ABB review

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The corporate technical journal



# Energy and resources

Power and productivity for a better world™


Mankind is becoming ever more innovative in finding ways to reduce the environmental impact of its activities. The wind turbines on the cover of this *ABB Review* are a visible and iconic mark of such an innovation. However, going green is not just about alternative energy. It is also about using what is available – be it energy or other resources – more efficiently. The inside cover depicts ABB's ultra-high voltage test lab. ABB's researchers are continuously improving components and systems to reduce waste.

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# Energy and resources

**Peter Terwiesch**
Chief Technology Officer
ABB Ltd.

**Dear Reader,**

Regular readers of *ABB Review* will have observed that major visual changes were implemented with issue 1 of this year. Beyond appearance, we are continuously seeking to fine-tune content to your needs and expectations and would like to reach out to you for your inputs through a brief survey (only 10 questions) on www.abb.com/abbreview. Please take part – your opinion is valuable to us, and you will have the opportunity to win one of several small prizes.

The present issue of the journal is dedicated to energy and resources. Not only is the world's population continuously rising, but so are overall standards of living. Especially in developing countries, more and more people are moving towards greater prosperity – and with it to more energy and resource-intensive lifestyles. As much as these improvements are to be welcomed, they also increase the pressures related to the finite availability of many resources. A broad range of resources, ranging from water to energy and basic minerals, is becoming scarce. Fundamentally, such scarcity can be addressed both by tapping new sources as well as through efficiency, ie, achieving more with less. The process of transforming raw materials to finished products or services involves many individual steps, all normally associated with cost, waste, and losses. Increasing efficiency and reducing waste in every one of those steps (and if only by a relatively small amount) yields significant savings. It allows companies and individuals to be more competitive and to reduce their environmental footprint – and permits the same resources to serve more people without requiring them to scale back their lifestyles.

An important aspect of optimizing any process is to control it better, permitting waste to be minimized and overall performance maximized. This journal looks at the potential for ABB's System 800xA industrial automation system. Another, complementary, technology that can unlock huge potential, both in terms of energy and improved controllability, is variable-speed drives.

Past articles in this journal have discussed their short monetary payback period. This issue looks at their broader environmental payback and shows that this is equally impressive.

While on the topic of drives, we also look at some more unusual applications. For example, moving the mighty roof panels of a large sports stadium, and thus providing an energy-efficient and flexible way of adapting the structure to different weather conditions and purposes.

Helping customers to improve operations to reduce their environmental footprint is just one part of the equation. As a manufacturing company, ABB is itself a large consumer of materials and energy. The company's new building at Longmeadow in South Africa integrates many sophisticated measures to save resources, and uses some of the company's own products in achieving this. And this is not a one-off project: In terms of energy consumption, ABB has set the goal of cutting this by 2.5 percent per employee annually.

As for the development of alternative sources, ABB's technologies are often an enabler for renewable power generation – in this issue as an equipment supplier for the Alpha Ventus wind park, including the generators and converters of the largest wind turbines to be installed in the world so far.

I trust this issue of *ABB Review* will provide fresh insights into solutions that help reduce our environmental footprint.

Enjoy your reading

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

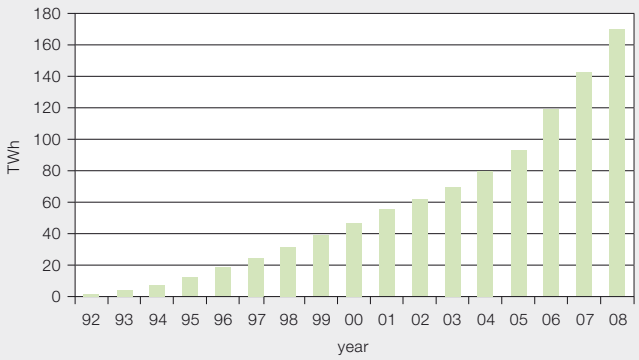

JibPLUS

# Driving down carbon emissions

## Environmental payback analyses with ABB drives

**JUKKA TOLVANEN, TIMO MIETTINEN – Environmental product declarations (EDPs) attempt to describe the environmental consequences of manufacturing a specific piece of equipment. The problem with this approach is that it takes no account of the benefits afforded by the future use of the equipment. ABB is therefore developing a new way of assessing the environmental impact of a piece of equipment over its operational life-span and beyond, taking account of the costs of production, its usage and its recycling potential, providing a value for the return on natural capital (RNC). By calculating RNC, a customer can assess the payback time for the equipment. The assessment of variable speed drives (VSD), for example, would provide an indicator as to how long the equipment would have to operate before it offsets the carbon footprint generated during its manufacture. Current EDPs take no account of the energy savings made throughout the operational life span of the equipment. The use of VSDs in industries using pumps and fans would make significant savings.**

1 The installed base of ABB low voltage drives saved about 170 TWh in 2008




**Energy saving in 2008 equivalent to the consumption of more than 42 million households in the EU-27 per year.**

Electric motors account for an estimated 65 percent of industrial energy use; however some 20 percent of this energy is lost through the wasteful methods used to control their speeds. Most often the speed of motors is controlled by some kind of throttling mechanism. The motor itself runs at full speed, but valves in a pump system or vanes in a fan application are adjusted to vary their effective operational speed. Similarly gears and belts can be used to regulate the speed of rotating machinery, but since the motor driving the operation continues to work at full speed, such mechanisms are inherently inefficient and wasteful.

Improvements in the operational efficiency of industrial drives have the potential to make major savings and help reduce $CO_2$ emissions. There are two main ways in which energy consumption for electric motors could be reduced:

- implementing efficient control over the speed at which they run
- increasing the efficiency of the motors themselves

In pump and fan applications the use of variable speed drives can cut energy bills by as much as 60 percent. A pump or fan running at half speed consumes only one quarter as much energy as a unit running at full speed. The speed of a motor can be adjusted by altering the voltage and frequency of its power supply. AC electricity is supplied at a fixed voltage and frequency, which means an AC-motor will continuously run at a fixed speed. By altering the voltage and frequency the speed of an AC motor can be adjusted. A change in frequency results in a corresponding change in motor speed (and torque). This means that the motor speed, and therefore the speed of the equipment being driven, can be set according to external production parameters, ie, flow rate or temperature by altering the voltage and frequency of the power supply. Variable speed drives (VSD) provide a system by which the voltage and frequency of the power supplied to the motor can be varied and controlled.

## Environmental payback

Many motors operate at less than full capacity, yet they operate at full-speed. VSD are designed to vary the speed of the motor so that the least amount of energy is consumed during the motors operation. This reduction in energy consumption can be quantified in environmental payback days. This is the time taken for the VSD to compensate for the $CO_2$ (carbon dioxide) emissions made during its production. With larger drives the reduced energy consumption of the motor can compensate for the energy required to manufacture the VSD in less than a day's operation. This means that subsequent days of operation will effectively reduce the $CO_2$ emissions that would otherwise have occurred if conventional methods were used to regulate the motor's speed.

An assessment of the RNC of a VSD would provide an indicator as to how long the equipment would have to operate before it offsets the carbon footprint generated during its manufacture.

2 Environmental product declaration (EPD) data for ABB's industrial drive, ACS800, 250 kW – emissions

| Environmental effect | Equivalent unit | Manufacturing phase | Usage phase |
|---|---|---|---|
| Global warming potential (GWP) | kg $Co_2$ / kW | 3.65 | 1,570 |
| Acidification potential (AP) | kmol $H^+$ / kW | 0.00 | 0.27 |
| Eutrophication | kg $O_2$ / kW | 0.05 | 18.20 |
| Ozone deleption potential (ODP) | kg CFC-11 / kW | 0.00 | 0.00 |
| Photochemical oxidants (POCP) | kg ethylene / kW | 0.00 | 0.27 |

## Regulating small motors

Although the efficiency of motors has improved on average by 3 percent over the last decade, further significant savings could be made since small reductions in speed can make major impacts on energy consumption.

It has been estimated that AC drives supplied by ABB over the last ten years for the speed control of pumps and fans have reduced electricity consumption by around 170 TWh per year ➔ 1. This is equivalent to the average annual consumption of electricity of more than 42 million European households. This corresponds to an average reduction of $CO_2$ emissions of over 140 million tons every year.

Despite the obvious energy saving advantages, 97 percent of all motors in applications less than 2.2 kW have no form of speed control at all. This corresponds to some 37 million industrial motors sold annually worldwide, and yet small VSDs have become less expensive year by year so that the financial payback time for a VSD is between six months and two years, depending on the application (two years for many pump and fan applications).

Improvements in the operational efficiency of industrial drives have the potential to make major savings and help reduce $CO_2$ emissions.

## Production versus usage

The term environmental product declaration (EPD) is frequently used to describe the impact of production on the environment. The problem with this approach is that it focuses only on the manufacturing stage and takes no account of the environmental impact of the future use of the equipment ➔ 2.

Environmental payback, on the other hand, is calculated as the amount of time required through the use of a product for it to compensate for the one-time environmental burden caused by its production. This is sometimes referred to as the return on natural capital (RNC).

Emissions data from the EPD show that the manufacturing carbon footprint of an ACS800 250 kW drive is 3.65 kg $CO_2$ / kW or a total of 912.5 kg $CO_2$ / ACS800 250 kW drive. Studies made at Tampere University of Technology indicate that environmental payback information for the same drive, in terms of global warming potential (GWP), is 0.5 days. In other words, by operating the drive for just half a day it is possible to fully compensate for the carbon emissions made during its manufacturing. The footprint then "turns negative" since the drive will lower emissions for the motor it controls throughout its operational lifetime ➔ 3.

The manufacturing of light weight VSDs obviously produce lower $CO_2$ emissions than those produced when manufacturing industrial class VSDs. However, the environmental payback time for the larger drives is shorter. This is due to the fact that the larger drives save considerable amounts of energy and therefore have a greater impact on the reduction of $CO_2$ emissions. In a typical pump or fan application a VSD saves 50 percent of the motors energy consumption.

## Energy consumption

The five major factors affecting the environmental payback period of a VSD are:
- the energy use of the drive
- manufacturing of circuit boards
- the final assembly
- the casing
- the capacitors

The most important factor influencing the environmental payback time of a VSD is the energy consumed by the drive during its operation. This can be improved not only by optimizing the control and efficiency of the VSD, but also by optimizing the efficiency of all equipment in the system, ie, the motor, pump, fan or extruder. Further savings can be made through design improvements and the optimization of drive use.

## Low manufacturing emissions

During the manufacturing of VSD the most important factor influencing the environmental payback time is the production of the electronic components. Over 50 percent of the $CO_2$ emissions are generated during its production. Here the manufacturing of circuit boards creates the heaviest environmental burden. Their transportation is generally less significant, provided they are not moved by air freight.

The manufacturing process itself can be optimized to reduce emissions, ie, the use

**3 Ecological payback (in days) for three types of ABB drives**

| Product | Power kW | GWP | |
|---|---|---|---|
| ACS140 | 0.75 | 6 | |
| ACS350 | 7.5 | 1.1 | |
| ACS800 | 250 | 0.5 | |
| **Product** | **AP** | **EP** | **POCP** |
| ACS140 | 6.0 | 8.0 | 15.0 |
| ACS350 | 0.9 | 1.2 | 1.3 |
| ACS800 | 0.4 | 0.9 | 1.0 |

Assumptions: drive provides 50 percent energy savings in typical pump or fan application using an average EU-25 electricity mix.

**4 A MET table can be used to evaluate the different components of a product's environmental load**

| Phase | Materials | Energy | Toxicity |
|---|---|---|---|
| – Manufacturing | – Weight (kg) – main material inputs<br>– Recovered materials<br>– Plastics (kg)<br>– Valuable metals (kg)<br>– Printed circuit boards and electronics) (kg, $mm^2$, layers)<br>– Water use in processes (l)<br>– Chemicals (kg)<br>– Volume ($m^3$) | – Energy consumption of manufacturing processes (kWh) (R&D, production equipment and plant allocated for one product) | – Chemicals used in manufacturing (amounts, toxicity, …)<br>– Emissions from manufacturing processes<br>– Materials of concern (to be separated at the end of life) |

of modular interchangeable parts that can be assembled easily, help optimize the assembly process increasing production efficiency and helping to reduce inventory, especially when the same part is used to manufacture different models. Such easy assembly can also help with the disassembly process, which means that parts

In pump and fan applications the use of variable speed drives can cut energy bills by as much as 60 percent.

can be sorted easily for possible reuse. Such considerations mean that the choice of raw materials for manufacturing becomes more significant.

The use of eco-efficient products and systems contributes toward reducing the environmental load. Consideration of recycling efficiency of VSDs at the end of the product's life-phase helps reduce its impact on the environment, either through the reuse of materials or by extracting their energy content. For instance aluminum parts can be recast, which avoids the costly environmental impact that results when extracting aluminum from aluminum ore.

For evaluating the environmental load of a product, factors at different phases of production can be gathered in a so called MET table (MET; materials, energy, and toxicity). Here we present the row for manufacturing → 4. The table usually includes rows for raw materials and the production of raw materials and components; their use; and their usefulness at the end of the product's life.

## Holistic approach

Manufacturers have tried to describe the environmental toll of a specific piece of equipment during its manufacturing process through an environmental product declaration (EPD). The problem with this approach is that no attention is paid to the future use of the equipment. Instead of EPDs, ABB has been developing a new way of predicting the life-time environmental costs. With these environmental payback calculations it can be shown that the environmental burden of manufacturing VSDs is paid back within days depending on the size and use of the VSD.

Despite the obvious energy saving advantages, 97 percent of all motors in applications less than 2.2 kW have no form of speed control at all.

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# Built for efficiency

## ABB's new manufacturing and logistics center in South Africa was designed to be green from top to bottom

CHESNEY BRADSHAW, PAULO DAVID – As one of the world's leading engineering companies, ABB is committed to helping its customers use electric power efficiently, increase industrial productivity and lower environmental impact in a sustainable way. In fact, the company's vision of power and productivity for a better world starts right in its own offices: ABB's new headquarters and manufacturing building for South Africa has taken on all these challenges, emerging as a technologically advanced, resource-efficient and energy-efficient workplace. The new building is helping ABB reduce environmental impact and lower operating costs.

Known as the ABB campus, the new high-tech facility is the manufacturing and logistics center for ABB in South Africa ➔ 1. The building was planned and developed with a focus on design, construction and facilities management automation, resource efficiency, recycling and ongoing minimal environmental impact. ABB's goal was to create a building that would be a model of resource and energy efficiency and would have minimal impact on human health and the environment, reflecting the company's green building policy.

Approximately 18,000 $m^2$ of the building is used as office space and 23,000 $m^2$ is designated as a warehouse and factory. Completed in 2009, the facility now houses more than 1,000 employees, who had been working at four different sites in South Africa.

## Building elements

The focus on energy efficiency is reflected in numerous different aspects of the $72 million (Rand 550 million) facility. It features key green building elements, including solar panels, a gray-water recycling system and energy-efficient lighting, and it also maximizes natural light in both the offices and the factory. The windows are coated with ultraviolet film and have louvers that create shade, which help reduce energy losses caused by the air conditioning. To further reduce the need for air conditioning, the building is insulated and ABB drives are used to maximize temperature control within the building together with the use of ABB's own high-efficiency ff1 motors and building management systems. Attenuation tanks are used to irrigate the indigenous landscaped gardens.

The expectation of the building is that it will reduce energy consumption through the use of hot water solar heating, the heat exchanger from air conditioning, the ff1 motors, the use of compact fluorescent lighting, the extensive use of gray water, and also by implementing ABB's building automation systems ➔ 2.

### Solar heating

A north-facing solar heating system on the roof of the building heats the water that is delivered to the showers. This free natural energy source also eliminates the need for electric heating and produces no carbon emissions. An impressive 80 percent of the energy for water heating is provided through solar power. Energy consumption for the heating system is also reduced through a heat

> An impressive 80 percent of the energy for heating the building is provided through solar power.

1 The energy-efficient ABB campus in South Africa

exchange system that uses hot air from the air-conditioning system to supplement the building's boilers. About 95 percent of all water heating is done via solar and heat recovery.

**Water conservation**

Another aspect of minimizing environmental impact is water conservation. All rainwater is collected from both of its roofs and the hardstands into an attenuation pond, which also adds aesthetic value. The factory roof and hardstand serve as a 40,000 $m^2$ catchment area; should a rainstorm deliver 100 mm of rain

With the installed insulation, cooling costs can be reduced by up to 8 percent in summer and heating costs can be reduced by up to 30 percent in winter.

(as is quite common in South Africa), a total of 4,000 l of rainwater will be diverted into two attenuation ponds that feed the indigenous gardens. The ponds are kept full through a top-up feature, enabling the gardens to be watered even on days it does not rain. A ball valve system automatically distributes this water.

Inside, water from the facility's showers and sinks is reused for flushing the toilets. This gray water is first collected, cleaned and recycled, and is then piped into the toilet reticulation systems. On average, 15 $m^3$ of gray water is collected every day.

