technology where innovation combines with care in terms of product reliability and vulnerability. The functioning of these ships involves not only economical cost, but also human and environmental safety.

Both types of vessels use the Azipod® propulsion system, distinctive for its great maneuverability, functionality and efficiency, which was developed by ABB Marine, a global leader in the marine propulsion market. With its engineering and manufacturing facilities in Helsinki, Finland, ABB Marine developed an entire propulsion monitoring system (Propulsion Condition Management System, or PCMS) that incorporates not only the Azipod® unit but also frequency converters, transformers, switchboards, generators, automation, controls and more. Collaboration with Royal Caribbean Cruises Ltd. to test a part of this system was instrumental in further developing the PCMS.

Shaft bearing diagnostics

One of the components with the most critical impact on the entire Azipod® system performance is a shaft bearing – more precisely, a set of bearings mounted on a short motor shaft that drives the propeller. Because of extreme, dynamic loads coming straight from the propeller, these bearings can deteriorate. For early detection of such rolling element bearing defects, ABB developed a bearing asset moni-

tor (ie, novel diagnostic algorithms) as part of its overall DriveMonitor™.

To minimize the risk of bearing malfunction, ABB introduced the following predictive maintenance strategy: If bearing faults can be detected early on and the residual lifetime can be predicted accurately enough, dockings can be well planned, the costs will be relatively low and the customer can coordinate the vessel usage to fit its docking schedule. The key goal then was to develop and use specific diagnostic techniques that would signal bearing problems early on, sparing the customer a potential economic disaster. Moreover, diagnostic components were to be integrated with the Azipod® propulsion control system, allowing ABB Marine to provide the end customers with a wide scope of control, monitoring and diagnostic functionality.

After several short-term piloting installations on different types of vessels operating on different sea conditions, a vast amount of vibration data was collected and used to fine-tune the diagnostic algorithms, making them reliable and immune to false alarms.

This real-world implementation was essential to obtaining genuine data that can be used to improve the bearing monitor component of the PCMS.

The key goal then was to develop and use specific diagnostic techniques that would signal bearing problems early on.

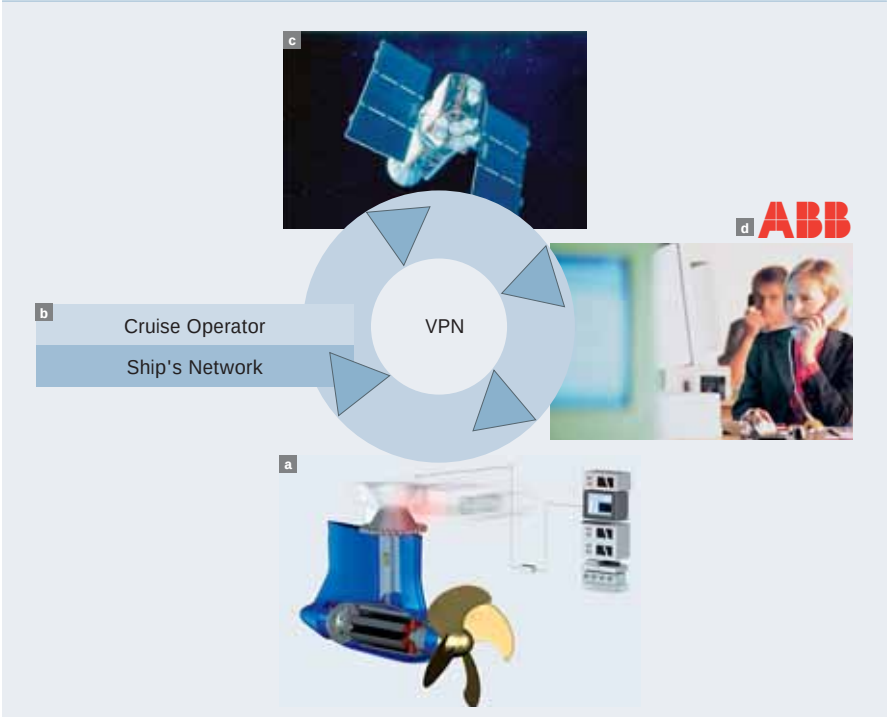
With Royal Caribbean's full trust in ABB's expertise and support of ABB's goal of improving its PCMS, the final system was deployed on one of Royal Caribbean's large cruise liners. Raw vibration data, together with the main shaft rotation speed and azimuth angle, were periodically measured and processed for almost a year.

The system concept was straightforward, yet used some advanced techniques. Vibrations at the bearing housing were collected with an industrial-rugged PC data acquisition unit mounted inside the Azipod®, where they were exposed in binary format as data vectors and transferred via wireless Ethernet to the diagnostic server installed in the ship's main electrical control room. Well-known high frequency enveloping techniques, as well as newly developed algorithms designed for early shock pulse detection, were used to process the vibration data. The entire cycle of data flow – from measurements to calculations – was automatically triggered at regular intervals.

During its operation, the automatic fault detection module found no signs of defects in the bearings. However, regular analysis of the vibration spectra revealed additional information about the Azipod®'s performance. Although not alarming, the clear existence of particular harmonics originating from electrical as well as mechanical designs brought complementary knowledge about the system behavior. Such knowledge is of great value at early design stages of shaft bearings.

The ability to remotely connect from ABB on-shore offices to the diagnostic system onboard the vessel was imperative. With the help of Royal Caribbean's IT personnel, a VPN-secured satellite connection was utilized to access the diagnostic server 1. It was then possible for the staff to see recent calculations and download the required data at their desks, checking the monitoring system's performance. The ship's crew technicians regularly sent mass amounts of raw vibration data on CDs to ABB for further analysis.

1 The concept of remote access to a PCMS onboard a ship a that utilizes connection to the ship operator's network b, secured with VPN tunneling and implemented over satellite link c to monitor AZIPOD performance from ABB service office d.



Developing the integrated PCMS

Diagnostics of the main shaft bearings, although crucial, cover only a small part of the entire propulsion system. It consists of many components, including ABB switchgears, protection relays, MV frequency converters, motors, transformers and control units, as well as third-party products such as hydraulic steering and cooling systems. For each of those components there are hundreds of different physical measurements already defined and used, partly for control purposes but mainly for visualization at the operators' panels. They bear direct information about the state of the device where the measurement is taken; moreover, they contain hidden

knowledge about the other components linked in the process.

The real challenge is to provide a condition monitoring system that successfully integrates all the information at hand and provides an easy means for engineering diagnostic relations between signals. Such a system will eliminate time-consuming, error-prone software development of diagnostic solutions for specific applications. And the result: an Excel-like approach to defining the type, timing and frequency of data collection as well as the necessary calculations, providing clear, consistent information about the state of a particular system subcomponent.

The technical vision of such a system perfectly fits with ABB Marine's service strategy as well as with the end-customer's need to support its technical crew with an integrated condition monitoring tool. The customer must have either local or remote access to both consistent information about the assets' conditions, as well as to the history log of the propulsion system operation conditions. To maintain the PCMS, the customer may also arrange personalized service contracts with ABB.

Implementing an integrated PCMS

The condition monitoring system for the MV drives used in the St. Gotthard Tunnel and the bearing asset monitor module used in the cruise ship both employ an ABB platform known as DriveMonitor™. Because the frequency converters used in the tunnel and in the propulsion system are nearly identical, the natural choice was to take advantage of the experience gained underground and apply it overseas.

Factbox Royal Carribean Cruises Ltd.

Three Norwegian shipping companies founded Royal Caribbean Cruises Ltd. in 1969. Royal Caribbean's first cruise ship entered service in 1970. It now has a fleet of 20 ships with a capacity of over 47,000 people. Royal Caribbean's Song of Norway was the first passenger ship to be stretched; it was cut in two and an 85-foot section was added to its middle. The company has a net income of over $700 million (reported in 2005).[1]

Reference

[1] www.royalcaribbean.com, retrieved June 2007

Hoisting gear at Sedrun. © AlpTransit Gotthard Ltd

The real challenge is to provide a condition monitoring system that successfully integrates all the information at hand and provides an easy means for engineering diagnostic relations between signals.

With steady improvements as ABB learns more from such field tests, the PCMS will eventually be able to communicate and collect data from all propulsion system subcomponents. For most of the signals it will connect to the Industrial IT System 800xA control and automation platform. Faults, alarms and raw data – from the protection relays, through the generators and transformers, to the Azipod®'s steering, sealing and cooling – will be imported to the PCMS. The number of parameters, signals, events and alarms from the frequency converter will be continuously monitored. In addition, third-party condition monitoring devices can be used to obtain precise and complementary information about the state of a particular asset. Should the Azipod® malfunction, it will be important to determine the external conditions at the time (ie, speed of the ship, course, wind speed and sea condition). Finally, remote access from shore to the main PCMS server in the electrical control room must be assured.