**Building shape: form follows function**

The design principle "form follows function" certainly played a role in the development of the ABB campus. Its H-shaped configuration helps reduce energy demand because the office workstations are located in the exterior portions of the building where they can receive ample natural light. The roof design of the factory has also achieved such savings by enabling good use of natural light.

**Lighting**

Each workstation is fitted with a photosensitive switch that turns the light on when people arrive and off when they depart. All lights are low energy, with 12 kV downlights and emergency lighting installed in all of the service areas. In the factory, low-energy compact fluorescent lights are fitted throughout. The power reticulation grid to the lights allows individual units within the factory to turn their lights on and off as needed.

**Insulation and air conditioning**

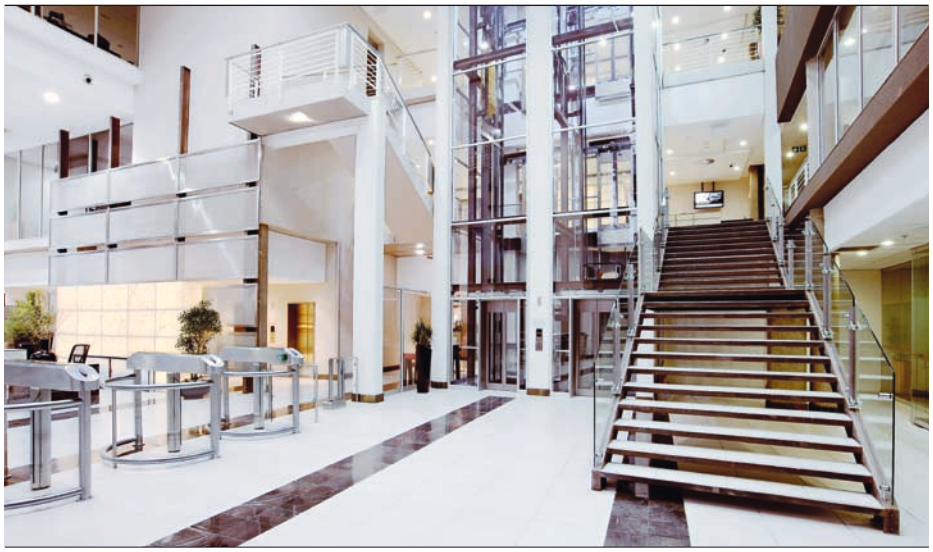
Another route to achieving greater energy efficiency is through climate control. The basement is open and was designed as such for effective natural ventilation. Fans are fitted throughout and have $CO_2$ detection meters that will automatically turn on air extraction when the $CO_2$ level reaches a predetermined value. The fans and air-conditioning plant are driven by

The fans and air-conditioning plant are driven by low-energy, high-efficiency ABB variable-speed drives.

low-energy, high-efficiency ABB variable-speed drives, which use energy more efficiently and pick up speed in a slow, controlled manner that eliminates high power demand bursts at startup.

Temperatures in the basement in winter can be as low as 5 °C and therefore the office floors directly above are made from a 200 mm thick concrete slab that is insulated with a 100 mm Styrofoam layer, as are the side walls and the roof of the building. The insulation ensures that the air conditioning plant is 20 to 30 percent more efficient in maintaining the right temperature. With the installed insulation, cooling costs can be reduced by up to 8 percent in summer and heating costs can be reduced by up to 30 percent in winter.

2 The manufacturing and logistics center makes use of the latest technologies to achieve the greatest savings.



**Building control**

A building management system (BMS) has been integrated into the new facility, and is programmed to automate, control and manage all of the energy demands in the building with the result that the entire operation is as energy efficient as possible. The BMS provides a wide range of control functions, including fire control, security, power monitoring, and air-conditioning control. Variable-speed drives, or VSDs, provide infinite control over the speed of motors driving pumps and fans, maximizing the building's environment by matching the temperature and humidity to the demands of the prevailing weather and the number of occupants. VSDs also contribute greatly to energy savings – by controlling the speed of the motor such that it only runs at the speed needed, energy consumption can be controlled via the BMS. This results in significant cost savings and also raises the building's green profile. Lower pump speeds extend mechanical life and reduce maintenance costs.

**Waste management and cleaning**

With a staff of over 1,000 employees, one can imagine the amount of trash that is created. A waste management plan was thus a necessity. The waste collection area and its management is outsourced to a waste management company. All waste is sorted, and paper, metal, glass and plastic are separated and removed for recycling. In keeping with the theme of reduced environmental impact, a company that uses environmentally friendly cleaning products is responsible for cleaning Longmeadow.

## An award-winning facility

The Longmeadow building attains the highest green building standards and, in addition to its regular functions, serves as the perfect setting for an event centered on more efficient products and solutions.

The office building and factory was the venue for the November 2009 Automation and Power World Africa – the company's largest customer event in Africa. The new facility was officially opened by ABB Chief Executive Officer Joe Hogan as part of the proceedings. The Automation and Power World Event included an event greening program to make the event carbon neutral through a three-pronged approach.

- Implementing sustainable food and beverage procurement strategies, sustainable waste management, a green cleaning program and sustainable procurement strategies for conference materials.
- Monitoring and calculating carbon emissions from the event. Carbon emissions were calculated for the following impact areas: delegate travel to Johannesburg by air and road, delegate travel to and from the event by road, energy use in accommodation and energy use at the event venue.
- Offsetting the carbon emissions from the two-day event by purchasing carbon credits and supporting projects focused on sustainability and environmental awareness with sustainability partners WWF-SA (World Wild Fund for Nature in South Africa).

> ABB won a prestigious top energy-efficiency performer award for its new manufacturing and logistics center building.

The building's energy saving efforts have not gone unnoticed. ABB in South Africa won a top energy-efficiency performer award in the industrial category of the eta energy efficiency awards sponsored by the utility Eskom and in association with the Department of Energy for its new building. The prestigious eta awards are granted in recognition of superior performance, creativity and innovation in energy efficiency. The award was one of three presented in the National Energy Accord category run by the National Business Initiative for outstanding performance in energy efficiency. The judges praised ABB for its energy-efficient building at Longmeadow, Johannesburg, and for the company's use of its own energy-efficient technologies as well as its lowered environmental impact. ABB also received a letter of congratulations from the National Energy Efficiency Agency of South Africa, commending the company for the lead that it has taken in energy efficiency specifically at its manufacturing and logistics center.

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# The drive to win

## ABB's direct torque control (DTC) technology is assisting with the world's largest roof and video display

BRAD COBO, KEN GRABER – As the saying goes, everything is bigger in Texas. The new home of the Dallas Cowboys – the US state of Texas' National Football League team – is certainly no exception. At a cost of almost $1.3 billion, this enormous structure encompasses over 3 million square feet, and seats up to 100,000 fans. Even though the first football playing season ended not so long ago, the stadium already holds some significant world records – such as the largest enclosed NFL stadium, longest single-span roof structure and largest high-definition video display. While football might be what this icon is best known for, the engineering that went into designing the structure is no less impressive. From the mechanization of the retractable roof, to the 600 ton video-board hoist system, ABB drives have played a major role.

The retractable roof is comprised of two moveable panels – each weighing over 750 metric tons.

With industry-leading features such as direct torque control and easily configurable master/follower operation built in to the motor drives for the massive sports arena, the choice for drives was clear. This stadium, utilizing ABB and a host of other technologies, has raised the bar on "moving architecture" for facilities that are used by millions of people.

### Moving architecture

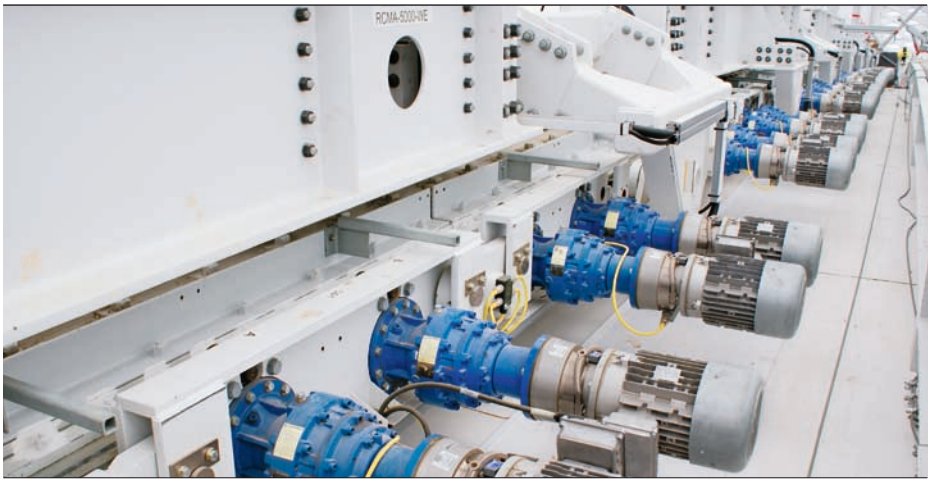
Building on a legacy that started 50 years ago, the Dallas Cowboys have gained worldwide recognition by winning five Super Bowls, eight NFC (National Football Conference) crowns and 19 division titles. Along the way, their home always has been as impressive as their record. The original home of the Cowboys, Texas Stadium, was widely known for the hole in its roof – a curious feature at the time. The open roof is one element that was carried over into the new stadium for practical reasons: The retractable roof and moveable end-zone glass doors allow ample sunlight and natural ventilation to flow through the stadium. This type of open design gives fans the sense of being outside, in the elements, where the game of football began. If Mother Nature should become too much to bear, as the weather frequently can be during hot Texas summers, the roof and doors can be closed in a matter of minutes. It is this kind of flexibility that makes the new stadium a true multipurpose venue. And with the football season lasting only six months each year, a host of other events are held in the off-season to maintain the venue's profitability.

To retract the roof, ABB's DTC algorithm calculates the current state of the motor 40,000 times per second and determines the best IGBT switching pattern to produce the needed torque.

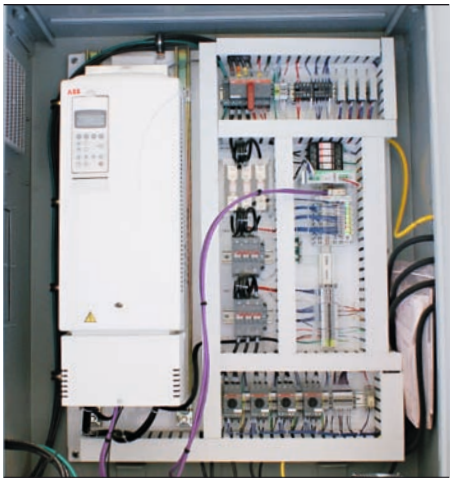
### Retractable roof

The retractable roof is comprised of two moveable panels – each weighing over 750 metric tons. Supporting that enormous load, a full 3.5 percent of the entire roof weight, are two box trusses that span the length of the stadium – over 370 m. Sitting on top of each truss is a steel rail similar to that used by train cars. The panels roll freely along this rail, but are anchored in place by a gear rail, or rack and pinion system. This is a critical component that allows a team of 128 7.5HP motors, with planetary gear reducers, to pull the panels up the inclined roof. The slope of the incline varies, up to 24 degrees when the panels are fully open. Multiple gear motors were chosen

1 128 7.5HP gear motors drive the retractable roof panels. Photo © Uni-Systems



2 ACS800-U11 line-regenerative drive. Photo © Uni-Systems



The Profibus network that connects each ACS800 drive to the PLC allows control and monitoring, as well as a safety feature called “torque proving.”

for the design, in order to provide redundancy and manage the safety risk created by the steep travel path. The multiple motor brakes and gear teeth engaged with the gear rack prevents the failure of any single component from allowing the roof panels quite literally to roll off the roof and fall into the parking lots. This redundant design also allows the retractable roof to be operated with up to five of the 32 motors offline in each quadrant ➔ 1.

## Optimal torque at zero speed

The steep incline creates one additional problem, too. When the panels are fully open and a command is given to close, the motors must start under an enormous load. This high starting torque demand normally requires the high-performance motor control provided by a closed-loop vector drive. This approach, however, was not advisable, due to the high cost and complexity associated with so many motor encoders. Instead, the engineers at Uni-Systems [1] took advantage of ABB’s direct torque control (DTC), which allows an almost identical level of performance without the headache of encoders. Using a 100 MHz digital signal processor, the DTC algorithm calculates the current state of the motor 40,000 times per second and determines the best IGBT [2] switching pattern to produce the needed torque. This feature is unique to ABB and is one of the main reasons these drives were chosen over those from competing vendors.

The ACS800 drives also are line-regenerative drives ➔ 2. This feature allows the drive to decelerate the motors without the use of a brake resistor. As the panels move from an almost level and fully closed position to a fully open position on a downward slope, they cross a point where the motors transition from motoring to braking. It is during this braking phase that the drives are called upon to slow the motors and keep the opening speed under control. This braking technique is accomplished by converting the kinetic energy of motion to electrical energy inside the drive – a process called dynamic braking. Normally the drive dissipates this excess energy as heat, using a brake resistor in much the same way a car braking while headed downhill causes the brakes to get hot. This heat, or thermal energy, is essentially wasted. A line-regenerative drive is an alternative solution that, instead, sends this energy back to the utility. While the amount of energy recovered is small, about $ 14 worth per opening cycle, the benefits of not having to install brake resistors were significant, and justified the additional cost of line-regenerative drives.

## Teamwork

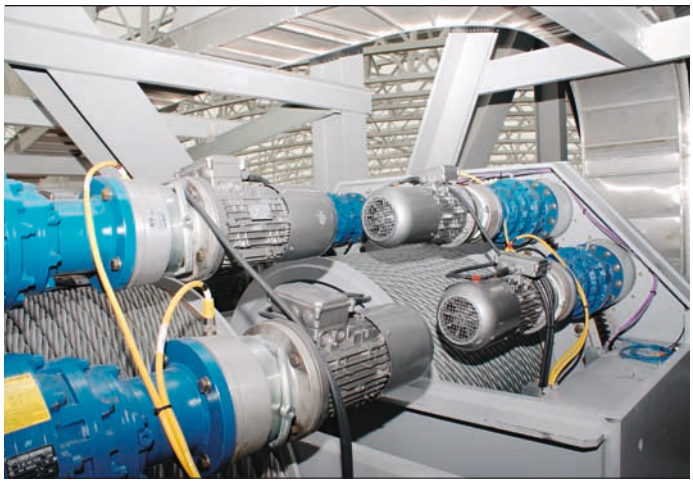
Coordinating the motion of 128 gear motors to ensure they all work together is no small feat, but one that the ACS800 drives accomplish fairly easily through their built-in load-sharing feature. A total of 32 drives, divided into four groups of eight, are used to drive the 128 gear motors (four motors per drive). Each group of eight drives has one speed-controlled “master” and seven torque-controlled “followers.” This so-called master/follower network allows these individual motors

**Footnotes**

1 See www.uni-systems.com
2 IGBT: insulated-gate bipolar transistor

3 600 ton high-definition video display.
Photo © Blake Marvin / HKS, Inc.

4 Video board hoist drums.
Photo © Uni-Systems



to work together as a team. The master drive runs at a speed given by the PLC (programmable logic controller) over Profibus and, using the DTC algorithm, calculates the actual torque needed to maintain this speed — and then sends this value over a fiber-optic link to the follower drives as a torque reference. The follower drives run at whatever speed is necessary (subject to a speed window) to achieve this torque value. This type of arrangement ensures that all of the motors will share the load equally. And with a master/follower update time of only 2 ms, the system responds to changes in load very quickly, ensuring that the roof panels stay well away from those parking lots.

While the Profibus network that connects each drive to the PLC allows both control and monitoring, it also can be used to implement one of many safety features critical to the retractable roof system. One such feature is called "torque proving," which makes sure that each motor is online and generating torque before allowing the brakes to be released. For example, whenever a roof panel is moved, the PLC will begin by sending all master drives a run command with a very slow speed set point. Since the brakes have not yet been released, this causes the drives to generate torque. Each drive reports its actual torque back to the PLC, where it is compared with a minimum value. Once the PLC sees that all drives are generating at least this amount of torque, it will give the final command to release the brakes. At that moment, the drives will assume control over the panel movement and begin accelerating. This torque-proving feature is a critical safeguard, but only one of several used on the roof system.

## Hoisting a $40 million view

Perhaps the most prominent feature of the stadium, the video board, also is the largest of its kind in the world ➔ 3. Manufactured by Mitsubishi Electric Diamond Vision™, the two 22 m by 49 m (72 feet by 160 feet) displays span from one 20-yard line through to the other. Each is a true high-definition display, capable of a 1920 × 1080 resolution in a 16:9 format. On the ends are two smaller displays, measuring 8 m (27 feet) high by 15 m (48 feet) wide. The net impact achieved via the 30 million individual LEDs pales only in comparison to its price tag: $ 40 million – more than the entire cost of the first Cowboys stadium.

While the video board initially was suspended from the roof at a fixed height of 27 m (90 feet), it soon became apparent that some method of raising and lowering it was needed. An upcoming concert by the internationally famous rock band U2 required that the board be raised another 3 m (10 feet), to accommodate their stage equipment. The Cowboys once again turned to Uni-Systems to design and install a hoist system for the video board. By using a cable drum design borrowed from previous stadium projects, they were able to complete the job with minimal cost and in a very short amount of time. The plan involved distributing the weight of the 600 ton board over 16 hoist drums, using four motors per drum for redundancy and load sharing. Each end of the video board is supported by a group of eight hoist drums, giving the ability to move each side independently, should the board need to be leveled. When working together, they can raise or lower the board from 8 m (25 feet) to 35 m (115 feet) above the field. Four 5 HP motors per drum were used and fed from two ACS800 line-regenerative drives. With one master and seven followers, the load-sharing arrangement was identical to that used on the roof. The torque-proving safety feature also was implemented as one of several layers within the overall safety system.

An additional eight drums were installed, but not for lifting purposes. These so-called stay drums use cables anchored to the four corners of the video board ➔ 4. This prevents any undesired back-and-forth swaying motion due to air currents passing through the stadium when the roof and end-zone doors are open. The drums are torque controlled and main-

The weight of the 600 ton video display is distributed over 16 hoist drums, using four 5 HP motors per drum for redundancy and load sharing.

5 Moveable end-zone glass doors. Photo: Brad Cobo

Driven by ABB ACS350 drives, five of the seven 12 × 37 m glass panels part in the middle to create a 55 m wide opening in 6 minutes.

tain a fixed tension on the stay cables any time the main hoist is operating. A speed-windowing feature in the drive also was used to place a limit on the speed the drive can run, while trying to maintain its torque set point. This important setting prevents the drives from releasing and regathering cable too quickly, and thus provides a degree of damping, which serves to resist any abrupt video board movements. The tuning involved to make this a success was simplified via ABB DriveWindow software, which is used to monitor the movements of several drums at once. With so many motors and drives required to operate in harmony, this real-time monitoring ability was essential.

## Moveable end-zone doors

At each end of the stadium, just beyond the end-zone goal posts, are moveable glass partitions, which are more similar to walls than doors → 5. Each wall is comprised of seven glass panels with each measuring 12 m (38 feet) wide by 37 m (120 feet) tall. Two outboard panels are fixed, and the remaining five are operable. Driven by ABB ACS350 drives, these panels part in the middle to create a 55 m (180 feet) wide opening in 6 minutes, blurring the distinction between what is indoors and out.

## Postgame

ABB is proud to have been a part of the moving architecture that is the new Cowboys Stadium. From simple conveyors to the world's largest retractable roof, ABB drives are regarded for their ability to provide high-performance motor control, while being very easy to use. With industry-leading features such as direct torque control, and with the help of competent technical partners like Uni-Systems, the Cowboys Stadium project is an example of how technology and know-how can come together to solve extraordinary problems – a winning combination every time. While the company's products are not immediately visible in the stadium, they are the products that provide a seamless experience for users, and deliver peace of mind year-in and year-out to the property owners.

Title page photo by Brad Cobo.

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# Laying the course

## Achieving fuel savings for anchor handling tug supply vessels through electric propulsion

TOR ARNE MYKLEBUST – Electric propulsion in platform or offshore supply vessels has been used since the early 1990s. The technologies have advanced over time, and today there are several optimal propulsion systems that reduce fuel consumption and environmental impact, simplify design and construction and better utilize onboard space, and create an improved working environment for the crew. The need to reduce fuel consumption and operational costs have been the driving forces behind the advancement of electric propulsion technology, and the economic benefits have been significant. Until recently, offshore supply vessels have been the focus. But now, the use of electric propulsion in anchor handling tug supply vessels is gaining more attention and is extending savings to another shipping segment.

Electric propulsion has demonstrated substantial fuel reduction compared with direct mechanical propulsion for offshore support vessels. The fuel savings can reach 15 to 25 percent in typical operation profiles, and as much as 40 to 50 percent in pure DP (dynamic positioning) operations ➔ 1.

Although most electric power and propulsion plants utilize the same fundamental concepts, there is nevertheless a range of different configurations on the market. To achieve optimum savings, ship owners, ship yards and designers must evaluate all available options and examine a number of criteria when considering products, systems and services ➔ 2.

## Achieving fuel savings

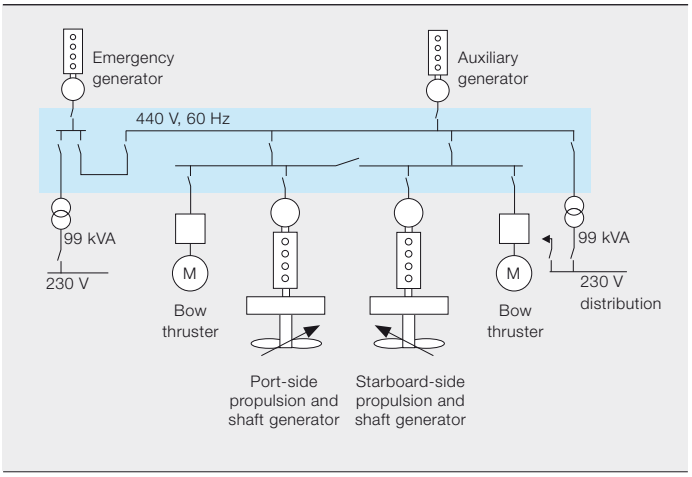
The introduction of electric propulsion requires the replacement of the shaft between the main engine and the propeller with a system comprised of generators, switchboards, transformers, drives and motors. The system has an efficiency of approximately 90 percent, which means that there are additional losses in the system that must be accounted for in some way. The variation of losses between the different electric topologies is small. However, electric losses are always minor compared with the hydrodynamic losses of the propellers and the combustion efficiency in the main engines. So although electric losses are introduced, the reduced hydrodynamic and combustion losses nevertheless lead to a reduction in the system's total losses.

Reduced fuel consumption in an electric propulsion system can be attributed to two key elements. The first is the variable-speed control of the propeller, which reduces the no-load losses of the propellers to a minimum compared with classical fixed-speed controllable-pitch propellers. The second element is the automatic start and stop of the diesel engines, which ensures that the engine load is kept as close to its optimum operating point as possible, within the limits of operation.

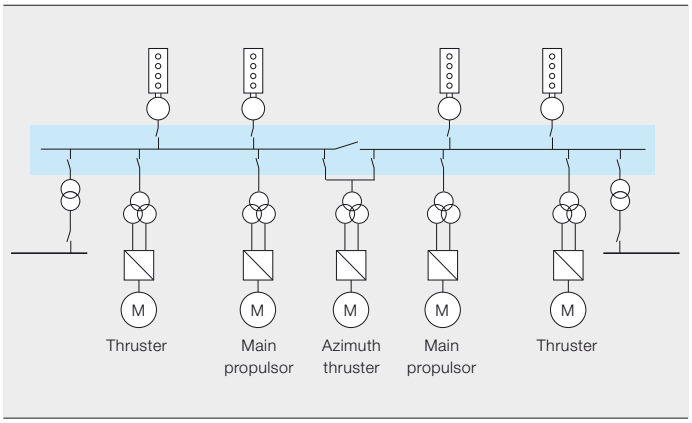
The classical design of an offshore support vessel, including the AHTS (anchor handling tug supply) vessel, is to use fixed-speed propellers with controllable pitch. Compared with variable-speed control of the propeller, this is a very inefficient way of controlling the thrust, due to the high no-load losses of the fixed-speed propellers ➔ 3. This alone contributes to most of the savings in electric propulsion when applied to offshore vessels. In addition, the utilization of the thruster capacity in DP operations is very low for most of the operational days in, eg, the North Sea, even though this is regarded as a harsh environment.

The other major impact of electric propulsion comes from its potential for optimal loading of the diesel engines by using a number of smaller engines, as compared with using a small number of larger units. Depending on the load, the automatic start and stop of the engines

**1 Propulsion systems for offshore supply vessels (OSVs)**




**1a Conventional direct mechanical propulsion**

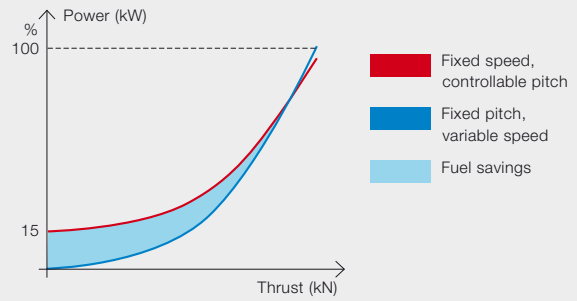



**1b Electric propulsion**

**2 Criteria for evaluating electric propulsion configurations**

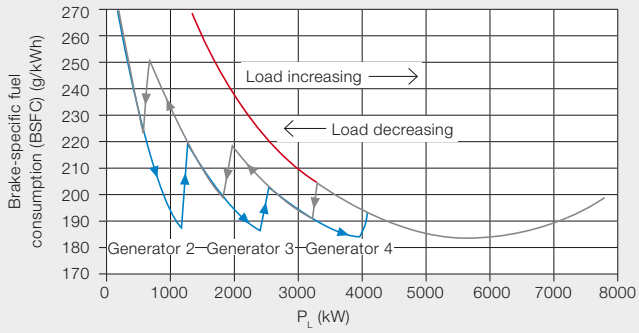
- Cost-efficient building and installation
- Flexible design that improves ship utilization
- Increased safety
- Availability of propulsion and station keeping systems used for DP (dynamic positioning)
- Reduced fuel consumption
- Reduced environmental footprint (ie, lower emissions)
- Improved working environment for the crew
- Low maintenance costs
- Ease of maintenance during the life cycle of the ship
- Ease of maintenance in the region of operation, often worldwide
- Spare parts availability
- Remote and onboard support
- Minimization of the constraints that lead to suboptimal performance
- Minimization of adverse effects on other equipment
- High ice-breaking and ice-management performance for icebreakers

### 3 The benefit of variable speed




**Comparison of shaft power versus provided thrust from a fixed-speed controllable pitch propeller (CPP) and a variable-speed fixed-pitch propeller (FPP)**

### 4 Fuel consumption per kWh of produced energy

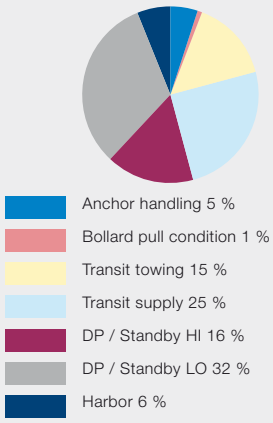


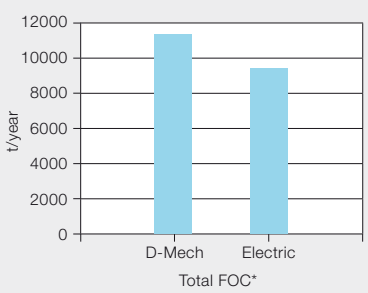

**Four equally sized diesel engines running in parallel, with automatic start and stop functionality of the power management system, compared with one large diesel engine providing the same total power (red line)**

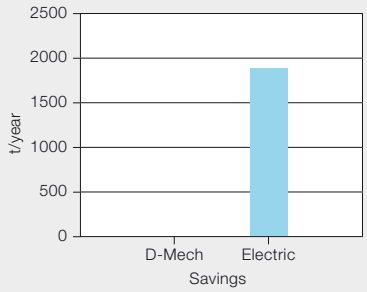
### 5 Electric propulsion and direct mechanical propulsion for a 200+ metric ton bollard pull AHTS

| | Fuel oil consumption | | |
|---|---|---|---|
| Operation mode | Base case D-mech (kg/h) | Electric propulsion (kg/h) | Operation profile (h/year) |
| Anchor handling | 2,280 | 2,295 | 438 |
| Bollard pull condition | 2,451 | 2,795 | 88 |
| Transit towing | 1,898 | 2,053 | 1,314 |
| Transit supply | 1,276 | 1,036 | 2,190 |
| DP/standby HI | 1,377 | 1,020 | 1,402 |
| DP/standby LO | 1,015 | 620 | 2,803 |
| Harbor | 26 | 25 | 526 |

| | | | |
|---|---|---|---|
| Total FOC* (kg/year) | 11,293,005 | 9,396,661 | |
| Total FOC* (t/year) | 11,293 | 9,397 | |
| Difference (t/year) | 0 | **1,896** | |




* Full operational capability

The variable-speed control of the propeller and the automatic start and stop of the diesel engines in an electric propulsion system can reduce fuel consumption.

yields better loading and thus reduces fuel consumption ➔ 4.

For a 200+ metric ton bollard pull AHTS, fuel consumption has been calculated at close to 1,900 metric tons lower when electric propulsion is used ➔ 5.

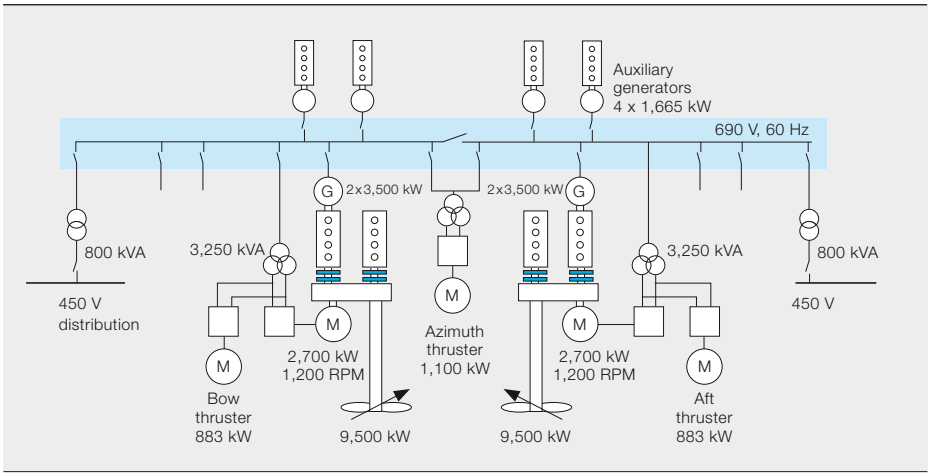
The required installed propulsive power for an AHTS is greater than that of a typical offshore supply vessel, and as a result, the cost of the propulsion systems and installation is also higher. In traditional AHTS systems, the design is optimized for the building costs and for obtaining the guaranteed bollard pull. In the past, less emphasis was placed on operational costs when designing and selecting propulsion concepts. With today's unpredictable fuel prices and mounting environmental concerns, this is subject to change. Now there are several vessel designs in which the operational costs and in particular the fuel consumption are the primary areas of focus.

## Hybrid propulsion

An alternative to the full electric solution is the combination of mechanical and electric propulsion systems – the so-called hybrid propulsion system ➔ 6. Here, the vessel can be operated in one of three ways.

- Full electric propulsion for low-speed maneuvering, transit and DP
- Full mechanic propulsion for tugging and high-speed transit
- Hybrid electric and mechanical propulsion, where electrical equipment can be used as a booster for

6 Hybrid electric and mechanical propulsion for a 200+ metric ton AHTS




the mechanical propulsion system to maximize bollard pull

In terms of installation costs, hybrid solutions are more economical than pure electric solutions, and are quite comparable in terms of fuel consumption. For these reasons, several new AHTS designs have been based on such hybrid solutions, especially those with high bollard pull.

However, the increased mechanical complexity of such hybrid systems – where the crew must be more active and manually select the optimum operational modes for the prevailing conditions – should not be disregarded. In pure electric propulsion systems, it is much easier to optimize the configuration of the power and propulsion plant automatically, ensuring that the system will always operate as closely as possible to optimal conditions, with or without minimal manual interaction.

## Propelling ahead

For AHTS vessels, traditional propulsion systems had been optimized to obtain guaranteed bollard pull and minimize building costs, but at a price – higher fuel consumption and substantial environmental emissions, especially $CO_2$, when compared with electric propulsion. With the adoption of electric propulsion by OSVs (offshore supply vessels) and now too by AHTS vessels, fuel consumption, emissions and operational costs are being drastically reduced.

Much of the same savings may be achieved by using hybrid electric and mechanical propulsion at a lower building cost than is the case with pure electric propulsion, but with the caveat that the crew must be actively involved in selecting the optimal configuration for varying operations.

Electric propulsion systems make fuel savings possible through the flexible operation of the vessel, even though the system itself introduces new losses in the energy chain. Efforts can of course be made to reduce these new losses, but in order to maximize the benefits of electric propulsion, the focus should primarily be on designing a simple, reliable and flexible system.

For a 200+ metric ton bollard pull AHTS, fuel consumption has been calculated at close to 1,900 metric tons lower when electric propulsion is used.