Having the opportunity to test these condition monitoring systems in real-world situations is the only sure way to fully develop a PCMS. Real data from real environments enable ABB to create enduring products with a multitude of applications. But to do this, customer collaboration is essential.

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Integrated operations

Creating the oil company of the future

Svein Vatland, Paula Doyle,Trond Michael Andersen

An ABB-led research and development consortium is helping Statoil develop technologies and work processes that will enable one of the world's leading oil and gas companies to operate seamlessly and in real time across organizational and geographical borders and make safer, better and faster decisions.

Known as "TAIL – Integrated Operations," the project will identify ways to increase daily production by 5–10 percent, reduce operating and maintenance costs by 30 percent, cut unwanted incidents related to health, safety and the environment by half, and develop technologies, processes and expertise that will extend the productive life of Statoil's oil and gas fields.

In April 2006 the Norwegian Oil Industry Association (OLF) published a report on the "Potential Value of Integrated Operations on the Norwegian Shelf." [1] The report found that if oil and gas companies active in the Norwegian shelf were to quickly integrate their operations, they could increase their revenues from the shelf by $41.5 billion. If they do not, they can expect to lose out on $10 billion in potential revenues within the next three years alone.

These are staggering figures that reflect an array of challenges the industry faces and the scale of the prize at stake. Although the prescribed solution to these challenges goes under different names – Integrated Operations (Statoil), eOperations (Hydro), Smart Field (Shell), Field of the Future (BP), and i-field (Chevron) – the key elements are broadly the same: the widespread use of advanced information and communication technology (ICT) and real-time data; the introduction of new work processes based on real-time access to that data; and or-

ganizational change, in particular the migration of functions and personnel from costly offshore sites to consolidated onshore locations.

By integrating their operations on the Norwegian shelf, the report concludes, oil and gas companies will be able to accelerate and increase production, reduce operating costs, improve safety and extend the life of their oilfields.

Statoil appoints ABB

Statoil Factbox 3 defines integrated operations (IO) as "collaboration across disciplines, companies and organizational and geographical boundaries, made possible by real-time data and new work processes, in order to reach safer and better decisions – faster." To help identify the methods, technologies and work processes necessary to integrate its operations, Statoil appointed ABB Factbox 2 to lead an R&D consortium consisting of IBM, SKF and Aker Kvaerner Factbox 1.

The project, known as "TAIL – Integrated Operations" was started in January 2006 and assigned the following targets:

- Increase daily production by at least 5 percent by reducing production losses caused by operational failure, maintenance stops and inadequate equipment performance
- Reduce operating, construction and maintenance costs by 30 percent
- Reduce the number of unwanted incidents relating to health, safety and the environment (HSE) by 50 percent
- Extend the lifetime of Statoil's oil and gas fields.

The consortium and Statoil are each contributing equally to the project in terms of input and resources. In addition, the Norwegian Research Council is a major contributor to the funding of the project, which has a budget of $24 million and will run for a period of three and a half years.

Statoil's extensive assets

Statoil produces 1.1 million barrels of oil equivalent (BOE) a day and is the world's third largest net seller of crude oil. It operates 25 offshore installations, some 6,000 km of pipeline, and onshore facilities and terminals in five European countries along the North Sea rim 1. Statoil is also one of the world's most environmentally efficient producers and transporters of oil and gas, and is consistently ranked by the Dow Jones Sustainability World Index as the world's best oil and gas company in issues of sustainability.

The implementation of IO across these assets requires both short- and long-term strategies. In the short term, the focus is on making improvements in daily operations and maintenance. These range from establishing support centers onshore, improving existing work processes, training staff in IO and cross-border cooperation, and investing in ICT to make real-time collaboration possible. An essential component of the process is the involvement of suppliers and external resources to support facility maintenance and operation. In the long term, investments in new technologies, work processes and competence will be necessary to make the transition to an IO company successful.

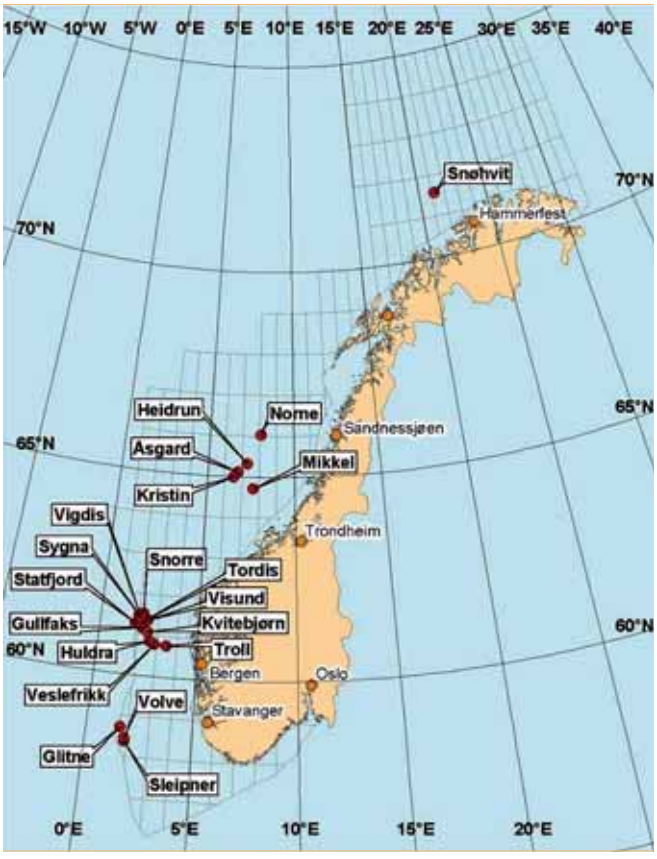
As its name suggests, TAIL-IO is aimed initially at improving operations at fields approaching the end of their lifespans.

Statoil is highly dependent on contractors and suppliers throughout the value chain to achieve its short- and long-term objectives. The traditional R&D model for asset management rarely involves suppliers and external competence in an optimal way. To rectify this, Statoil initiated a new partnership model with leading suppliers, the result of which, in the field of asset management, is the contract between Statoil and the ABB consortium.

The R&D collaboration model is an IO initiative in its own right. It requires cooperation between different companies, cultures and functions (R&D and business units), as well as joint management and the use of a gate process[1)] for project control. Even more importantly, the lessons learned from the partnership will demonstrate how Statoil and its leading suppliers create value by allowing their best R&D resources to collaborate in an environment without borders. Collaborative research is about common objectives, it is about trust and it is about working with meaningful targets.

From the consortium's point of view, the project is a unique opportunity to get customer feedback at a very early stage of the R&D process. This enables ABB and its consortium partners to

1 Statoil production sites



Footnote

1) See also p. 12 of this edition of *ABB Review*.

focus on real customer needs. It also ensures that the technologies and methods developed are validated in pilot installations in an operational environment.

With each R&D team composed of representatives from all five partner companies, the project offers team members the opportunity to experience and learn from different R&D cultures and to exchange knowledge and know-how. TAIL-IO is an ideal opportunity for the consortium to develop the oil technologies of tomorrow in cooperation with a leading end-user like Statoil, and to field-test new concepts and technologies before taking them to the global market.

Factbox 1 Consortium members

IBM

IBM is the world's leading supplier of middleware and the second largest software company overall. It is the leader in business consulting, with more than 3,000 oil and gas professionals worldwide, and has the world's largest industrial research organization, with some 3,400 employees and eight research laboratories worldwide. Group revenues in 2006 were $91.4 billion.