## ABB's electric propulsion offerings

ABB is the world leader in electric propulsion and offers a full range of systems – from variable-speed electric machinery for shaftline propulsion and mechanical thrusters to a unique family of podded propulsion systems, most notably the Azipod®. ABB has delivered hybrid electric propulsion systems to a number of OSV/AHTS vessels, including those from DOF ASA, Farstad Shipping ASA, Island Offshore AS, REM Offshore AS, Solstad Offshore ASA, Ezra Marine Services and China Oilfield Services Ltd., providing low-voltage generators, transformers, drives and electric motors for main propulsion and maneuvering.

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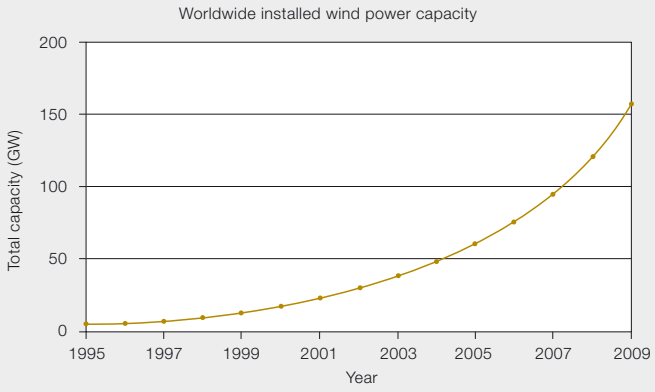
# Facing the wind

## ABB and the Alpha Ventus wind park

MELANIE NYFELER, ANDREAS MOGLESTUE – The sea has always presented a unique challenge to mankind. Humans have often been driven to the limits of their ingenuity and stamina to overcome its forces – or at least live with them. It may be that today there are no longer any unexplored shores, and that voyages that were once adventurous undertakings have become regular trading routes. The sea, however, remains a source of unpredictability and continues to test those who face its fury. One place where this manifests itself is in the erection of offshore wind turbines. ABB was involved in the pioneering Alpha Ventus project, which was built off Germany's North Sea coast. The company's contribution includes generators, frequency converters and gas-insulated switchgear. Installation and commissioning involved facing unpredictable weather, strong winds and rough seas.

**1 Worldwide installed wind-power capacity**




Source: Bundesverband WindEnergie e.V., Global Wind Energy Council

The wind is a rapidly growing source of energy. Worldwide generating capacity has increased from 4.8 GW in 1995 to 158 GW in 2009 ➔ 1, and this growth is set to continue. Wind energy has clearly advanced from the domain of experimental and niche applications to making a real contribution to the energy balance of the countries and regions that have invested in it. Although economies of scale and the accumulation of know-how have reduced the price (per MW) as well as the risk of new installations, cost efficiency is still an important objective. There is thus a trend towards larger and more powerful turbines. Interest in offshore wind farms is increasing, due both to questions over the acceptability of such huge towers in inhabited regions, and to the simple fact that there is more raw wind energy available more of the time at sea.

As simple as the logic of building offshore wind farms may seem, their realization is connected with numerous challenges. These range from the difficulties in installing and anchoring the turbines in rough seas, to assuring they function as intended over long periods of time despite being battered by strong winds, high waves and a moist atmosphere, and being difficult to access for repairs and maintenance.

The Alpha Ventus wind farm is an experimental installation located 45 km north of the German North Sea island of Borkum ➔ 2. It is a joint project of the utility companies, E.ON Climate & Renewables, EWE and Vattenfall Europe. The installation is of experimental nature, and experience gathered here will flow into other offshore projects. The Alpha Ventus windpark features 12 turbines each rated at 5 MW. In a first phase, six turbines supplied by Multibrid were installed in a grid-like arrangement on an area of 4 $km^2$ – standing about 800 m apart. In a second phase, the wind farm was extended by the addition of six RePower turbines. The Alpha Ventus turbines are the largest wind generators installed in any offshore application in the world so far. The hub of each rotor is 90 m above the sea's surface, which is itself about 30 m above its bed ➔ 4. At its apex, the rotor reaches a height of 148 m, or 1 m more than the Cheops pyramid. The steel of each tower weighs about 1,000 tons, or as much as 200 adult elephants. The tips of the blades circumscribe a vertical area of one hectare, or the area of London's Trafalgar Square. In doing so, they can reach speeds of 324 km/h, comparable to a Formula 1 racing car.

> The work at sea required thorough planning. There was no way to quickly return to the support ship for a forgotten tool.

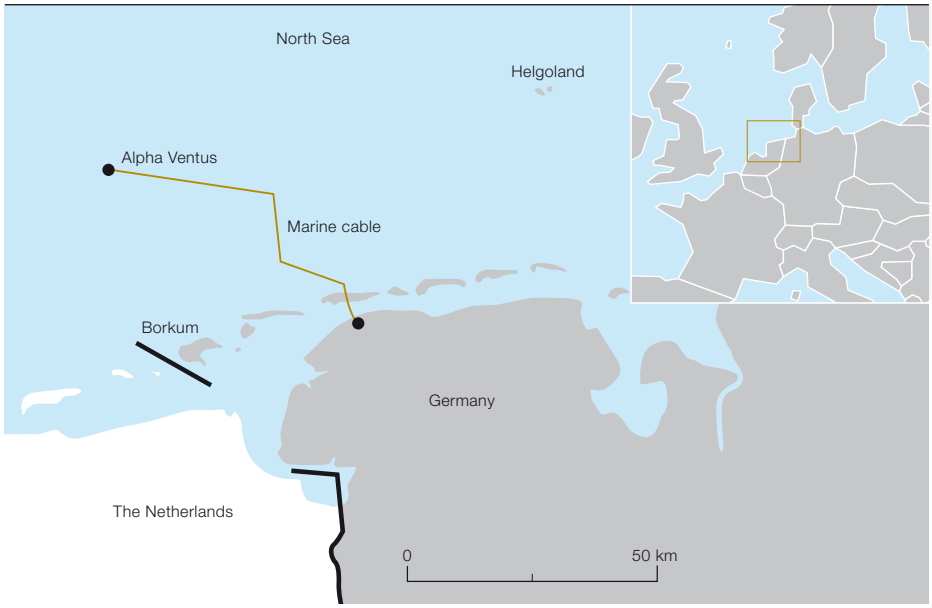
The generators for these turbines were supplied by ABB. They are permanent-magnet synchronous machines [1], a concept that enables high reliability, a crucial factor on account of their inaccessible location. ABB also supplied the PCS 6000 Wind frequency converters that connect the generators to the grid ➔ 5. These converters are sufficiently compact to fit on a single level inside each of the towers ➔ 6. A separate dedicated platform accommodates the wind farm's transformer, switchgear, control equipment and various auxiliary equipment.

The turbines of the first phase commenced operation in August 2009. This followed a commissioning phase lasting from mid July to late August. The components of the towers, including the rotors were positioned by floating crane platforms – a job requiring millimeter accuracy. In order to reduce the risk of poor weather hampering installation work, as many components as possible were pre-assembled on shore, including much of the electrical installation. Nevertheless, inclement weather forced the work to be interrupted several times. ABB was Multibrid's only sub-supplier to be on-site during the commissioning, reflecting the importance of ABB's contribution for the project as a whole. In fact up to four ABB people were on-site from mid July to late August.

**Footnote**

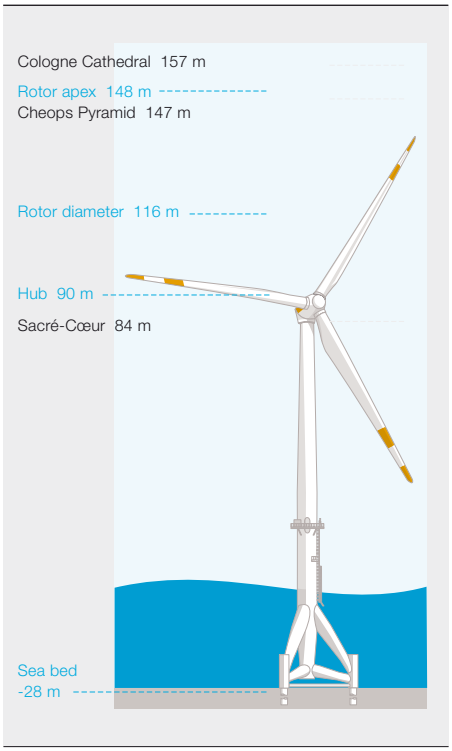
1 See also "The attraction of simplicity: Permanent magnet machines are here to stay" on pages 29–34 of *ABB Review* 2/2009.

2 The Alpha Ventus windfarm is located 45 km north of the island of Borkum




3 The commissioning of the turbines involved facing many challenges.

4 The wind turbines stand almost as tall as the Cheops Pyramid




The ABB technician, Uwe Heydel, who brought in a wealth of experience from his oil rig days, was part of the team that commissioned the frequency converters. He recalls that on account of the high waves, the docking of the inflatable boat sometimes proved a greater challenge than actually working on the electrical installations inside the tower. An additional challenge arose when during assembly, a protective bag failed to detach from one of the turbines' wings. A Multibrid employee had to rope down from the turbine's hub → 3. The man who attached this rope to the hub was ABB's Uwe Heydel. Recalling the incident later, he confesses that he would have loved to do the job himself. Such situations were part of his rigorous training, which also including simulating a helicopter crash and surviving as a castaway at sea. Uwe Heydel muses that despite being on site to install advanced technology, some of the greater challenges lay in dealing with some very low-tech problems.

The work at sea required thorough planning. There was no way to quickly return to the support ship for a forgotten tool. Communication was also a challenge. Although the support ship was equipped with a satellite phone, it was mostly at night that this crackling and unreliable link could be used for support calls.

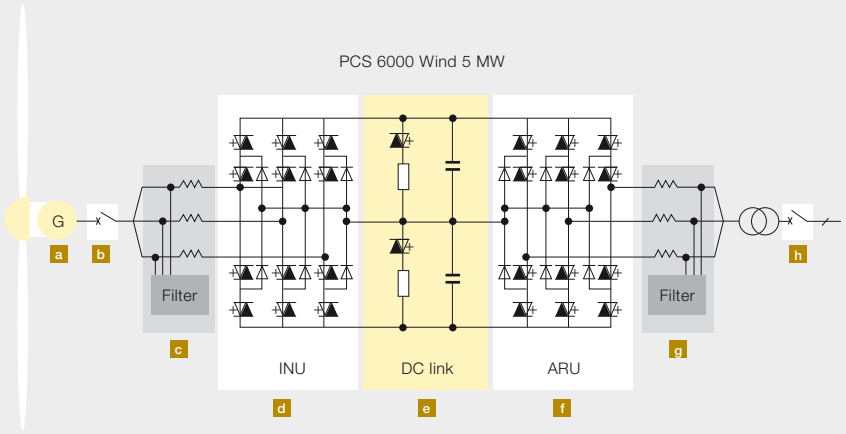
5 Offshore converter: the PCS 6000 Wind

The generators ABB supplied for the Alpha Ventus project are speed-variable permanent-magnet synchronous machines, a choice of technology selected for its low maintenance requirements in line with the inaccessibility of the location. The generator output is thus of variable frequency. ABB has developed the PCS 6000 Wind converter specifically for such wind power applications with a power above 3 MW. This four-quadrant converter is based on IGCT technology. Besides assuring the connection between the generators and the grid, the converters can absorb or supply reactive power to support weak grids. In fact they can operate in 100 percent reactive power mode to help a re-start after a blackout. Being four-quadrant converters, they can support energy flow in both directions. In normal operation, energy only needs to flow from the generator to the grid, but for blade positioning, for example, an inverse flow is required. The converter is controlled by ABB AC 800PEC controllers *).

The converter's special features include its high power density, low maintenance requirements, electromagnet disturbances and water condensation (it fulfills IP54 in terms of ingress protection). Thanks to its compact design, the converter and all its auxiliary equipment need only a single platform inside the turbine's tower.

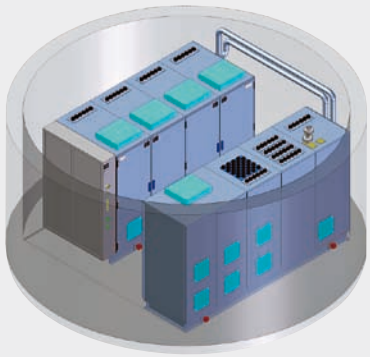
The PCS 6000 high reliability is supported by its remote service capabilities. ABB's Diagnostic Information Analysis System (DIAS) helps remotely diagnose the converter and also permits remote supervision to support local service teams.

* See also "Design patterns: Co-design patterns for advanced control with AC 800PEC" on pages 62-65 of *ABB Review* 2/2006




a Permanent magnet synchronous generator
b Circuit breaker generator
c dV/dt filter
d 5 MW generator converter
e DC link brake chopper
f 5 MW grid converter
g Grid filter
h Circuit breaker transformer

6 The entire frequency converter fits on one level inside the tower.



The tips of the blades circumscribe a vertical area of one hectare, or the area of London's Trafalgar Square. In doing so, they can reach speeds of 324 km/h, comparable to a Formula 1 racing car.

ABB's involvement did not end with assembly, but a important part of the contribution of ABB's staff lay in taking the turbines into operation and fine tuning to assure their optimal performance.

Since starting to feed power to the grid at the end of August 2009, the equipment has been performing satisfactorily. Remote access and diagnosis tools are supporting the operation. So far, ABB's technicians have not had to return to the site. The company's generators and frequency converters are weathering the challenges of this tough operating climate.

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**Further reading**

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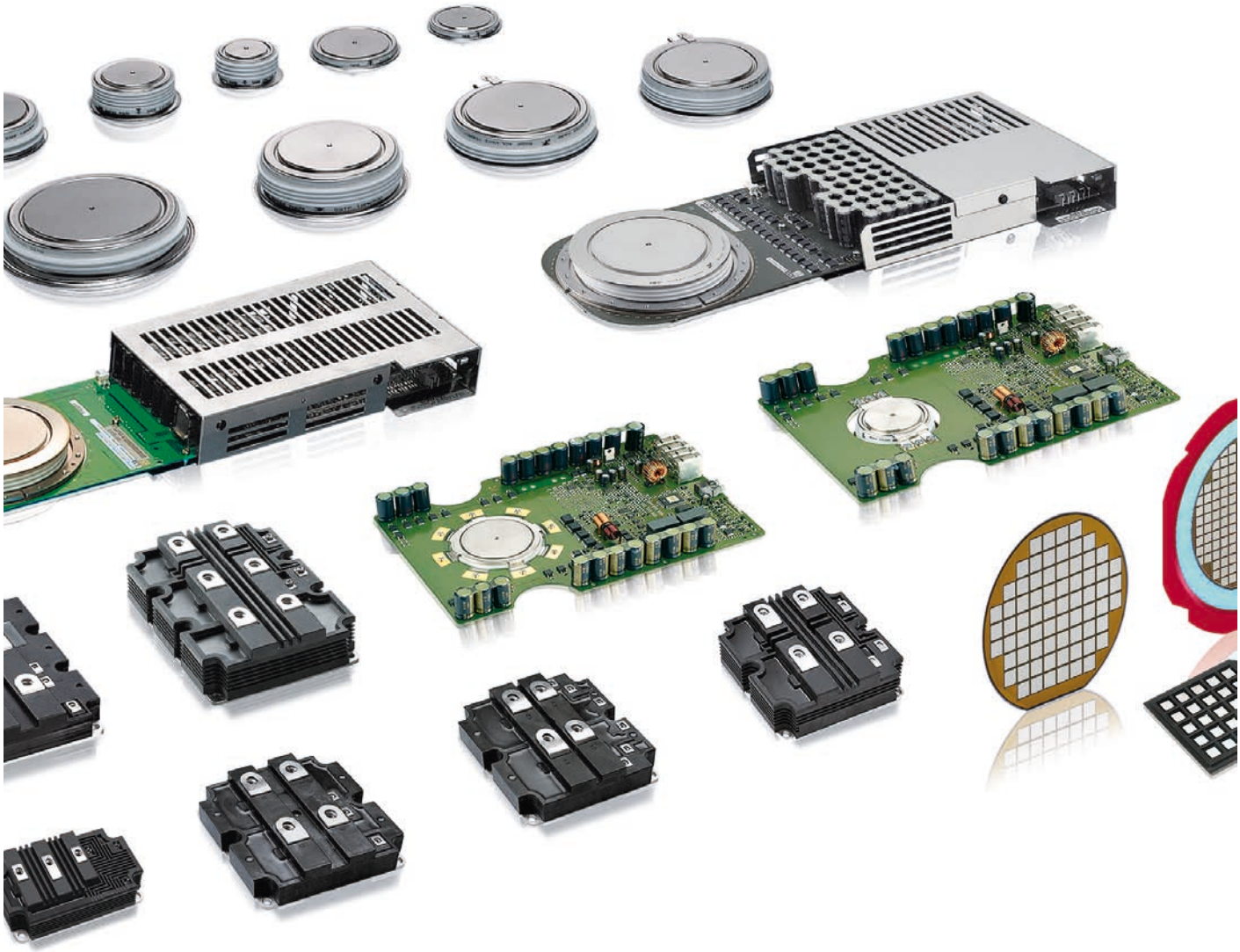
– Kreusel, J., Harnessing the wind: How the wind is leading to a paradigm change in electrical power supply, *ABB Review* 2/2007.