SKF

SKF is a leading supplier of products, solutions and services in roller bearings, seals, mechatronics, services and lubrication systems. Its Reliability Systems business unit provides value-adding systems, software and consultancy in machinery reliability. Group revenues in 2006 amounted to $7.7 billion

Aker Kvaerner

Aker Kvaerner is a leading global provider of engineering and construction services, technology products and integrated solutions in oil and gas, refining and chemicals, mining and metals, and power generation. Group revenues in 2006 were $8.4 billion

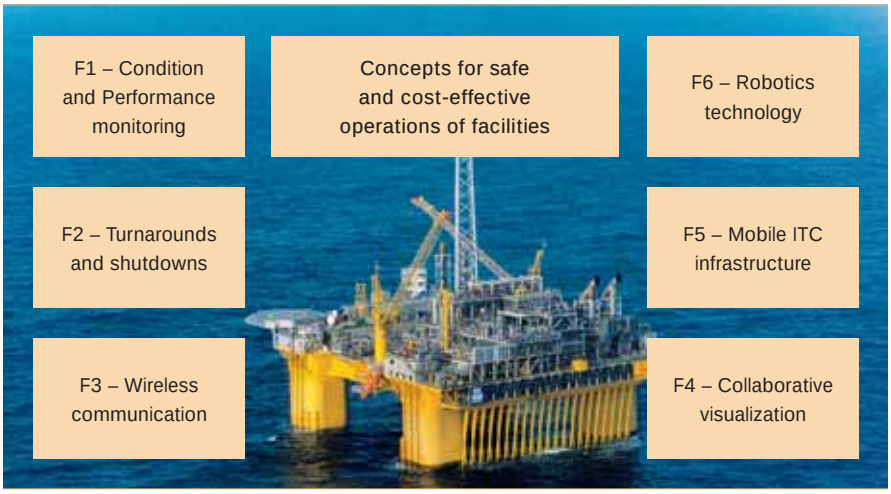
By integrating their operations on the Norwegian shelf, oil and gas companies will be able to accelerate and increase production, reduce operating costs, improve safety and extend the life of their oilfields.

Tail-end production

As its name suggests, TAIL-IO is aimed initially at improving operations at fields approaching the end of their lifespans. Tail-end production is a major challenge facing all oil and gas companies. It is the stage where the production rate is declining, the facilities are aging, and the cost of operation is high. Extending the economic lifetime of these fields is vital to all companies, especially those operating in the Norwegian shelf.

TAIL-IO is divided into six subprojects, also known as technology areas. Each technology area is closely linked with the others and collaboration between them is encouraged 2.

2 Subprojects of the TAIL – Integrated Operation



1. Condition-based maintenance and performance monitoring

The objective is to create a condition monitoring portal that will contain plant condition data on all critical subsea and topside equipment, and support work processes at IO centers. The project will develop methods for early fault detection and residual life prediction and for condition monitoring of critical assets like pumps, valves and electrical, rotating and static equipment.

2. Corporate decision support model for strategic planning of turnarounds and shutdowns

The goal is to develop a tool that can accommodate a vast and complex range of data with the ultimate objective of eliminating asset shutdowns.

3. Wireless communication and sensor systems

Among the objectives are the design of new and open communication systems, the installation of wireless instrumentation to reduce cabling and capital expenditure, and the automation of maintenance tasks to reduce maintenance man-hours.

4. Collaborative visualization tools for preparation, training, executing and supporting maintenance operations

The aim is to develop a tool that can support a wide range of functions (including multi-organizational team collaboration) to perform maintenance operations and diagnostics and improve the level of assistance from centers of excellence.

5. Mobile ICT

The focus is on man-machine technology, work processes and mobile ICT infrastructure that support plant personnel. The growing deployment of wireless networks and devices is increasingly making it possible for maintenance technicians to have continuous access to support systems and personnel via a wireless connection and PDA (personal digital assistant).

6. Robotics

The sixth subproject concentrates on robotics technology to supplement

Factbox 2 ABB and Statoil

ABB and Statoil have a long and close relationship that goes back many years and encompasses most segments of the oil and gas value chain.

Troll A – one of the world's largest natural gas fields – is powered by two unique ABB technologies: HVDC (High Voltage Direct Current) Light and Very High Voltage Motors. This, the world's first power-from-shore solution, enabled Statoil to increase capacity by 25 million cubic meters of natural gas a year and reduce annual CO_2 emissions by 230,000 tons (left).

Snohvit gas field and Hammerfest gas liquefaction plant (right) are equipped with a complete and fully integrated ABB automation, safety and electrification system. This will enable Statoil to operate and monitor the subsea installation from one onshore location and achieve an energy efficiency level unmatched by any other LNG (Liquefield Natural Gas) facility worldwide when production commences in late 2007.

and extend human inspection and intervention capabilities at subsea, topside and onshore facilities. The objective is to develop solutions that combine tele-robotics and advanced visualization to enable remotely operated inspection and maintenance operations, as well as to identify and close technology gaps.

Creative collaboration

Establishing a project culture that nourishes creativity and innovation is a concern when so many partners and interests are involved. To add to the complexity, a large number of external research institutes are also taking part in the project (TAIL-IO is currently hosting five PhD students and five postdoctoral candidates).

Factbox 3 Statoil

Statoil is an integrated oil and gas company and the leading operator on the Norwegian continental shelf. With exploration and production activities in 15 countries, Statoil is one of the world's largest suppliers of crude oil and a substantial supplier of natural gas to the European market. Revenues in 2006: $71.7 billion

> If oil and gas companies active in the Norwegian shelf were to quickly integrate their operations, they could increase their revenues from the shelf by $41.5 billion.

The creativity factor has been solved by providing researchers with a supportive and challenging environment conducive to sustaining high levels of creativity in individuals and teams. By offering researchers a variety of challenges with respect to technology, work processes and collaboration – and the possibility to follow the R&D process from idea generation to pilot installation – the TAIL-IO project is already proving a success.

Openness and the sharing of new ideas is likewise a challenge. To ensure that good ideas are not held back and that the originators get the credit for their ideas, a system for registering invention disclosures has been established. The objective is to translate those ideas into solutions, turn successful pilot installations into Statoil assets and, for the consortium members, release the technology into the global marketplace.

Pilot rollout

TAIL-IO is now entering the phase of pilot rollout, with a number of technologies and solutions ready to proceed to the pilot stage. For instance, extensive testing of wireless technology for industrial environments has taken place in the laboratory and is about to be piloted at several Statoil sites. A large-scale robotics test rig is ready for installation at an ABB laboratory, and several condition and performance monitoring technologies that enable access to data independent of location – true IO enablers – are due to be piloted. The proof of the success of these and other technologies and solutions developed in the TAIL-IO project will come with their eventual deployment over a wide range of assets and installations.

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[1] The Norwegian Oil Industry Association (2006) Potential Value of Integrated Operations on the Norwegian Shelf.

What loops can tell us

Plant performance monitoring with the aid of loop control

Manfred Rode, Ulrich Dombrowski, Jörg Budde

Large industrial facilities such as power plants consist of a multitude of components and sub-processes that all work together to form the overall process flawlessly and as optimally as possible. This is made possible with hundreds, sometimes thousands of control loops, which run the plant the way the owner intends it to. The plant can only run optimally if all control loops are perfectly aligned with each other. So far, this alignment has proven too time-consuming and costly in practice, because each modification and each upgrade as well as the aging of plant components require constant re-optimizing. For that reason, almost all plants operate at a sub-optimal level. Together with STEAG, ABB has now developed processes of control performance monitoring for power plants that allow continuous post-monitoring so that plants can operate at their optimum level.

When we talk about "plant performance monitoring", we refer to the performance control of a production plant. Performance control is determined by many factors. In addition to the natural aging of plant components, interruptions and faulty adjustments, such as poorly aligned valves, play a role. Process-related modifications always lead to repercussions for the entire behavior of a plant, which hadn't been originally planned. Time and cost factors would lead operators to temporarily run the plant below its capacity following such modifications. The complex task of analyzing causes can be daunting, since the positive identification of a sub-optimal function requires the interpretation of vast amounts of data.

Large facilities like power plants often have between several hundred and several thousand control loops. Only a limited number of them usually receives special attention, because their malfunctions directly impact operations. The majority of control loops, on the other hand, more or less works in the background, as malfunctions on their part don't have an immediate impact on the performance of the plant. However, they still play a significant role when it comes to the optimal performance of the plant as a whole.

Control loops are essentially the nerves of a facility, and based on their "state of being", conclusions can drawn on the condition of a plant.

The relationship between the "wellbeing", meaning the performance, of a plant and a control loop becomes evident if we keep in mind the function that a control loop has within a plant.

The control deviation – a measurement for the deviation of the process variable to be controlled (controlled variable) and of the required target objective (set point) – is the initiator of an energy or mass flow. In addition to the controlled variable and the set point, a control loop also has an output variable. That's the variable that controls the energy or mass flow based on the control specifications that are applied. These are used to manipulate a plant component so that the controlled variable is realigned with the set point. Inducing this realignment and especially maintaining it under the impact of unforeseen interruptions are the primary purposes of a control loop.