# Semiconductors demystified

## Part 1, The chips at the heart of the evolving power grid

CLAES RYTOFT, BERNHARD ESCHERMANN, HARMEET BAWA, MARK CURTIS –
ABB has been manufacturing high-power semiconductors for several decades. These key components are found at the heart of many leading ABB technologies such as high-voltage direct current (HVDC) transmission systems and variable-speed drives. Investment in highly specialized facilities in Lenzburg, Switzerland, has created the capacity for ABB to develop and manufacture sophisticated power semiconductor devices. These facilities provide ABB with the unique advantage that it can apply the best-suited devices to its ever expanding portfolio of power-electronics-based products.

Power electronics deals with the conversion and control of electricity using solid-state switching devices ➔ 1. In recent years advances in power semiconductor technology have resulted in an ever expanding array of applications. The adverse effects of global warming, resulting from the burning of fossil fuels, have played a major role in driving the increased use of power semiconductor technologies aimed at utilizing renewable energy generation and increasing energy efficiency.

Even in the very early days of electricity, transmission efficiency had an impact on the type of electricity that prevailed, ie, direct current (DC) or alternating current (AC). Initially, for historic reasons, electric power systems were predominantly DC circuits. However, the inability to alter DC voltage levels, at that time, limited its use. Power generators were built therefore to satisfy the load on the circuit (eg, at a voltage level required for lighting or motors). Inefficient transmission at such low voltages meant that these generators had to remain within a short distance of consumers.

The subsequent development of AC generators and transformers provided the much needed technology that would allow power to be stepped up to 110 kV or more, to facilitate efficient long-distance power transmission. This meant

## 1 Power electronics

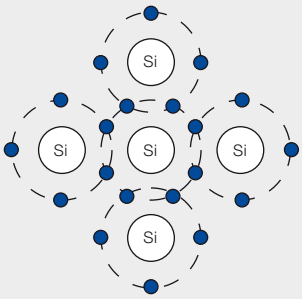
Power electronics stems from the discovery of semiconductors and identifies a significant change in technology toward solid-state electronic switches* as a means to modify electricity.

Semiconductors, such as silicon, have electrical properties that fall somewhere between a good conductor (eg, copper) and an insulator (eg, rubber). If placed in a circuit they act for much of the time as insulators, forming a barrier to the flow of electrons, but sometimes, under certain conditions (elevated temperature, exposure to electromagnetic fields, etc.), they behave more like conductors, allowing electrons to flow freely. The conductivity of a pure semiconductor, often called an intrinsic or I-type semiconductor ➔ 1a, can be drastically changed by adding other elements, known as impurities, so that a new and different crystal is formed in a process called "doping." Dopants used for silicon-based semiconductors have either a three- or five-electron valency, which is one less or one more than silicon's four.

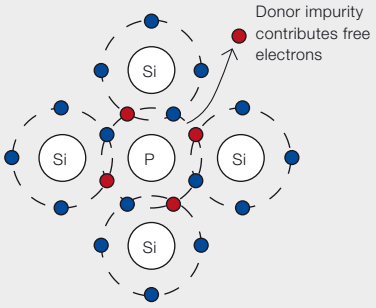
By adding small quantities of phosphorus, for example, with a valency of five, the properties of an I-type semiconductor are altered so that more free electrons are introduced, since its fifth electron remains unpaired. This creates an excess of negative electron charge carriers, leading to the creation of an n-type crystal ➔ 1b. These weakly-bound electrons can move about in the crystal lattice relatively freely and can facilitate conduction in the presence of an electric field. Similarly, by adding small quantities of boron, with a valency of three, the properties of an I-type semiconductor are altered again. This time, however, it is the fourth electron of silicon that remains unsaturated when it covalently bonds with the dopant boron. Unsaturated bonds are repaired by electrons from neighboring bonds, leaving positive "holes" or p-type regions in the semiconductor ➔ 1c. The continued process of repair creates a chain-like reaction that results in positively charged holes moving around the crystal. Current can be carried either by the flow of negatively charged electrons or by the flow of positively-charged "holes" in the crystal lattice of the semiconductor material. Both n- and p-type semiconductors behave like insulators below a threshold voltage, resisting current flow, but above that threshold they behave like conductors, allowing the current to flow freely. The conductivity of these n-type or p-type semiconductors can be varied between insulating and conducting by the level of dopant incorporated into the silicon lattice. To control the direction and magnitude of the current required to switch the semiconductor from an insulator to a conductor, p- and n-type semiconductors can be arranged adjacently in the same crystals, forming a junction in which the negatively charged electrons from the n-type semiconductor fill the holes resulting from unsaturated pairing in the p-type semiconductor. This creates a thin nonconductive I-type semiconductor junction at the border between more conductive p- and n-type semiconductors. This non-conductive barrier must be overcome by an external voltage source to make the junction conduct. By manipulating this non-conductive p–n junction, the electrical properties of the device can be controlled. The property and arrangement of such doped semiconductors provides the key element that led to the development of the transistor, and now forms the fundamental building block of all modern solid-state electronic devices.

**Footnote**

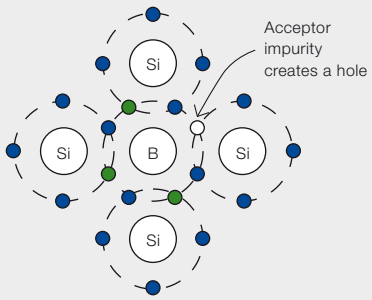
* Circuits or devices built entirely from solid materials without moving mechanical parts.




**1a I-type semiconductor, no impurities added**

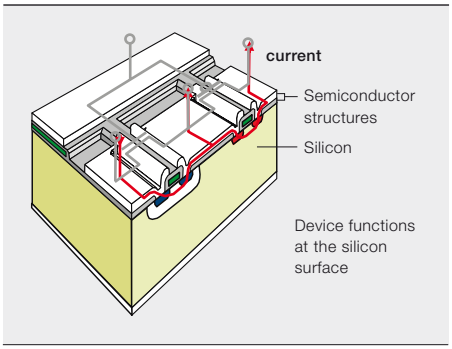



**1b N-type semiconductor, phosphorus added as impurity**

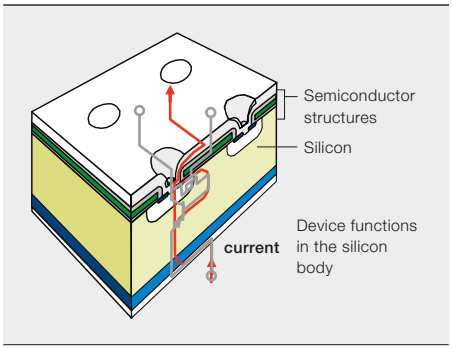



**1c P-type semiconductor boron added as impurity**

2 Semiconductors found in consumer electronics




3 Semiconductors found in power electronics




that power generators need not remain close to their end users, nor did their voltage levels need to match the class of load attached to their circuits (since step-down transformers could be used to alter the voltage to suit the load). These early developments in technology played a pivotal role in determining the nature and architecture of power transmission and distribution systems.

Today new demands have been placed on electric power systems, including greater energy efficiency and sustainability, yet developments in technology remain a major influence on their evolution.

In the last few decades, developments in semiconductor technology have had a major impact on the architecture of the power systems that operate around the world. Innovations that have been made possible through such technology include the efficient bulk transmission of electric energy in the form of high-voltage direct current (HVDC), the introduction of energy-saving variable-speed drives, the conversion of AC at one frequency to AC at another (50 / 60 Hz or 50 / 16.6 Hz) through the use of frequency converters, and the introduction of FACTS (Flexible AC Transmission Systems) to enhance control and increase the power transfer capability of the network.

In the last few decades, developments in semiconductor technology have had a major impact on the architecture of the power systems that operate around the world.

## Semiconductor devices

Today the vast majority of semiconductor devices are used in the consumer electronics industry. These products include computers, DVD players, cell phones, household appliances and video games. These types of products generally operate in the nanowatt to milliwatt range. The miniaturization of such devices continues to develop with ever increasing complexity so that today's integrated circuits, known as microchips, contain hundreds of millions of switches operating at the nanowatt level. The function of these devices is typically achieved by structuring the surface area of the semiconductor material ➔ 2.

In addition, many low-power semiconductors are used today to modify the form of electrical energy (ie, to modify its voltage or frequency), including:

- DC/DC converters found in most mobile devices (eg, mobile phone, mp3 player). They maintain the voltage at a fixed value, whatever the charge level of the battery.
- AC/DC converters (rectifiers) used whenever an electronic device is connected to the mains (eg, computers, televisions, game consoles).
- AC/AC converters used to change either the voltage level or the frequency. These are found in international power adapters, light dimmer switches, etc.
- DC/AC converters (inverters) used, eg, to supply power to AC devices in a car from a DC battery.

Today, similar semiconductor devices can be used to modify electric energy in the megawatt power range. They are generally silicon-based and the functionality to either block or conduct current involves the whole 3-D body of the semiconductor ➔ 3. Generally these devices are less visible to end users than their miniaturized cousins in the consumer electronics industry, yet they modify voltage and frequency in much the same way, only on an industrial scale, forming robust high-power switches that are either "on" or "off."

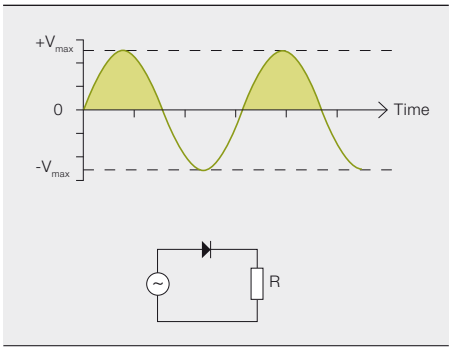
Although power electronics form a relatively small segment in the semiconductor market, rapid growth in demand for high-power semiconductor devices in the last five years has seen significant increases as new applications for this technology are recognized. ABB is a world leader in the production and development of high-power semiconductor devices and is uniquely positioned to widen the scope of applications across a range of products to increase energy efficiency.

## Power semiconductor devices

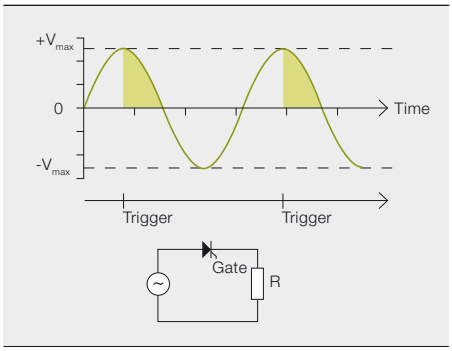
Power semiconductor devices first appeared in the early 1950s eg, with the 7 kW semiconductor diode. This device maintains the flow of electric current in one direction (called the diode's forward direction), while blocking the flow in the opposite direction ➔ 4. ABB's parent companies, ASEA and BBC, immediately identified the potential of semiconductors for power electronics and have played a significant role in their development and manufacture since about 1955. Semiconductor diodes provided the first solid-state rectifiers. Early high-voltage diodes produced by ABB's parent companies were used to convert AC to DC in electrolysis plants for aluminum production. These pioneering efforts of both ASEA and BBC have helped ABB to evolve as a world leader in high-power semiconductor devices.

In the late 1950s a new bipolar semiconductor, known as a thyristor, was developed. These are similar to diodes in that they block electric current flow in the reverse direction, but they also prevent current flow in the forward direction unless triggered to do so. In this way, the power (or current) that is supplied to a load could be controlled by triggering

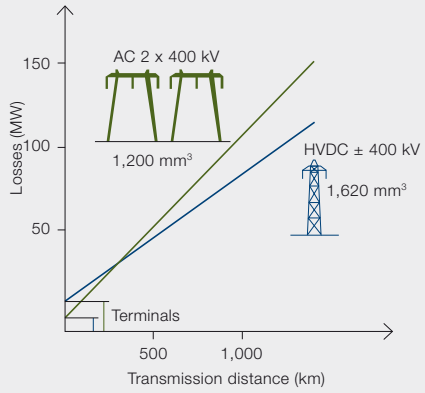
4 A simple diode rectifier




5 A thyristor switched on by a trigger and off at the zero cross point

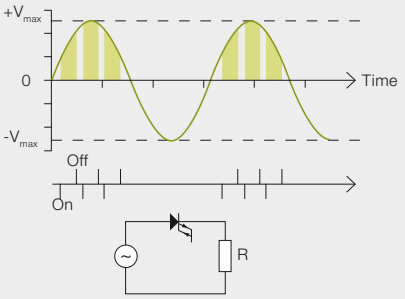



6 A comparison of the losses for overhead line transmission of 1,200 MW AC and HVDC





7 A gate-turn-off thyristor can be switched on and off at high frequency




conductance at a particular phase of the waveform. Once switched on, the thyristor remains "on," switching "off" once per cycle when the current drops to the next zero cross point ➔ 5. Once switched on, the thyristor behaves essentially like a diode. Since thyristors can switch power at the MW level they can be used to convert AC to DC and DC to AC for HVDC transmission. ASEA installed the world's first HVDC transmission line in 1954, providing 20 MW, 100 kV to the Isle of Gotland over a distance of 96 km. Although this system originally used mercury arc rectifiers exclusively, the conversion stations were supplemented in 1970 with thyristor valves, which were connected in series to the mercury-arc valves, raising the voltage to 150 kV and the transmission capacity to 30 MW. Today HVDC Classic systems (with thyristors connected in series) are capable of carrying 6,400 MW of power over several thousand kilometers, providing efficient methods to transport electrical energy from remote sources of generation to busy population centers. An HVDC transmission line has lower losses than optimized AC lines for the same power capacity. The losses in the converter stations have of course to be added, but since they are only about 0.7 percent of the transmitted power in each station, the total HVDC transmission losses come out lower than the AC losses for distances above a certain threshold (eg, around 500 km for overhead lines) ➔ 6. In addition, HVDC is the only practical solution for subsea cable connections over 70 km.

ABB, through its parent companies ASEA and BBC, identified the potential of semiconductors for power electronics and has played a significant role in their development and manufacture since about 1955.

Although thyristors assembled in series can function in the several thousand MW range, a similar single thyristor can be used in the 10 MW range to modify the supply of voltage and current through a medium-voltage drive to efficiently control the speed of an industrial motor. Applications driven by electric motors account for an estimated 65 percent of all industrial energy use; however a significant portion of this energy is currently lost through the wasteful methods used to control their speeds. By altering the voltage and frequency using power electronics, the speed of an AC motor can be adjusted with much lower losses. Typical applications using variable-speed drives can reduce energy consumption by 30 to 50 percent.

Further developments in semiconductor technology have resulted in the gate turn-off thyristor (GTO), which can be switched off at an arbitrary point in the waveform, providing greater control over the power output ➔ 7. Such devices are


8 Lenzburg semiconductor facility


| | |
|---|---|
| Factory facts | Production from 1978 (Bipolar), BIMOS was added in 1997, expansion ongoing, scheduled to be completed by 2010 / 2011, approx. 500 employees |
| Production line | Bipolar<br>BiMOS wafer-fab<br>BiMOS module-fab |
| Focus | Bipolar (PCTs [phase controlled thyristors], IGCTs, diodes, GTOs), range 1.6 kV - 8.5 kV<br>BiMOS wafer-fab (diodes, IGBT chips), range 1.2 kV - 6.5 kV<br>IGBT module line (HiPaks, StakPaks), range 1.7 kV - 6.5 kV<br>Pulse power assemblies |

Power Semiconductors in ABB


common in frequency converters used to alter the power frequency of the domestic grid to suit the power frequency used by electric trains and metros. The first two modern frequency converters making use of GTOs, rated at 25 MVA each, were put into operation in 1994 in Giubiasco, Switzerland. Many similar devices have been used around the world to modify the electricity supplied by the grid to suit the needs of electric rail transport providers.

The landscape of the power electronics industry changed with the introduction of the insulated-gate bipolar transistor (IGBT), a fast switching device able to control the flow of electricity and efficiently convert its waveform and frequency.

Not long after the development of the GTO, an improved type of device known as the integrated gate-commutated thyristor (IGCT) was developed. These devices, like the GTO, can be switched "on" or "off," but since their turnoff times are much faster, they can operate at much higher frequencies than GTOs. They are able to cope with high rates of voltage rise and have lower conduction losses. Today there are many thousands of drives worldwide using IGCTs. The IGCT is a single integrated component capable of switching power at high voltage levels and is emerging as a key element in static var compensators [1] and other components of the electric grid.