Control loop signal analysis

Control loops are essentially the nerves of a facility. Based on their "state of being", we can draw conclusions on the condition of a plant. Since the control loops are connected to each other through the plant components, a malfunction in one component will have an effect on another, possibly remote, component of the plant. Although attempts are made to minimize this mutual impact by means of process-related decoupling, such as buffer memory, it can't be eliminated entirely.

All three control loop variables (set point, controlled and output variable) together are usually enough to assess the functionality of a control loop and thus the appertaining plant component. Usually the functionality of the control loop is tested by analyzing set point disturbances during activation. Keeping in mind the multitude of controls within a plant, we can easily understand why this kind of quality control is used less and less during running operation, given the costs and lack of time.

A proven concept

The concept of applying the state of control loops as an indicator of the condition of a plant was intensively researched during the 1980s. One focus point was the paper industry. The main idea was to get way from having to analyze every single control loop, as in the classic disturbance method mentioned earlier. There had to be a way to use the signal patterns during running operation to obtain information about the quality of the control loops and to draw conclusions about the performance of the plant as a whole.

Another issue was to eliminate a problem caused by the increasing lack of qualified personnel. Whereas an engineer used to be responsible for maybe a dozen control loops, today he or she often has to deal with several hundred control loops. Time-consuming individual monitoring is therefore no longer an option.

Using terms like Control Loop Monitoring, Control Loop Performance Assessment, Loop Auditing and Control Performance Monitoring (CPM), engineers have developed methods that are similar in nature. Based on a multitude of statistical variables and their interconnections, they provide a quantitative analysis of an individual control loop [1].

At this point, these methods have been tested in practice and are functionally sound. They appeal not only to the paper industry but also increasingly to the chemical industry. This comes as no surprise if we bear in mind the amount of money the chemical industry has to invest in one control loop: Factoring in the measuring system, the actuator, the controls and the signal transfer, it can easily range from 5,000 to 100,000 EUR [2]. In this context, possible surcharges of 100 to 200 EUR per control loop for the introduction of CPM are actually less significant.

When it comes to plant performance monitoring, there's another argument for the use of CPM: The aforementioned quality problems associated with setting and dimensioning the controls. According to estimates, roughly one third of control loops works well and another third only works usefully on average. About 30 percent of controls are mostly operated manually, because their control performance is inadequate.

Factbox STEAG GmbH

STEAG GmbH, a subsidiary of RAG, is the fifth largest power producer in Germany. Its core business is electricity generation in hard-coal-fired power plants.

- Total installed electric capacity: 9,000 MW
- Revenues in 2006: € 2.73 billion
- Employees: almost 5,000

http://www.steag.de (June 2007)

… Why not use It for power plants?
The ABB-developed software tool Optimize^{IT} Loop Performance Manager (LPM) includes algorithms that analyze control loop signals online and provide an up-to-date, virtual control analysis. In other words, a separate test of the individual functions based on the set point/disturbance method is now obsolete in this case: The behavior of the plant under normal operating conditions already provides enough information about the quality of the controls.

The process control team at the thermal power plant STEAG in Lünen, Germany (see title picture), was very keen on trying out the ABB process for performance analysis at his power plant. “We have enormously wide-ranging data material about our controls that can be used for testing the power plant compatibility of the CPM process”, was their challenging statement.

In this respect, an important asset was the long-standing, positive cooperation of STEAG with ABB: On the one hand, the power plant already had an ABB process control system, on the other hand, the ABB Service had been maintaining the power plant for years – basic conditions that came in handy for the pilot test. What was particularly promising was the synergy between the personnel of the power plant, the longstanding service experience of ABB and the know-how of the ABB scientists for developing a new approach to condition performance monitoring in the sector of power plants.

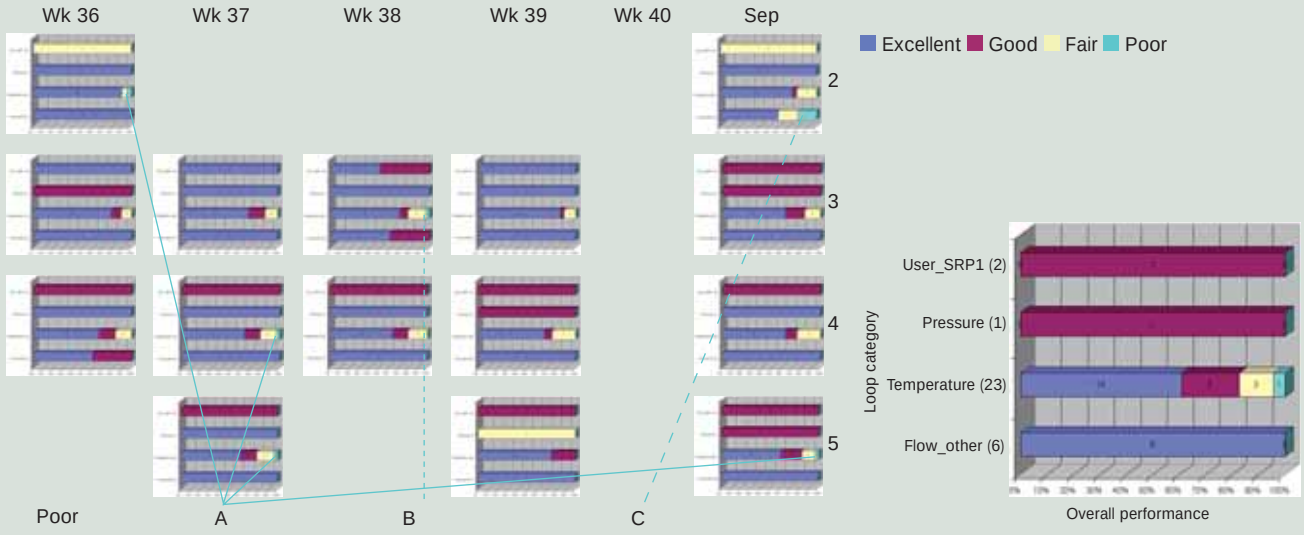
The test scenario chosen for the power plant was the induction of air into the combustion chamber. This is an area known as a possible source for malfunctions because of the large quantities of air, the long air ways and scattered mills. The engineers deliberately chose a restricted area of the plant. That way, they were able to concentrate on peculiarities unique to power plants and to make sure that the outcome could be verified using traditional methods as well. To be able to analyze archived data too, the algorithms, partly developed at the ABB research center, were packed into a software frame that made it possible to access exported archive data and to display the results of the analysis in EXCEL®. This approach rendered a solution that was independent of process control systems 1.

CPM readily allows both sporadic and cyclical control loop analyses at large intervals thereby eliminating the need to install a special analysis PC.

Initial applications on site quickly revealed the differences between power plants and paper factories. Whereas today’s thermal power plants, including those designated for basic operations, can certainly operate at full load one time and at light load the next on any given day, the production of paper takes place under relatively consistent basic conditions. So the working conditions of a control differ accordingly in a power plant.

It soon became evident that not all required data was available in one archive. That’s because data analyzes

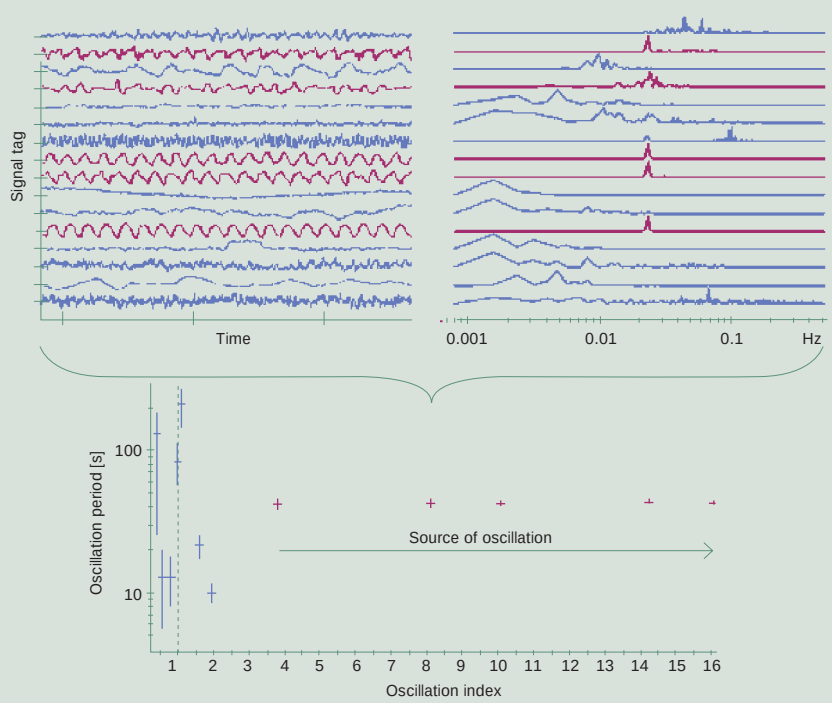
1 Result of a control loop signal analysis spanning several weeks.



The grey part is the summary of a loop performance analysis over week 36 to 39 in September of 2005. The blocks of bar graph below the week numbers and the month inform about qualitative loop performances (Excellent, Good, Fair, Poor) in that week / month, represented by special colors. There are up to four bar graph blocks in a date column as there were different load cases (eg, low load, middle load), represented by number 2,…, 5 at the right side of the picture, in September – the assessment is not an over all assessment, each load case is assessed separately.

The letters A, B and C represents coal-mill loops which are of poor quality. That is a strong indication for a real problem with that loops and an indication to have a look at the coal-mill control.
The loop assessments are clustered. All loops of a loop category (e.g. temperature control loops) are collected together. Such an assessment overview is zoomed below to show this more accurate. The numbers in the bars correspond to the count of (Excellent-, Good-, Fair-, Poor-) loops of a category. For example, 14 of all (24) temperature control loops are of excellent quality and only one is of poor quality.

2 Procedure of a PDA



Signals of suspicious control loops are collected and sent to the PDA tool via an EXCEL file. An oscillation analysis show which signals have similar oscillations. These signals are clustered. All signals of such a cluster are highlighted in red (upper left: Time series of investigated signals, upper right: Signal spectra – the impulse at the same frequency point is an indication for similar oscillations).

The calculation of the oscillation index versus the oscillation period of a signal (below) informs about the main source of an oscillation. The higher the oscillation index the higher is the probability that the signal is the source of the oscillation of a cluster of signals. The vertical line of the cross of an oscillation index is a measure of the variance of the oscillation period and therefore a value of oscillation symmetry.

based on mathematics also require variables that are often neglected in purely empirical analyzes based on curves.

However, the close cooperation between the highly motivated staff of the power plant, the ABB Service and ABB Research made it very easy to come up with solutions. While the staff of the power plant went about completing the archive data, the ABB Service paved the way to the most efficient data export. This involved vast quantities of data that were analyzed in the laboratories of the ABB Research Center at Ladenburg. That was also the site where the necessary supplements to the analytical algorithms were developed.

Accessing vast amounts of control loop data from a power plant made it desirable to apply a process that hitherto had not been planned for use in power plants. Known by the term Plant-wide Disturbance Analysis (PDA), it involves a method for the analysis of signal data that differs from traditional CPM methods [3]. PDA allows for better analyses of the coupling between plant components. It's also a more reliable way of tracing back the cause of an interruption 2.

The evaluation and discussion of the analysis results of about three dozens of control loops – in addition to the distribution of air, the steam-overheating control was later added to the monitoring process – across a period of about one month gave captivating new insights into the analyzed plant components. Based on the control loop data, engineers were able to present the client with links that were not apparent otherwise. Some of the client's open questions were answered that way. As a result of the success of the on-line analysis, the process is now being expanded across the entire block of the power plant.

CPM for broad application

The question whether CPM can be applied to plant performance monitoring in power plants has now been answered – it can! The ABB Service portfolio has now grown to include this service as well. Not only does this additional service make work easier for the qualified staff of the power plant, it also forms the foundation for establishing a universal knowledge base for the behavior of control loops in power plants.

Furthermore, there's no need to install a special analysis PC and to incorporate it in the plant network. CPM readily allows both sporadic and cyclical control loop analyzes at large intervals. The discussion concerning the results of the analysis between the power plant staff and ABB Service substantiates the measures that have to be taken. In any case the analysis is based on well-founded data material. The joint development project with STEAG has shown once again that the combination of experts from different scientific fields can be a very successful one.

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Transforming history

The ABB power transformer story

Thomas Fogelberg, Åke Carlsson

Imagine for a moment, a world without power transformers: It would be a world without high-voltage transmission systems and there would be no means to economically transport electric power over long distances. Power supply infrastructure would have neither the economies of scale nor the pooling of reserves that it enjoys today. More recent developments that would not have occurred include international power trading and the large scale tapping of wind power in remote regions, with their respective benefits for customers and the environment. Growing concerns over grid reliability additionally reflect the need for transformers of sufficient capability and robustness. Without the transformer, electrical power today would be less reliable, more expensive and more wasteful, and industries and homes would look quite different.

Through practically all the history of commercial transformers, ABB and its predecessor companies have been at the forefront of their manufacturing and ongoing development. In this article, ABB Review traces some highlights of this development.

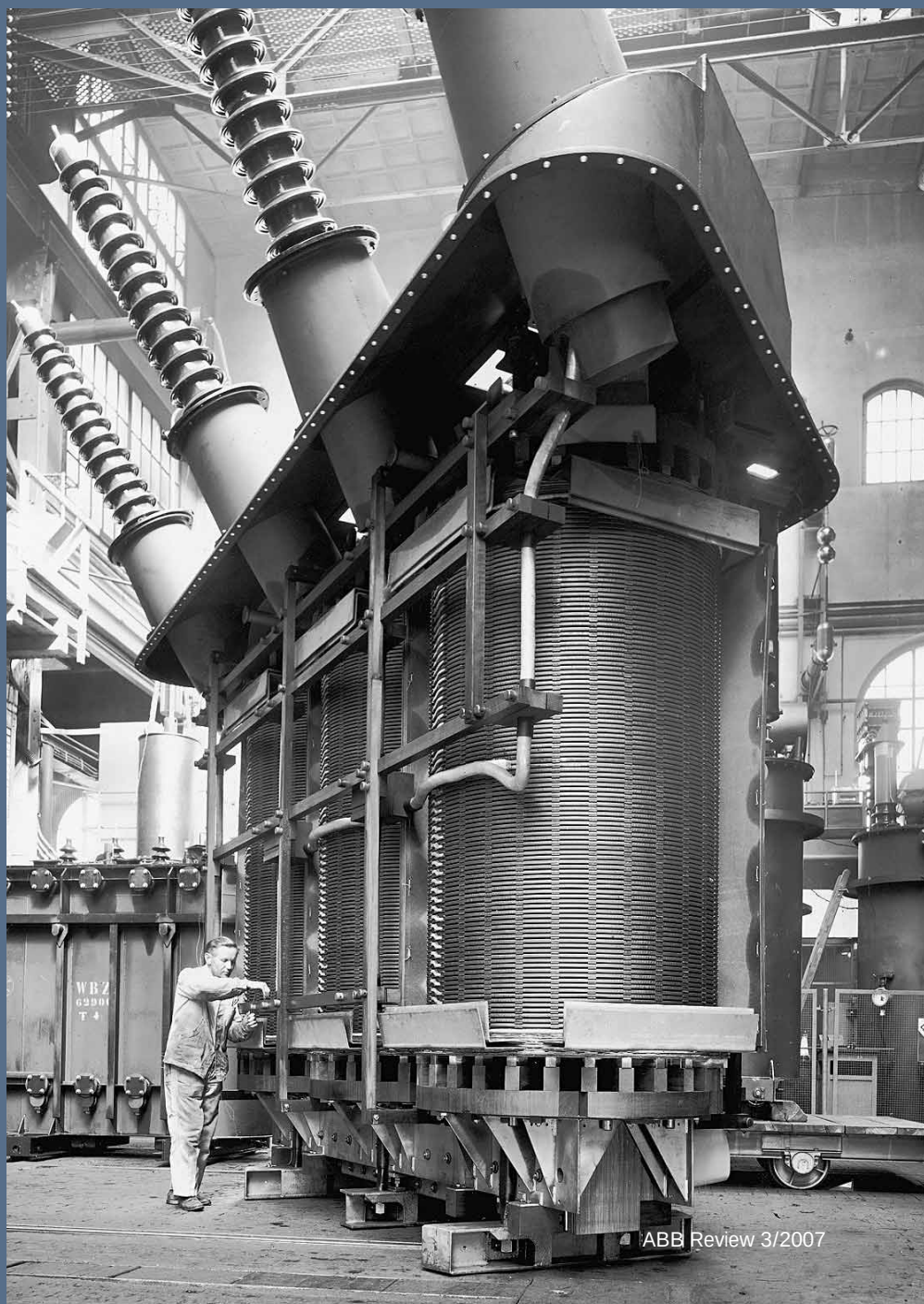

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ABB has always been well positioned to meet the demands of the power transformer market, ranging from single pieces of equipment in point-to-point transmissions to vital ingredients of interconnected power systems sprawling over vast areas.