Two decades ago, a seemingly simple variant of the silicon power MOSFET (metal-oxide-semiconductor field-effect transistor) began to change the power electronic landscape with the creation of the insulated-gate bipolar transistor (IGBT). In 1997, ABB began to invest in a wafer manufacturing facility for IGBTs in Lenzburg ➔ 8. The IGBT is noted for high efficiency and fast switching (switching "on" and "off" multiple times per cycle) and relies on BiMOS (bipolar-metal-oxide-semiconductor) technology. These devices can be assembled in a variety of ways to modify the voltage or frequency of electrical power for a range of applications from HVDC Light® power transmission systems ➔ 9 to low-voltage variable-speed drives ➔ 10. Both variable-speed drives and HVDC Light require rectifiers and converter topology. How-

9 BorWin alpha, the platform-based HVDC Light converter station

10 Variable speed drives

ever, as with all applications, the way in which semiconductor devices are assembled in these applications determines the power rating at which they can operate.

The different types of semiconductor devices and the way they are assembled, define their suitability for a particular application. Each device is packaged, not only to maintain its integrity and performance, but also to ensure its safe operation and longevity when working in harsh environments. ABB's family of HiPak™ IGBT modules are used in the harsh environment of traction and industrial markets. These modules are expected to operate in a wide range of temperature and humidity or under conditions of intense vibrations or shock. They must also cope with extreme thermal cycle stresses. HiPak modules are used in traction, drives and wind turbines. Another IGBT package, the StakPak™ is unique to ABB and is particularly suited to the reliable series connection of many IGBT modules needed for high-voltage applications.

Power semiconductors are a key element in an increasing number of ABB products and systems taking a lead role in almost all electrical applications. They allow drives to efficiently operate motors from 10 W to several hundred MW. They enable electrical energy up to 6 GW to be transmitted through HVDC lines at 800 kV. They provide the capacity for trains, cranes and elevators to run smoothly and allow renewable energy sources, such as wind turbines and large hydropower plants to connect to the grid. Even radar systems emitting high-power pulses depend on power semiconductors to securely operate air traffic. ABB's prominent role in the design, development and production of semiconductors has helped maintain its current world leader status in the supply of power-electronic converters for various applications. ABB's continued expansion at its Swiss facilities, as well as the acquisition of Polovodice a.s., a semiconductor producer in the Czech Republic, highlight its commitment to strengthen this lead position and to improve energy efficiency and productivity across a broad range of industries.

Power semiconductors are a key element in an increasing number of ABB products and systems taking a lead role in almost all electrical applications.

This article serves as an introduction to power electronics and is the first in a series of articles that address the importance of semiconductors to ABB and the power industry.

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**Footnote**

1 A static var compensator is a device typically made up of thyristor-switched capacitors, thyristor-controlled reactors and harmonic filters and is used to inject or absorb reactive power in order to enhance voltage stability.

# Reaching new levels

## ABB's new ultra high-voltage (UHV) test center is the most advanced high-voltage DC test facility in the world

RALF HARTINGS, THOMAS K. LARSSON – One of the challenges facing many economies is the efficient transmission of clean and renewable energy over long distances. The use of HVDC at 800 kV has been one way of addressing this challenge, especially in countries like China, India and Brazil. However, the global demand for power continues to grow and meeting it means facing up to enormous challenges from all fronts, from getting more power to those difficult-to-reach places to adherence to strict environmental regulations.

For many years ABB's high-voltage center in Ludvika, Sweden has been leading the way in the development of high-voltage transmission technology. High-voltage testing is a prerequisite to qualify all new equipment and therefore significant investments have been made to ensure the proper facilities are in place. However, in early 2007 it became clear that there was an urgent need to increase the ultra high-voltage (UHV) testing capacity at the center. The development of a new 800 kV DC transformer and wall bushing had just been successfully completed, and with upcoming ultra high-voltage DC (UHVDC) projects in China and India combined with an increasing interest in UHVAC, the testing capacity available to test UHVDC bushings and HVDC valves [1] was deemed to be inadequate. The capacity was insufficient both in terms of the maximum voltage level and the corresponding insulation gaps, as was the time available for testing.

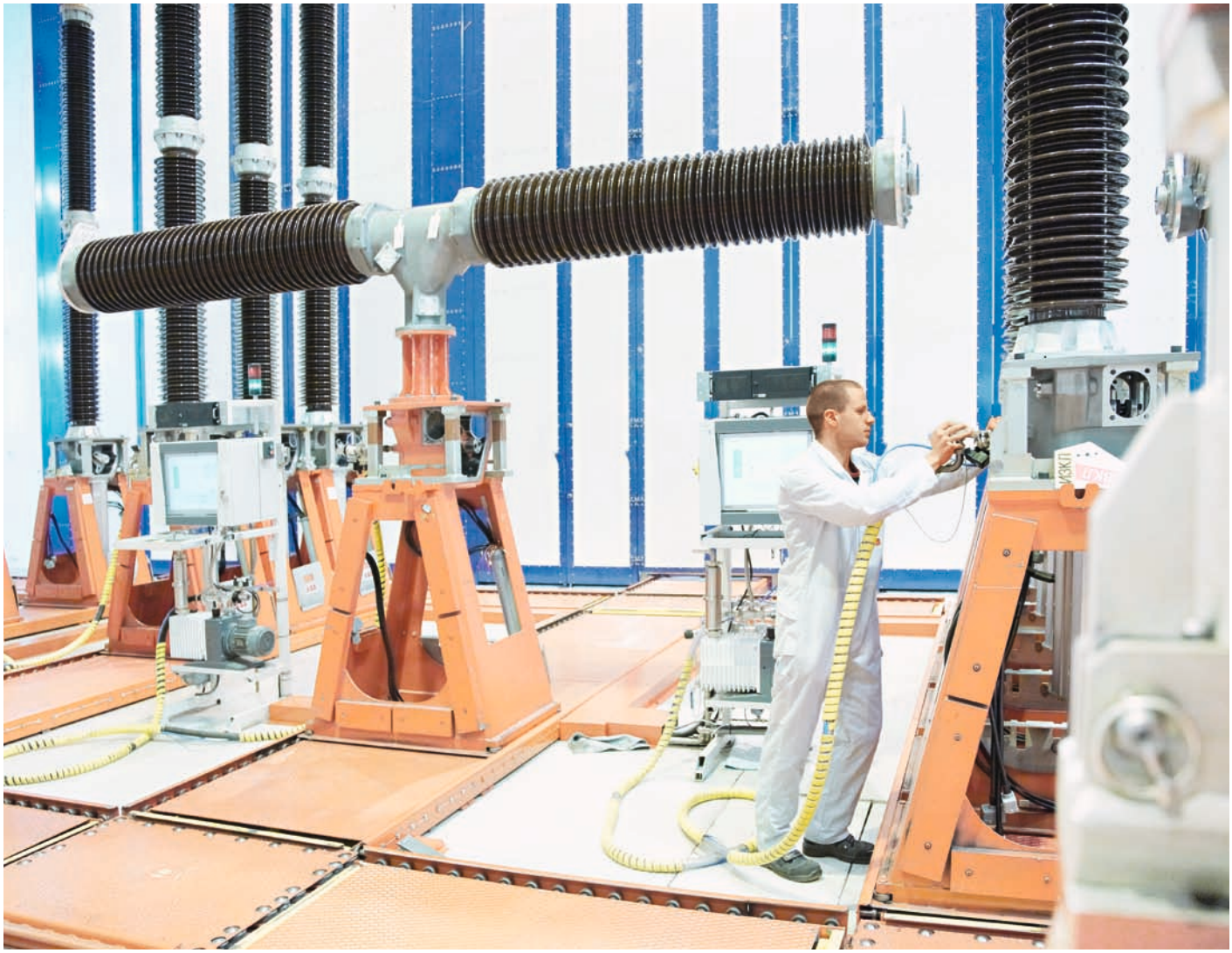
The new test facility was based on future expected market requirements for 1,200 kV AC and 1,000 kV DC transmission systems. These system voltage levels require a certain margin for both type and limit testing. Although not formally required, limit tests help determine the risk of failure when operating at nominal and overvoltage levels so that action can be taken to reduce this risk to an absolute minimum. A failure in such UHV transmission systems has a dramatic impact on the availability of the transmission system and the ability to deliver power to millions of people.

The maximum required testing voltage levels deemed necessary are:
- DC: 2,000 kV
- AC: 1,700 kV
- Switching Impulse: 2,500 kV
- Lightning Impulse: 3,600 kV

Given these voltage levels, the dimensions of the testing facility were determined by:
- The dimensioning voltage stress type, the switching impulse (SI) voltage
- The expected maximum size of a 1,000 kV DC wall bushing
- The air withstand properties defined by various experts around the world and compiled by Cigré.

With inner dimensions of 35 meters in height, a width of 40 meters and length of 60 meters, ABB's "UHVen" [2] has become the most advanced testing facility

High-voltage testing is needed to qualify all new equipment and therefore the proper test facilities must be in place.



A high-voltage testing facility must ensure that testing does not affect the supply of power to the public and is itself not affected by outside disturbances.

in the world for UHVDC. In addition, it can be used for the dielectric testing of AC and DC bushings as well as for testing HVDC valves for the highest rated electric power transmission systems in the world.

A major challenge for any high-voltage testing facility is ensuring it is properly shielded. This means making sure that testing does not affect the supply of power to the public and local industries and in turn is not affected by any outside electrical disturbances.

Test bushings require a background electrical disturbance level of about one to two pico coulombs (pC) as testing needs to verify that a bushing does not generate internal discharges higher than 5 pC. This requirement is extremely difficult to fulfil in a test set-up at such UHV levels without proper electrical shielding. Poor or inadequate shielding will enable the connections between the test object and the voltage sources, which act as huge antennas, to pick-up even the smallest electrical disturbances from the outside. To ensure this doesn't happen, a Faraday cage is built inside the external building. Although the concept of a Faraday cage is simple in theory, for an industrial testing facility of this size – equipped with three cranes and many doors – it is quite a challenge to assemble. The cage is electrically insulated from the external building by thousands of small insulators and grounded separately via an interconnected grid consisting of long rods (16 meters in length) driven into the soil/rocks underneath the testing facility.

The facility has been in use since March 2009 but was officially inaugurated in June 2009.

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**Footnotes**

1 Both are developed and produced in Ludvika. UHVDC bushings are produced by ABB Components and the HVDC valves by Power System, Grids. Without the new UHVDC testing facility ABB would not have been able to provide solutions for UHVDC (800 kV DC and above).

2 UHVen is a combination of UHV (ultra-high voltage) and the Swedish word for an owl (uven), which is common to the region of Dalarna in Sweden where the test center is situated.

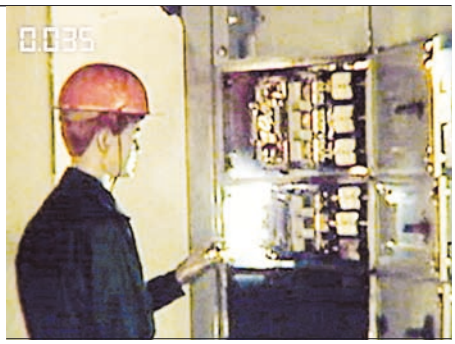

# Arc Guard System™

## A guard that saves lives and business

AHMED H HASSAN AND RICHARD PETERSSON WIGH – Every day throughout the world, hundreds of people are seriously injured or die as a result of electrical arc accidents. These accidents aren't just restricted to countries with low safety regulations. Even countries with strict safety regulations suffer deaths and serious injuries. According to public data, one person dies each day in North America due to arc flash accidents and several more are injured. ABB's new Arc Guard TVOC-2 protection device reduces the risk of arc accidents, saving lives and equipment all over the world.

1 The capacity of ABB's ArcGuard System to provide protection

1a Arc accident without protection



1b Arc accident with ABB's ArcGuard System™

After more than 35 years, ABB's well known Arc Guard System™ has become the market leader in switchgear safety. Today the Arc Guard System™ is considered to be a standard part of switchgear equipment in northern Europe. Although the system cannot prevent arcing faults, it can reduce the threat to human life and equipment. Arc faults are usually caused by external factors, mainly human error or negligence. Their occurrence, therefore, can never be totally prevented or predicted. What can be prevented, however, is the extent of the damage and injury caused. An arc fault normally begins as a short circuit between two or more contact points. If it lasts for a few hundred milliseconds, the internal core temperature may reach 20,000 °C, posing a serious threat to personnel and the switchgear assembly within its proximity ➔ 1a.

Since switchgear is found in all industries as well as power utilities, commercial buildings, hospitals, ships, and many other locations, ABB has tried to produce 'arc-proof' switchgear through mechanical design as well as the choice of electrical components. These design innovations, together with ABB's new Arc Guard TVOC-2 system, will help reduce the risk of arc accidents and there consequences in the future ➔ 1b.

## Safety

Safety has always been an important issue in the generation and distribution of energy. Increased legal and regulatory requirements have served to emphasize the importance of safety in recent years and have led ABB to introduce TVOC-2 and encourage the adoption of safe working practices. TVOC-2 alone will not prevent accidents from happening but it will significantly reduce the damage such accidents cause.

Although the previous Arc Guard system was simple and reliable, the TVOC-2 was introduced with additional and improved features and functions so that it would maintain its strengths in reliability and simplicity, while providing greater flexibility.

ABB's new Arc Guard TVOC-2 protection device reduces the consequences of arc accidents saving lives and equipment.

Reducing the consequences of arc faults is all about timing and each millisecond is paramount. TVOC-2 reacts in just a millisecond and over-rides standard protection time delays when tripping breakers ➔ 2.

With a design that satisfies safety integrity level 2 (SIL 2), the Arc Guard TVOC-2 is approved for applications today and for the future.

## Risks

Everyday hundreds of people face serious injuries or death due to arc accidents.

In any plant, the risk of arc accidents can be reduced through the mechanical and electrical design of the system together with good routines for working with electric equipment. The importance of safety has led ABB to develop 'arc-proof' switchgears. Here the mechanical design, as well as the choice of electrical components, reduces both the risk of an arc accident and its consequences.

Unfortunately, despite these measures, protection against arc accidents are frequently insufficient for two main reasons:

(1) Most accidents happen with the switchgear door open, which reduces the effectiveness of mechanical protection.

(2) Breaker protection is based on overcurrent only and often includes time delays.

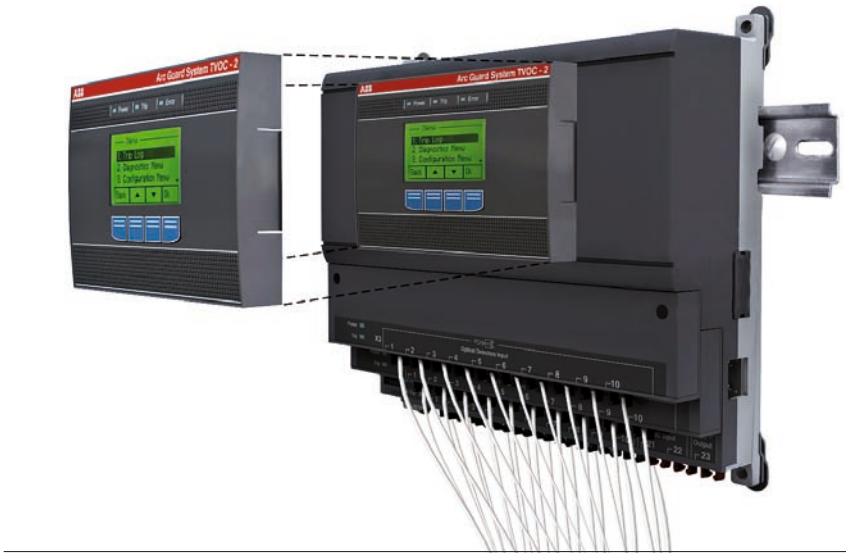
## Benefits

1 Increased arc safety in switchgear, which saves lives and reduces damages, since the total tripping time will be faster and more reliable when an accident occurs. It also saves money and time since downtime in production is minimized.

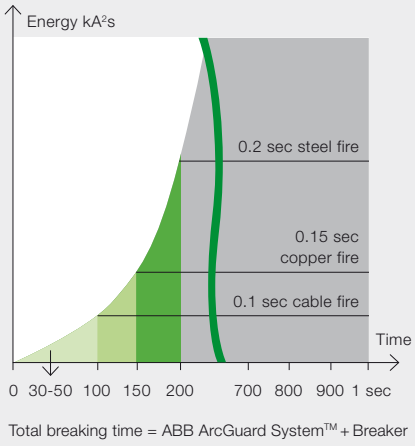
2 Point sensor design makes it simple and fast to locate the error and restart production after an accident.

3 TVOC-2 has a user friendly start-up menu and all connections are accessible from the front, which gives easy access to the required information. It

2 TVOC-2 showing the possibility to put HMI (Human Machine Interface) mounted on a panel-door



3 TVOC-2 reacts in just a few milliseconds




has a trip log with time stamp, tripping breakers and a host of additional features.

Functional safety design
- Faster and more reliable tripping than short circuit protection
- Modularized one unit product that is easier to design, expand and fit into a limited space.
- HMI on the door, easier than flush mount and gives more information ➔ 3
- Reliable arc monitor TVOC-2
- Functional safety design, SIL 2, gives a reliable and future proof product.