Power and voltage development

At the end of the nineteenth century, the transformer proved itself an indispensable component for competitive transmission of electric power. A 20 kV setup was demonstrated at the electrotechnical exhibition in Frankfurt am Main in Germany in the year 1891, proving the feasibility of power transformers. Two years later, ASEA, one of ABB's parent companies, supplied one of the first commercial three-phase transmissions in Sweden – from a hydro power plant to a large iron ore mine some 10 km away.

Transformers made it possible to generate electric power at low voltages and then transform it to a higher level at which transmission incurs considerably lower losses, and finally transform the voltage back to a safer level at the site of consumption.

Transformer manufacturing emerged in most countries in Europe and in the USA. ASEA, BBC, General Electric, Westinghouse and other companies rapidly gained expertise in the manufacturing and installation of transformers 1. At the time, these were all domestic companies with technology of their own serving local state-controlled utilities in tight partnership.

Countries such as Sweden with practically no domestic fossil fuel reserves but ample potential for hydro power – albeit remote from the user – were especially eager to make use of electric power transmission. As transmission distances increased, the transmission voltage had to rise to keep losses down and to reduce the number of lines needed in parallel.

In the early 1950s, Sweden commissioned the world's first 400 kV transmission with a length of about 1000 km and 500 MW capacity. This breakthrough in voltage and capacity set a new standard in Europe 2.

This extra high voltage (EHV) strained not only the design and manufacturing capacity but was also a challenge in testing. Long transmission lines presented a risk of transient voltages. New and more stringent test procedures had to be established for the dielectric integrity. These new tests were then incorporated into the acceptance tests of the transformers.

Soon much of Europe was following Sweden's lead in adopting 400 kV EHV. The Canadian province of Quebec had a similar situation to Sweden, with limited fossil fuel but abundant hydro power, and large geographic distances between these and industrialized areas. Even higher voltages were needed to make efficient use of these power sources. In the second part of the 1960s, the power company Hydro-Québec introduced 735 kV transmission (a level later called 800 kV).

1 An early three-phase transformer built to a patent of Johan Wenström patent, the technical genius of the early years of ASEA. Wenström called his transformer triple-converter

2 The Harsprånget 400 kV generator step up transformers: Single-phase units with three low voltage windings to serve three generators in parallel, each generator rated 105 MVA

In the early 1950s, Sweden commissioned the world's first 400 kV transmission with a length of about 1000 km and 500 MW capacity.

In the USA, the building of large thermal power plants gathered pace, with plants reaching block sizes of 1000 MW and more. For such large plants to be viable, the power had to be distributed over long distances covering vast areas. A 765 kV system was therefore introduced in addition to an existing 345 kV system.

While 765 kV systems were being built, existing 500 kV systems were being extended. One example of development work on large interconnection transformers concerned the early 400 MVA single phase units rated 500/161 kV that were delivered to Tennessee Valley Authorities, TVA.

The first deliveries from ASEA in Ludvika for this purpose used a five-limb core with three limbs wound in parallel. Later, the number of wound limbs was reduced from three to two for the same rated power. Finally the last delivery to the same specification was built with one wound main limb and the voltage regulation part on one of the side limbs. On all these transformers, the high and low voltage windings were separated; ie, there was no auto connection.

In addition to saving manhours in manufacturing because of fewer wound limbs, the transition from the earlier to the later design reduced the total dry mass by a quarter. Also the total losses (no-load and load losses)

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3 The 1785 kV UHV transformer installed at the AEP-ASEA test station outside South Bend, USA. The transformer is installed on an insulated platform to study the effect of line voltages up to 2200 kV phase-to-phase

4 1000 kV test setup with transformer and shunt reactor at ENEL research station in Italy

5 One of six converter transformers installed at the receiving end of the Pacific intertie transmission serving the Los Angeles area

were reduced by about 20 percent. After completion of these deliveries, the customer started to acquire and install auto-connected transmission transformers whose specifications were otherwise the same.

In the early 1970s, TVA commissioned its first 1200 MVA power plant at Cumberland, Tennessee. ABB Ludvika built the generator step-up transformers (rated 420 MVA) to a single-phase design. These transformers represented a technical breakthrough in terms of power capacity on one wound limb.

At the same time, ABB Ludvika launched a development program together with American Electric Power, AEP, – the largest private power company in North America – with the aim of finding the highest technically feasible transmission voltage. For this purpose, ABB built a full-size single-phase network transformer whose highest voltage was 1785 kV, rated at 333 MVA. The transformer had one wound limb, and with a core extended to three wound limbs on a five-limb core, the capacity would have been 1000 MVA per phase; ie, a total capacity of 3000 MVA for a complete three-phase bank. The transformer was installed and operated at the research facility jointly run by ABB and AEP. The transformer served successfully until completion of the research program 3.

Similar development programs were also embarked upon by some of ABB's other predecessor companies – aiming to achieve transformer designs capable of handling transmission voltages of 1000 kV and above. One example is a full-size transformer and shunt reactor built in Italy for 1000 kV and installed at ENEL test station Suveto 4.

Changing patterns in power production and grid build-up deferred the move to still higher transmission voltages and extreme transformer capacities. Voltages higher than 400 kV in Europe and 800 kV on other continents have so far not been commissioned for commercial operation. The need for high capacity, long distance transmission – eg, to reach large and remote hydro power stations – has resulted in renewed interest for voltages in the range of 1000 to 1200 kV in China and India.

Transformer types

The majority of transformers are built on the core type concept – a concept that today can be described as cylinder-shaped windings arranged concentrically on a cylinder-shaped core. An alternative design concept is the so-called shell type concept where the windings have a rectangular shape and segments of low and high voltages are more or less interleaved. For certain applications the shell type concept has found a viable position; eg, large generator transformers with special requirements. The large difference in production techniques for the two designs makes it feasible to have different workshops for the two concepts. ABB has therefore allocated the production of most of its shell type transformers to its factory in Spain.

Restructuring of manufacturing footprint

Power transformers were previously considered to be more or less strategic products, and several countries deemed it important to have domestic manufacturing capacity. Thus ASEA established close ties with existing transformer manufacturers and established new factories in several countries such as Germany, South Africa, USA, Canada, Norway and Brazil. BBC, with transformer factories in Germany and Switzerland, established a factory in Brazil. Westinghouse supported the build-up and provided know-how to factories in Italy, Spain and Australia.

Power transformers are complex "engineered-to-order" products requiring competence and experience in engineering and manufacturing. Such a business should be built up around defined instructions which are reflected in tools in engineering and production.

In order to make efficient use of available resources, design and production methods were unified for all factories within the group. ASEA's Ludvika factory served as a technical resource and gave advice and support on technical and manufacturing issues. Once a year – or more often when needed – the technical and manufacturing man-

agers met for an exchange of information and to learn the latest news on development work. Engineers from the different companies were often invited to Ludvika for training and education, and highly skilled Ludvika engineers were given the opportunity to serve in leading positions in the individual companies.

Design rules and manufacturing procedures were documented in special standards or instructions covering individual phases in the process of building transformers. This way of working made it possible to accumulate substantial experience in each phase of the design and manufacturing of the power transformer. The large total production base additionally made it possible to maintain and support a comprehensive development team.

The close cooperation between the individual manufacturing units continued after the forming of ABB. All participating units were given access to common information and support from all employees within the ABB group. The IT tools used in design and engineering are now the same around the globe.

Long distance transmissions

For improved utilization of existing lines and rights of way, three types of equipment have emerged: HVDC converter transformers, phase-shifters and shunt reactors.

HVDC converter transformers

Transmission with HVDC has several advantages when it comes to long-distance transmission. The mode was first used on long cable transmissions to reduce the need to mitigate the excessive voltage build-up along the cable caused by reactive power in an a.c. transmission. In HVDC transmissions, the power transformer not only modifies the voltages to permit power to be exchanged between the a.c. and d.c. systems; it also transforms the a.c.-voltage from a three-phase system to a six-phase system. This permits the harmonics generated by the valve currents to be reduced. Furthermore, the transformer acts as a barrier for the d.c.-potential, preventing d.c.-voltage from entering the a.c.-system. Current harmonics from the valves and d.c.-potential applied on the valve side of the transformer implied new technical challenges for the transformer engineer. The harmonics give rise to additional losses, which need to be taken into account and minimized to avoid dangerous local overheating in the transformer. The d.c.-potential on valve windings results in a dielectric stress pattern different from the stresses generated by the normal a.c.-voltages.