## Product specifications

- Fiber optic sensors eliminate risks of EMC distortions via the detector cables.
- Pre-fabricated and calibrated sensors in different lengths, removing risks of faulty mounting.
- 10 sensors as standard, modularized design, gives possibility of up to 30 sensors, adaptable to the customer's need.
- DIN rail / wall mounting – flexible and simple assembly.
- Up to 2 HMI, product, external or both, typically mounted on cabinet door, easy to mount and access.
- Easy to extend the system with one unit design (modularized)
- Current condition if required
- Trip selectivity, possible to trip different breakers depending on sensors, reduces the need of several arc monitors and makes a special design simple.

## Overcoming challenges

One of the biggest challenges was to achieve SIL2 certifications.

ABB had to change its first product concept. All safety related activities are made by traditional electronics without any software. The micro controllers used are partly for diagnostics purpose, partly for user friendliness.

The requirement specifications are based on a number of interviews with customers and potential customers that prioritized their most critical functions. This provides added value compared with competitors and ABB's old generation product.

All the work with functional safety was guided by the Safety Manager Dr Zaijun Hu from ABB Research in Germany.

## Perspectives

**Reliability**
- Certified according to functional safety (SIL 2) standard
- Over 35 years of experience in Arc Guard Systems
- Pre-calibrated optical sensors

**Flexibility**
- HMI can be mounted on the panel-door
- Expands with up to 30 optical sensors
- Configuration according to various needs

ABB's well known Arc Guard System™ has become the market leader in switchgear safety.

**Simplicity**
- User-friendly start-up menu
- DIN-rail or wall-mounted
- Easy to expand as the switchgear grows

TVOC-2 is designed with its main focus on reliability. Every aspect is covered. This includes sensors being precalibrated at the factory as well as major features such as the self-monitoring systemof the arc monitor.

To ensure that we have not left a single part to chance, TVOC-2 is designed according to the functional safety (SIL 2) concept. This compliance means that the product is designed so that a fault in a component will not result in a safety function failure. For example, certain capacitors have built-in redundancy to cope with component break-downs. Critical functions of the system are self-monitoring providing alerts should anything go wrong. Many of the added functions are handled by a microprocessor, but importantly, none of the safety functions.

## Functional safety for the future

The world wants safer and more reliable equipment and is moving quickly and decisively in that direction. One example is the new EU machinery directive (2006/42/EC) that requires the machine builder to eliminate risks throughout the foreseeable lifetime of the machine, even when misused.

Harmonized standards provide tools for verifying that these requirements are met. Functional safety is a tool not only used to ensure safety, but reliability as well. Using TVOC-2, which is SIL 2-certified according to IEC 61508 and IEC 62061, ensures that the diagnostic coverage meets the safety level demands. This corresponds to performance level d according to EN ISO 13849-1. Arc Guard System™, clears an arc within an extremely short time, reducing the energy in the arc so that personal injury and equipment damage are kept to a minimum. Using TVOC-2 means that customers can meet the highest safety requirements. For example, NFPA70E, a US standard for the safe installation of electrical wiring and equipment, states: “a flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the Flash Protection Boundary and the personal protective equipment that people within the Flash Protection Boundary shall use.” With Arc Guard System™, these calculations will show that the energy from an arc flash is decreased to a level that reduces the need for additional protection. Note that the requirements for functional safety ensure the reliability of the figures used in these analyses.

## Flexibility

TVOC-2 is built as a flexible unit that fits into a wide range of switchgear and system sizes. ABB’s goal is to provide customers with a system they actually need. The standard configuration includes 10 detectors to cover the need for normal-sized switchgear. If a customer’s system grows or requires additional sensors, the product can be extended to include up to 30 detectors by simply adding two extension modules on the main unit. Customers can mount TVOC-2 on either a DIN-rail or directly on a panel wall. Furthermore, the HMI that shows the customer the system information and setup, can be placed either on the product itself or on the door. If required, it can even be mounted on both. To fit a customer’s application, we have added functionality to trip up to 3 breakers. The system can be configured to trip different breakers depending on where in the switchgear the arc occurs.

> Today ABB’s Arc Guard System™ is considered to be a standard part of switchgear equipment in northern Europe.

## Simplicity

One of the most important aspects of designing the TVOC-2 has been to make it simple for ABB’s customers and end-users. This is important not only to make the system design and installation easy and simple, but also to minimize the risk of errors. ABB have designed TVOC-2 as a single unit (even if customers choose to extend it with additional sensors) and with the minimum number of parts. At installation, all in/outputs, sensors and settings are accessible from the front to give a good clear overview that minimizes the risk of error. The HMI menu has a user-friendly interface that guides the customer through installation. Here the customer can, for example, check the trip log to see which sensor was triggered at what time. Even better, since it can be placed on the door, the customer can do this without opening the switchgear. As the customer’s business grows so too can the TVOC-2 system. The customer has complete flexibility, from expanding the number of sensor modules to simply adding other components to the system – all done in minutes.

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# Disconnecting circuit breaker (DCB)

## Air insulated substations with DCBs give maximum availability with minimum footprint

HANS-ERIK OLOVSSON, CARL EJNAR SÖLVER, RICHARD THOMAS

– The development of circuit breakers (CBs) has led to a change of design principle for substations. Previously the substation's design was based on the fact that CBs needed a lot of maintenance and were therefore surrounded by disconnectors (DSs) to enable maintenance without disturbing nearby circuits. With today's CBs having a maintenance interval of 15 years plus, the design principle is more focused on the maintenance of overhead lines, transformers, reactors, etc. The change of design principle has enabled the integration of the disconnecting function with the CB, thereby creating a new apparatus called a disconnecting CB (DCB). Since the primary contacts for DCBs are in an $SF_6$ protected environment, free from pollution, the disconnecting function is highly reliable and the maintenance interval is increased, providing greater overall availability of the substation. In addition the DCB solution reduces the substation footprint by about 50 percent.

The development of circuit breakers has led to a change of design principle for sub-stations.

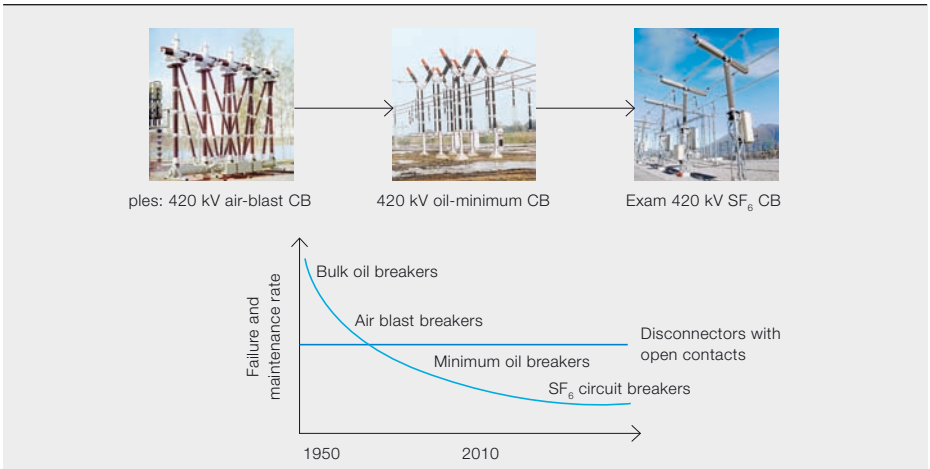
Development in circuit breaker (CB) technology has led to a significant decrease in maintenance and an increase in reliability. The maintenance intervals of modern $SF_6$ CBs requiring the de-energising of the primary circuit is now 15 years or more. No significant improvements in maintenance requirements and reliability have been made with open air DS, which during the same period focused on cost reductions by optimising production materials. The maintenance interval for the open-air DS's main contacts is in the order of two to six years, depending on user practices and pollution levels (ie, industrial pollutants and / or natural pollutants, eg, sand and salt).

Reliability of CBs has increased due to evolution of primary breaking technology, from air blast, oil minimum, $SF_6$ dual pressure into today's $SF_6$ single pressure type CBs. At the same time the number of series interrupters has been reduced and today live tank CBs up to 300 kV are available with one interrupter per pole. Removal of grading capacitors for live tank CBs with two interrupters has further simplified the primary circuit and thus increased the availability. Today CB's up to 550 kV are available without grading capacitors, enabling the development of DCBs up to this voltage level. Operating mechanisms for CBs have also improved going from pneumatic or hydraulic to spring type, leading to more reliable designs and lower maintenance → 1.

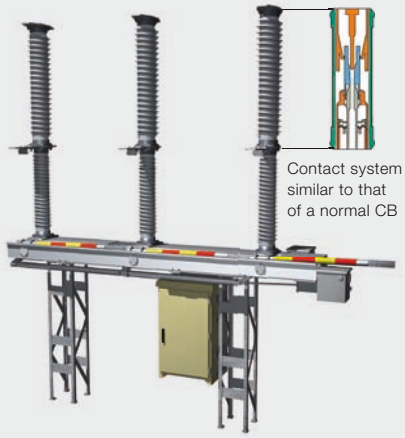
The change of design principle has enabled the integration of the disconnecting function with the circuit breaker, thereby creating a new apparatus called a disconnecting circuit breaker.

In the past the design principle when building substations was to "surround" CBs with DSs to make the frequent maintenance of CBs possible. Due to the large reduction of failure and maintenance of CBs, the disconnecting function today is required more for the maintenance of overhead lines, power transformers, etc. The reduced maintenance on CBs together with customer's reliability problems with open-air DSs, led to the close co-operative development of the DCB with some of ABB's major customers [1, 2, 3]. The DCB combines the switching and disconnecting functions in one device, reducing the substation's footprint and increasing availability [4]. The first installation of the DCB was in 2000 and today

1 Development of CBs and corresponding reduction in failure and maintenance rates




2 DCB 145 kV. An earthing switch is integrated on the support structure




Disconnecting circuit breakers will significantly reduce maintenance in air insulated switchgear substations and reduce the risk of failure due to pollution since all primary contacts are enclosed in $SF_6$.

DCBs are available from 72.5 kV to 550 kV voltage level.

## Design of disconnecting circuit-breakers

In a DCB, the normal interrupter contacts also provide the DS function when in an open position. The contact system is similar to that of a normal CB with no extra contacts or linkage systems → 2. The DCB is equipped with silicone rubber insulators. These insulators have hydrophobic properties, ie, any water on the surface will form droplets. As a result they have excellent performance in polluted environments and the leakage current across the poles in the open position is minimized.

DCBs will significantly reduce maintenance in air insulated switchgear (AIS) substations and reduce the risk of failure due to pollution. By replacing the combination of CBs and open-air DSs with DCBs in substations, availability will be significantly improved.

A DCB has to fulfill both applicable CB standards and DS standards. A specific standard for disconnecting circuit breakers was issued by IEC in 2005 [5]. An important part of this standard was the combined function tests. These tests verify that the disconnecting properties of the DCB are fulfilled during its service life, despite contact wear and any decomposition by-products generated by arc interruption. This is ensured by making all the breaking and mechanical tests first and thereafter confirming the disconnecting dielectric properties.

The DCB is available for rated voltages from 72.5 to 550 kV → 4. Around 900 three phase units have been installed or ordered.

## Safe earthing

When a part of a substation or network is to be maintained or repaired, one or more DSs are opened to isolate it from the rest of the system and the isolated equipment is earthed for personal safety. This can be achieved in different ways:

– With conventional air-insulated DSs, the visible open contact gaps verify that the part of the system is de-energised and then the isolated system is earthed
– DCBs are locked in the open position in a failsafe way. The locking consists of electrical blocking of the operating mechanism, as well as mechanical locking of the linkage system to the main contacts. Thereafter the adjacent earthing switch is closed. The visible closed earthing switch verifies that the part of the system is de-energised and safe for workers → 3.

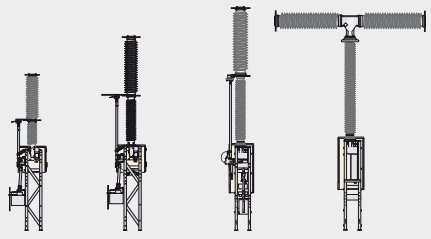
## Maintenance aspects

In the past the complexity of CBs required high maintenance, which focused attention on how to isolate them, while keeping the other parts of the substation in service. The main reason for DSs introduction about 100 years ago was to enable CB maintenance. Single-line configuration was thus built-up with CBs surrounded by DSs to enable CB maintenance → 5.

A traditional double busbar solution with separate CBs and DSs versus a sectionalized busbar solution with DCBs, for a

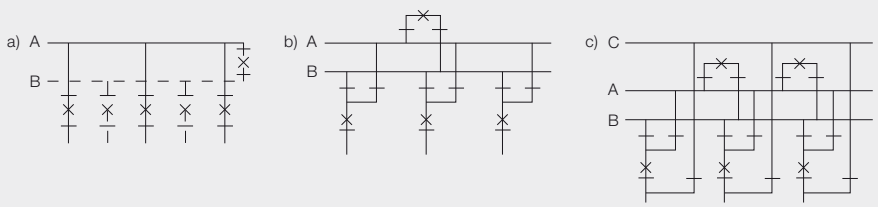
3 DCB 145 kV with built in current transformers and closed earthing switch

4 The range of disconnecting circuit breakers




| Type | LTB 72,5 | LTB 145 | HPL 170-300 | HPL 362-420 | HPL 550 |
|---|---|---|---|---|---|
| Rated voltage, kV | 72.5 | 145 | 170-300 | 362-420 | 550 |
| Rated current, A | 3,150 | 3,150 | 4,000 | 4,000 | 4,000 |
| Circuit-breaking cpacity, kA | 40 | 40 | 50 | 50 | 63 |
| Rated frequency, Hz | 50/60 | 50/60 | 50/60 | 50/60 | 50 |

5 Different types of single-line configurations based on the requirement for the frequent maintenance of CBs, which are no longer required




132 kV substation with four overhead lines, two power transformers and one bus-coupler or bus-section CB, are shown in ➔ 6. The DCB solution will reduce the switchyard area by more than 40 percent. Outages for an incoming / outgoing bay, due to maintenance on the switchgear main apparatus are shown in ➔ 7. Assumed maintenance intervals are in accordance with manufacturer's recommendations, ie, 5 years for open air DS and 15 years for CB and DCB. Introduction of the DCB thus reduces the average maintenance outage from 3.1 to 1.2 hours per year.

The reduction of maintenance activities will give the following advantages:

- More satisfied consumers (depending on substation / network topology, the maintenance work can lead to loss of power supply to some consumers).
- Less risk of system disturbances (black-outs) since the risk for primary faults during a maintenance situation (ie, when there are people in the substation) is higher than during normal service and during maintenance a system is "weaker"because not all equipment is in service
- Lower employment costs for maintenance work on site
- Higher personnel safety since all work on the substation's high-voltage system has the potential risk of injury due to electrical shock, or falling from heights, etc.

The disconnecting facility is a point in the switchgear that is prepared for fast opening of the primary connection between the DCB and the busbar. When the DCB is disconnected in this way the other parts of the substation may be re-energised while work continues on the DCB itself.

## Fault aspects

Equipment and apparatus are getting more and more reliable, however faults still happen even though they occur with longer mean time between failures (MTBF). Faults are a stochastic process, which means that even with very long MTBF, the fault could happen at anytime and ABB's customers must design the substations accordingly. When clearing a fault there is also a slight risk that some CB should fail to open, requiring back-up CBs to operate.