Several transformer technologies as well manufacturing plants and procedures had to be unified within the shortest possible time – and this without lessening the momentum of normal production.

The design of the modern converter transformer has its origin in the units built for the Itaipu project in Brazil in the 1980s. A d.c. transmission voltage of 600 kV was achieved with two series-connected converters. In this means of connection, the transformers for the upper bridge must be capable of a dielectric withstand of 600 kV. There are a total of 24 single-phase converter transformers at each end of the HVDC transmission, with a total capacity of 6000 MW. The transformer is built as a single phase unit with two valve side windings, one for delta connection and the other for wye connection (both being needed to reach the necessary phase split). The two valve side windings are built on separate limbs on a common core and act electrically as two independent transformers[1)].

In 2004, ABB delivered single-phase units with a rating of 620 MVA to the Pacific Intertie (USA) for a d.c. transmission voltage of 500 kV 5. These are the largest converter transformers manufactured so far.

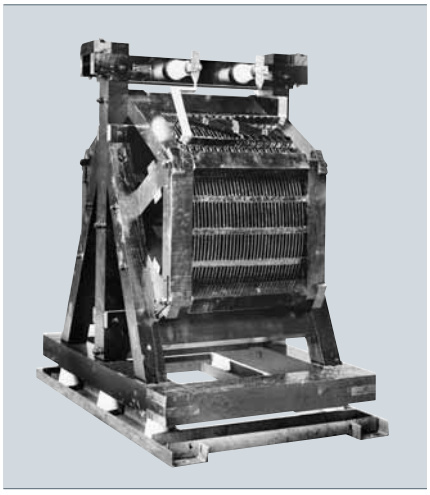
Presently ABB is in the final stage of the development of converter transformers for 800 kV d.c. transmissions[2)]. Long point-to-point transmissions, especially in China and India, stand to benefit from the use of higher voltages than are currently available. The environmental advantages lie in the lower transmission losses and the reduction in land use for the right of way.

The phase shifter

The power flow in highly meshed high voltage transmissions needs to be controlled to achieve an efficient load distribution between power lines in parallel. The load in the individual

6 400 kV quadrature booster with a throughput capacity of 1630 MVA, installed in the Italian network for power control of the interconnection between Italy and France

7 A reactor from 1923, built for short circuit protection and control



Footnotes

[1)] Parallel to the HVDC transmission, an 800 kV a.c.-transmission runs from Itaipu to the Sao Paolo area – this was mainly built by the BBC factory in Mannheim.

[2)] See also Asplund, G., Ultra high voltage transmission, Alternative scenarios for long distance bulk power transmission – 800 kV HVDC and 1000 kV HVAC, *ABB Review* 2/2007 pp. 22–27.

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lines is governed by the phase displacement between the nodes in the transmission system. A phase-shifter provides a means to control this displacement and thus the load flow.

Such a phase-shifter is installed in series with the power line and has an outgoing voltage equal to the incoming voltage but with a (variably) shifted phase angle. With only a limited need in phase-angle shift, the complexity of the phase-shifter can be reduced to produce a quadrature voltage only and the apparatus will be called a quadrature booster 6. Physically a quadrature booster is built as two transformers: one magnetizing unit and one series unit[3].

The shunt reactor

The reactor (sometimes called inductor) is not a transformer in the sense of a device transforming power from one voltage level to another, but its similarity in construction and manufacturing makes it a highly suitable product for a transformer plant.

The reactor found its application in the early part of the last century as an efficient piece of equipment for the control of overcurrents and thus short circuit protection 7.

Long-line transmissions as well as extensive cable networks on high voltage generate a substantial amount of reactive power. If not balanced, critical voltage rises develop during low loads. A reactor (the shunt reactor) installed between the power line and earth provides an efficient means to control and balance such reactive generation. Essentially, the shunt reactor acts as a sink for reactive power.

The modern shunt reactor was introduced in the late 1960s using components and technology from the core type transformer 8.

The design of the modern converter transformer has its origin in the units built for the Itaipu project in Brazil in the 1980s.

Industrial transformer

A substantial segment of the ABB product family is made up of large transformers for industrial applications, such as furnace transformers and rectifier transformers 9. These transformers are characterized by the comparatively low voltage on the secondary side – but have appropriately high currents. Load currents of 60 kA or more are not unusual. These high currents with their high harmonic contents pose significant challenges, especially in terms of high magnetic fluxes around exit leads within the tank and around the airside part of the leads.

In furnace transformers, the high currents are accompanied by frequent short circuits during the initial phase of the heating of the steel in the melting pot. The resilience to such short circuit forces and the requirement for large regulating ranges call for special care in design and manufacture.

Forming ABB

In August 1987, the Swedish ASEA and the Swiss-German BBC decided to merge and jointly form the ABB company. Shortly afterwards, ABB was also able to acquire the transformer manufacturing segments of Westinghouse in the USA, Ansaldo in Italy and Spanish factories. The National Industry in Norway and the Finnish Strömberg had become part of ASEA just before the merger.

In fact, ABB can today, through its various predecessors, claim the combined experience of 700 years of transformer manufacturing Factbox. Several transformer technologies as well manufacturing plants and procedures had to be unified and made

Repairing an HVDC transformer in Drommen, Norway

8 A 150 Mvar shunt reactor in the Swedish 400 kV grid

9 An air-cooled rectifier transformer rated 91.74 MVA

to work together within the shortest possible time – and this without lessening the momentum of normal production. This was truly a gargantuan task.

A number of task forces and R&D groups were established to evaluate the individual technologies and to select the most viable ones. Although the principle of transformer technology is universal, there are many differences in the fine-tuning. Major objectives were lower costs, shorter production time, and higher quality measures in terms of test room failures. It was important to package all design and production variables into a seamless engineering IT system supporting customized engineering and manufacturing.

ABB succeeded in unifying its technology, and today offers the same product and high standard of quality wherever the transformer is manufactured, be it in Germany, Canada, Brazil, India or China. Power transformers are expected to deliver reliable service for 30 to 40 years in all types of networks.

Several of the participating manufacturing plants needed substantial renovation and modernization to fulfill the ABB standard when it came to cleanliness and competence for building transformers meeting today's requirements. Many new greenfield investments were made permitting a quick ramping up of production using this common technology base and with substantial help from engineering support teams. ABB established an engineering training school in Germany: the Knowledge Communication Center.

The increased manufacturing volume resulting from the formation of ABB made it possible to initiate several development programs, including the exploration of innovative transformer designs. Studied design concepts included superconducting transformers (a 630 kVA saw one year of service) with HTSC[4] winding conductors, high voltage foil-wound windings (three units in service), large dry and air-cooled windings based on cable technology (two units in service). By embarking on these and similar more or less speculative projects, ABB has acquired a vast quantity of knowledge that it also applies to conventional transformer technology. And even if

Factbox TrafoStar™, 700 years of pedigree

ABB can today look back on the combined experience of 700 years of transformer manufacturing, having inherited designs and expertise from the following companies:

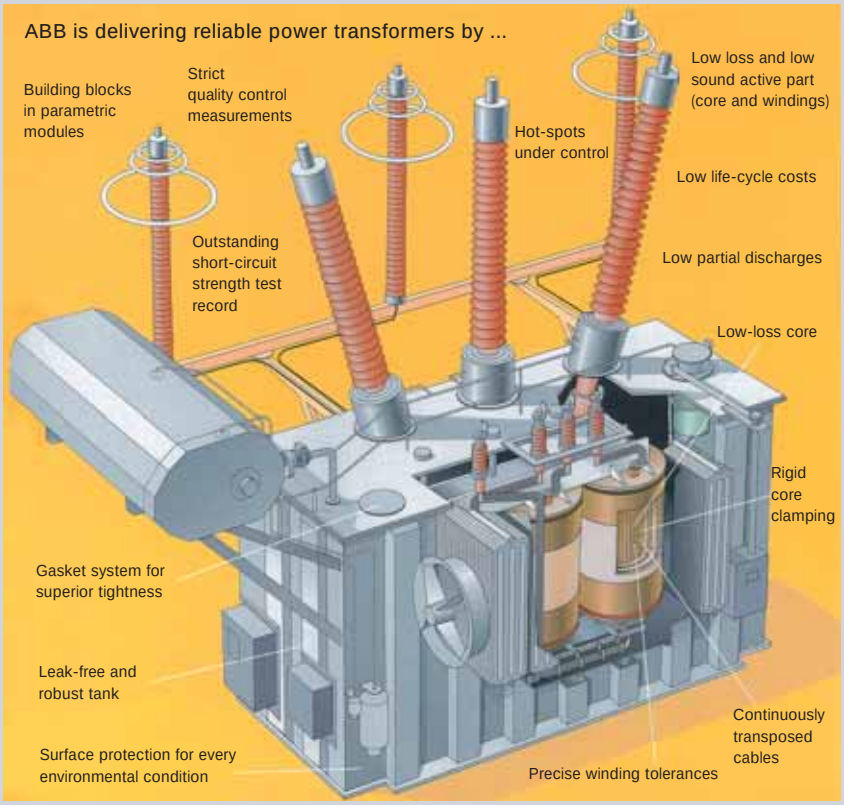
- Asea
- Ansaldo / Ital Trafo / IEL / OEL / OTE
- BBC
- GE, USA
- National Industri
- Strömberg
- Westinghouse
- and more …

These 700 years reflect the knowledge ABB has of different technologies in transformer design and manufacturing, combined with service experience in the networks around the world.

ABB draws on this considerable knowledge-base and combines the best practices of its predecessors in its global, common business concept: TrafoStar™-platform.

Each TrafoStar™ transformer follows common engineering, supply chain and manufacturing rules. A modularized construction allows a high level of re-use, reducing factory throughput time, while minimizing variation and achieving highest quality. The production of 1400 units a year provides a base for a unique performance and key parameter analysis, permitting continuous improvements in all plants.

ABB's customers do not benefit only through the new transformers the company delivers. The broad knowledge base, now documented in the TrafoStar™ concept, permits ABB to provide service and support on all 400,000 power transformers now in service around the world.



Footnotes

[3] A quadrature booster uses a shunt transformer to phase-shift the supply voltage by 90° (hence the term quadrature). The output of this shunt transformer is tapped, permitting the amplitude to be varied. A series transformer is then used to add this to the main circuit.

[4] HTSC: High Temperature Superconductor

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the market has still not fully accepted these innovations, the solutions are available.

In view of the total capacity of the newly formed ABB, the transformer segment could continue its predecessor's active participation in international bodies such as CIGRÉ, IEC and IEEE. This participation has made it possible to establish standards on test levels and test procedures to verify transformer integrity under various operational conditions. The application of stringent quality requirements in design and manufacturing has reduced the risk of unforeseen operational difficulties during a long service life.

More than the sum of its parts: assembling a transformer

10 An ABB distribution transformer in Brazil

After the merger, ABB had developed a range of transformers covering the full transmission chain, from generation to the outlet socket in the residential home. The transformers used in the last steps of this chain are generally called distribution transformers. These transformers are more or less bulk products built to suit the network topology in each individual region of the world 10.

ABB makes full use of its knowledge and capacity in developing and manufacturing strategic transformers materials and components in special plants. In this respect, high quality products such as transformer boards and winding insulation kits manufactured according to the company's own technology must be mentioned. ABB is also one of the world's major suppliers of all types of tap changers and bushings. The company's own technology in transformers, insulation materials, tap changers, bushings and up-coming transformer electronic control places ABB in a unique position in being able to offer a complete product portfolio in transformers and provides a strong basis for future development.

In the late 1980s and 1990s, expansion and build-up of generation and transmission slowed down in the western world while new ABB factories were established in China and India.

Geographical shift in production

The impact of the formation of ABB was largely limited to Europe, where most of the transformer manufacturing plants were located. Later on, acquisitions on the North American continent followed.

However, in the late 1980s and 1990s, expansion and build-up of generation and transmission slowed down in the western world. The existing capacity was more or less sufficient for covering demand. The abundant availability of oil reduced the need to convert energy supplies into electricity. This led to overcapacity in the power transformers market.

At the same time, the economy in the Pacific Rim as well as in the Far East picked up and the need for electric power surged. Transformer plants in Europe and North America had to close while new ABB factories were established in China and India.

What about the future?

Transformers based on the induction principle will remain the base of voltage conversion for many decades to come. Changes in the materials used will help reduce both costs and better control of thermal capability. These developments will affect conductor materials as well as solid and liquid insulation materials; however, no substitutes for the electrical steel and the transformer core are in sight.

In the future, new ways of rating transformers through better control of the thermal capability will help reduce the use of expensive materials. Transformer specifications must evolve to place more emphasis on the load profile, future growth and emergency loadings – with the hottest areas for aging being covered by new standards. The new ways in which such international standards will rate transformers will require the integration of more intelligence. Other goals are to further increase the mechanical, thermal and dielectric integrity of transformers – to make them better equipped to deal with the greater stresses that will affect future networks.

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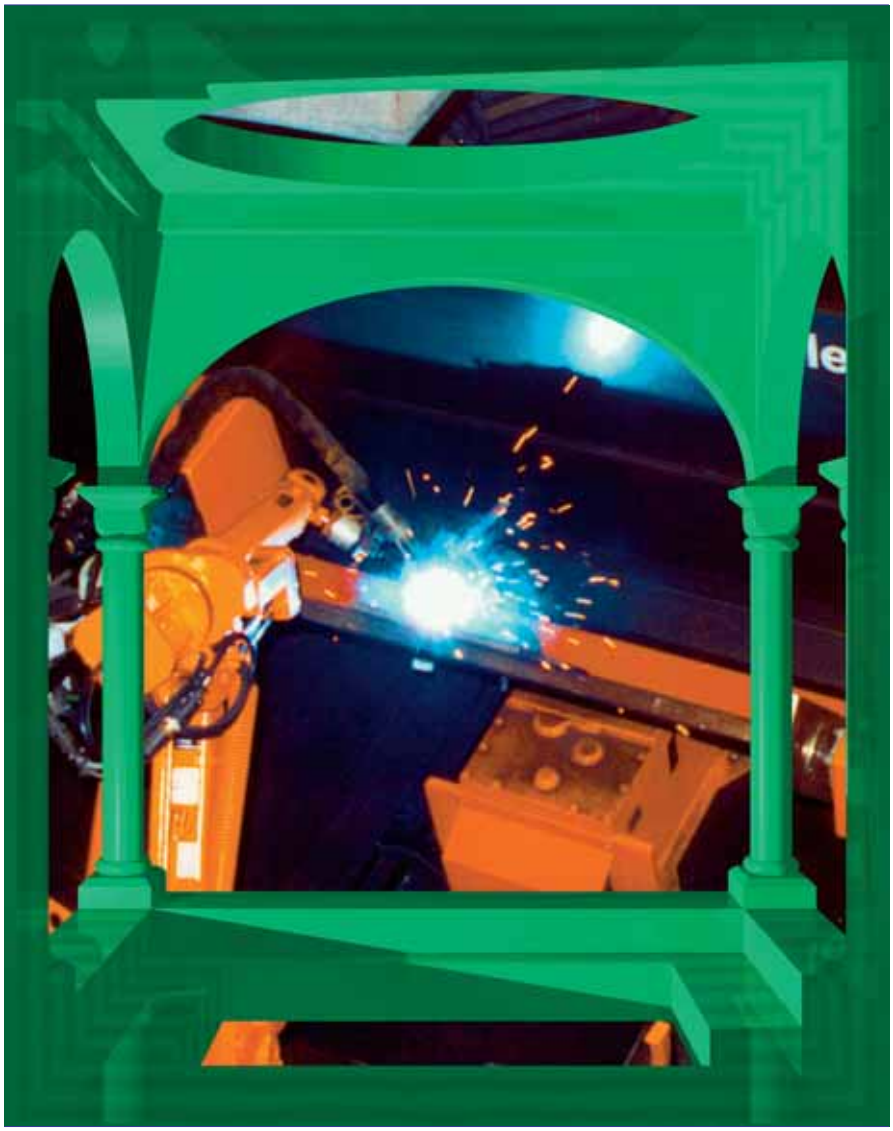

Innovation highlights

The best technical innovations are those that make good products great or create an entirely new product to satisfy an unmet need. Each year, the technology and innovation management team at ABB evaluates the potential value of its innovations, for the company and its customers alike. If all forecasts hold, 2007 will be a very successful year from a business as well as an innovation standpoint. *ABB Review* 4/2007 highlights the year's best innovations.

Advanced circuit breakers, new converters, 800 kV DC equipment, innovative steps in instrumentation and fresh approaches to remote services are explored. New applications for robots and innovative substation automation are examined, and further progress in on-site repair is also addressed.

Energy efficiency, a major asset of ABB's offerings that was discussed in detail in *ABB Review* 2/2007, is again on the agenda; and the security of information systems that operate plants is highlighted. The history of motors, one of the most developed products of ABB, concludes the year-end edition.

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