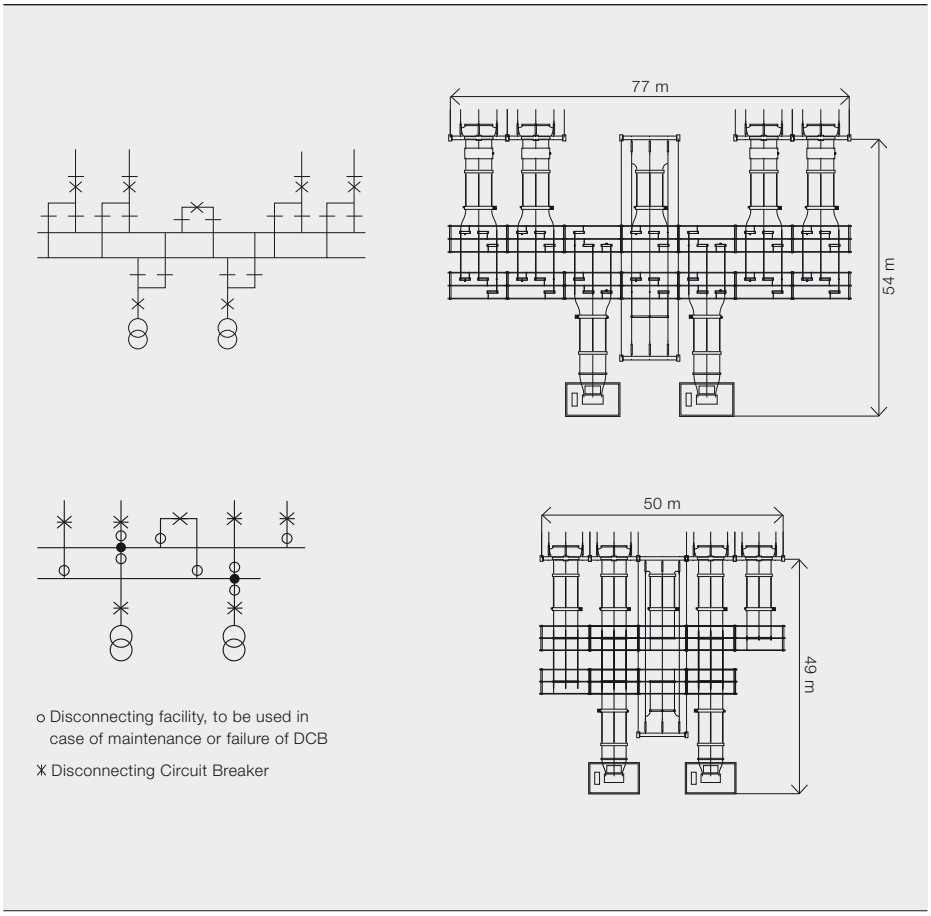
For the single line configuration shown in ➔ 6, a primary fault on one of the outgoing objects, plus CB failure for that bay, would lead to de-energisation of one busbar section. A failure in the bus-section or bus-coupler breaker will lead to loss of the whole substation. For important substations it might not be acceptable from a system security perspective to have a risk of loosing the whole substation at a primary fault. To make the substation "immune" to busbar faults and to minimize the disturbance if a CB fails to open at a primary fault, 1 ½-breaker ( ➔ 8 left side) or 2-breaker ( ➔ 8 right side) configurations can be used.

In ➔ 9 single line diagram and corresponding space requirement is compared, for a traditional type of solution with CBs and DSs versus a solution with DCBs, for a typical 420 kV substation with three OH-lines, two power transformers and one shunt reactor. By using DCB the outdoor switchyard area is reduced by almost 50 percent.

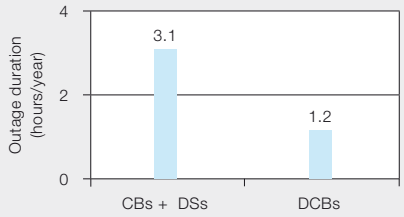
Outages for an incoming / outgoing bay, due to faults in the switchgear, are shown in ➔ 10. Failure frequency input are taken from international statistics sources, such as CIGRE and CEA, which gather information from apparatus in service. Since the DCB is very similar to a traditional CB, failure statistics are assumed to be the same for CB and DCB. The introduction of the DCB thus reduces outages by 50 percent. Unplanned outages may be very problematic and lead to loss of power supply to consumers, which is not acceptable "no black-outs please".

The disconnecting circuit breaker will reduce the switchyard area by more than 40 percent.

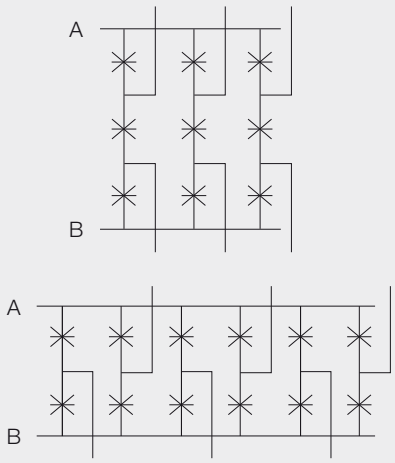
6 Single-line and layout for 132 kV traditional CBs and DSs vs the DCBs solution




7 Outage duration due to maintenance of 132 kV switchgear apparatus




8 Single-line configurations "immune" to busbar faults




## Application of DCB

DCBs can be applied in most traditional substation configurations, and directly replace traditional CB / DS arrangements. This reduces the substation's footprint substantially, reduces maintenance activities and reduces outages due to maintenance and faults, ie, increases availability. The increased availability could be used to simplify the single-line configuration and still keep the availability to the level it was before.

The total investment cost for the substation could be decreased using DCBs (depending on the cost of preparing land, piling, blasting, land fill, etc., which would differ from case to case). Operation costs will be reduced thanks to lower costs for outages (this is usually the highest cost) and maintenance.

**Example – 420 kV substations in Sweden**

Svenska Kraftnät (SvK), the transmission system operator (TSO) in Sweden, is responsible for the 420 kV and 245 kV systems in Sweden. The Swedish 420 kV system started in the 1950s, and was real pioneering work since it was the first system in the world at that voltage level. Today the Swedish 420 kV system consists of about 70 substations, most of which are coming to the end of their life, so SvK now makes a complete renewal (retrofit) of about 3 substations per year.

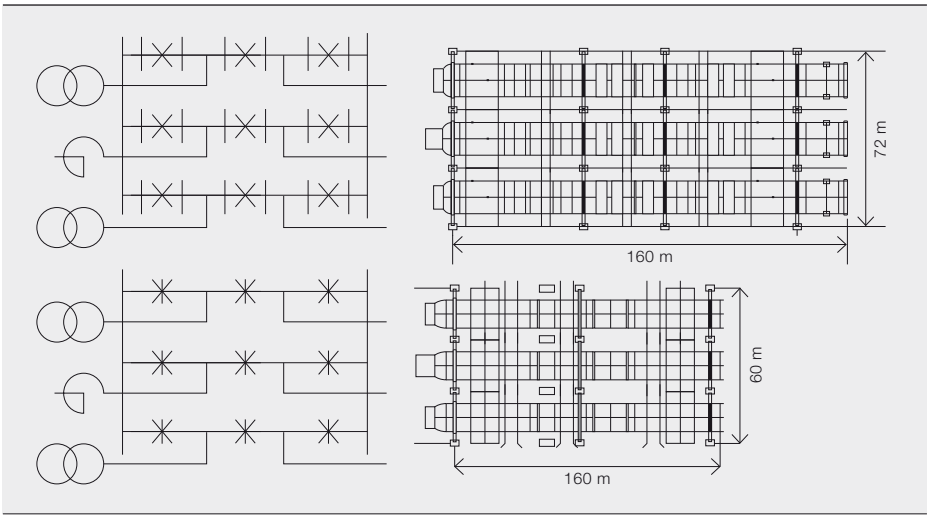
> Since, disconnecting circuit breakers can reduce a substation's frequency of maintenance and outages, they can contribute significantly to reductions in substation operational costs.

Basic principle for renewal of the substations is to make a complete exchange of all primary and secondary equipment. By doing a complete renewal, a number of technical and commercial advantages can be obtained such as:

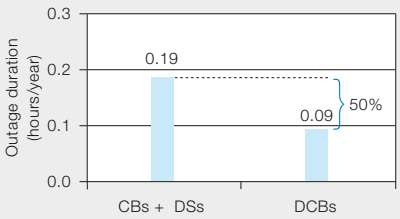
- Future work will be minimized since all equipment has the same "vintage".
- Single-line configuration can be adapted to developments of high-voltage apparatus and to possible changes in the importance of the substation to the network since it was originally built.
- Outage times can be kept to a minimum by using the existing equipment to keep the substation in service during the renewal.
- SvK personnel can concentrate on a few larger projects and the renewed substations will not need any "attention" for many years after the renewal.

Already by the end of the 1970s the open-air DSs were identified as apparatus that required high levels of maintenance compared to CB, so SvK started to reduce the number of DS in their substations → 11b. When DCB's were introduced in 2000, SvK made the first in-

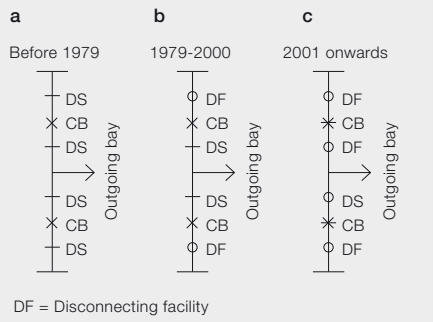
9 Single-line and layout for 420 kV traditional CBs and DSs vs the DCB solution




10 Outage duration due to primary faults in the 400 kV switchgear.




11 Evolution of 2-CB system for Swedish transmission network.




**11a** Solution with traditional apparatus
**11b** Modified version by removing busbar DS
**11c** DCB solution

stallation in a 245 kV station to obtain operational experience of this concept. In 2001 the first 420 kV substation renewals using the DCB started and since then the DCB solution has been used exclusively for large and important substations in the 2-CB scheme ➔ 11c. For the smaller 245 kV substations, the single busbar scheme is also applied. SvK's operating experience with DCB is good.

The footprint of the substation is reduced by almost 50 percent when going from the traditional CB / DS to the DCB solution. This reduction of the footprint can be advantages, not only for new substation, but also when making substation renewals ➔ 12. During these renewal works the old apparatus (pink) together with old busbar (red) is kept in service, while the new equipment, including a second busbar are erected in the area labelled in green on opposite side of the old busbar. Thanks to the small footprint of the new primary equipment the three existing line towers marked in blue can be kept in the original position saving cost, outage time and reduce risks.

The disconnecting circuit breaker is equipped with silicon rubber insulators.

After installing and testing, the service is changed to the new equipment. The complete renewal of this substation was done with less than one week of outage.

**Example – 132 kV substation Grytten**

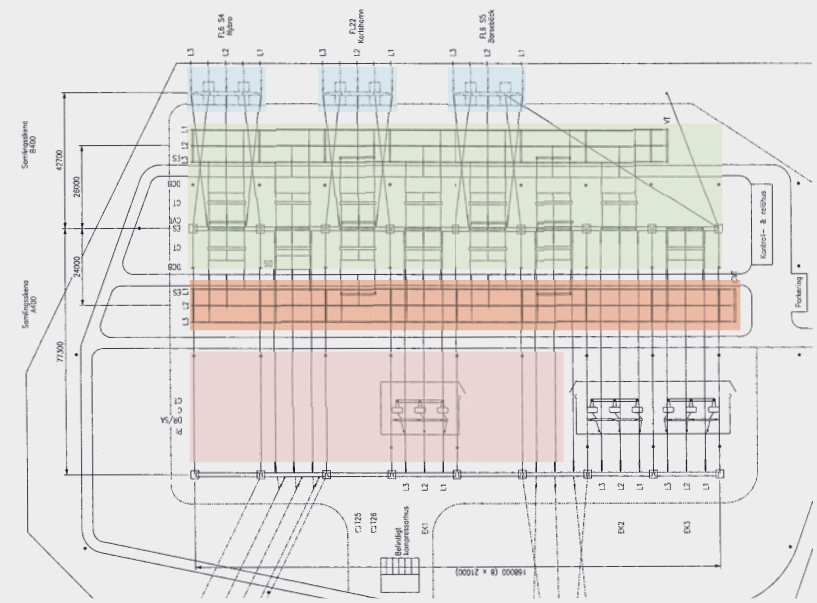
The Grytten substation is part of the Norwegian TSO Statnett's regional grid. The substation was originally built around 1970. The substation was designed in a traditional manner with a double busbar system (➔ 5a and ➔ 5b), and a transfer bus ➔ 5c.

The large number of disconnectors in the substation, made operational switchovers complicated. Furthermore, periods with reduced service capability occurred since portions of the substation had to be taken out of service to enable the maintenance of the disconnectors. In Statnett's maintenance plans, the useful service life for disconnectors was set at 35 years and the disconnectors at the substation were accordingly scheduled for replacement. In addition, at this time it was decided that the substation's control equipment should be replaced.

To simplify the substation, DCBs together with a single sectionalized busbar, were introduced. It was found that the existing transfer bus could be used as a busbar in the new substation. It had the correct length and was located at the most appropriate place, and there was even space for the sectionalizing breaker. Because a transfer bus is only used during CB maintenance, it could be disconnected from the rest of the substation without affecting the operation. The new equipment could then be completely assembled, and the

The primary contacts for DCBs are in an $SF_6$ protected environment, free from pollution, making the disconnecting function highly reliable and extending the maintenance interval so that the overall availability of the substation is increased.

## 12 Example of renewal of a Swedish 420 kV transmission substation



Old main busbar reused and extended

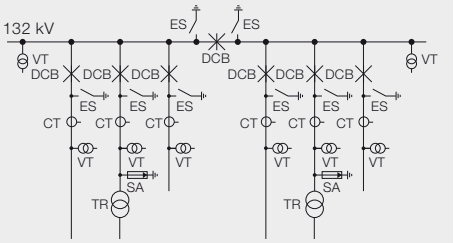
Location of old equipment

New equipment located beside old substation equipment

Existing line towers can remain due to low space requirement of DCB

Outage less than one week for whole renewal of S/S

## 13 Substation Grytten after refurbishment




reconnection of lines and transformers could be scheduled so that the service was not interrupted. The refurbished substation was completed in 2007.

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Reliability of CBs has increased due to the evolution of primary breaking technology, from air blast, oil minimum, $SF_6$ dual pressure into today's $SF_6$ single pressure type CBs.

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In the last few issues of *ABB Review*, you will have noticed a new look and feel, which is in line with ABB's overall new brand strategy. But it's not just how it looks that is important – it's also what is inside that counts. Your opinions matter, so please help us to make *ABB Review* even better, by completing a short online questionnaire on

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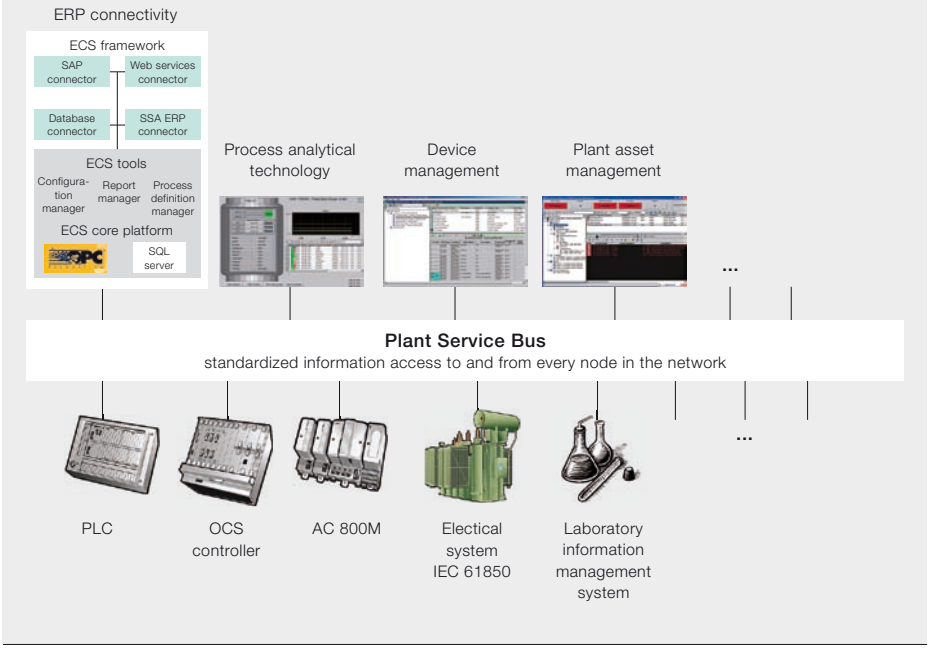
# Collaborative process automation systems

## ABB's System 800xA as a perfect example

MARTIN HOLLENDER, IIRO HARJUNKOSKI, ALEXANDER HORCH, ALF ISAKSSON, CHRISTIAN ZEIDLER – Control systems that automate and manage production are at the heart of process industries. These systems are networks of interconnected sensors, actuators, controllers and computers, often distributed across vast processing plants that help manufacturers run their operations safely and cost-effectively, minimizing waste and ensuring consistent product quality. In the past three decades, ABB's innovations have dramatically improved industrial productivity by expanding traditional automated control to provide a common platform for a plant's entire operations, from engineering to process optimization and asset management.

1 Plant service bus




In today's globalized economy, production sites face intense world-wide competition. In the longterm only those plants that simultaneously manage to optimize quality, availability, flexibility and cost will remain competitive. Production must adhere to increasingly complex, all-embracing regulations. The public image of a company can be damaged by one single incident, if the company is not able to prove proactive and systematic safety management.

A collaborative process automation system (CPAS) is often defined as a method to unify previously diverse systems in order to achieve operational excellence. CPAS allow plant personnel, from operators to managers, to get away from complicated workflows where they must interface with multiple systems in order to assess situations and perform tasks. This unified workflow environment enables collaboration and helps the different functional roles to work together with an understanding of their specific requirements with regard to the bigger picture. Sharing the data, knowledge and functional views ensures that each functional group in the plant understands the operational situation, their interdependencies, and their role in improving it. In essence, this is the integration needed to truly deliver on the promises of collaborative process automation.

The automation of technical processes with the help of computers has a history of almost 50 years. During this time various terms have been established to describe computerized automation systems:

- Distributed control system (DCS) originating in refineries,
- Programmable logic control (PLC) originating in discrete manufacturing, and
- Supervisory control and data acquisition (SCADA) for geographically distributed processes like pipelines and utility networks.

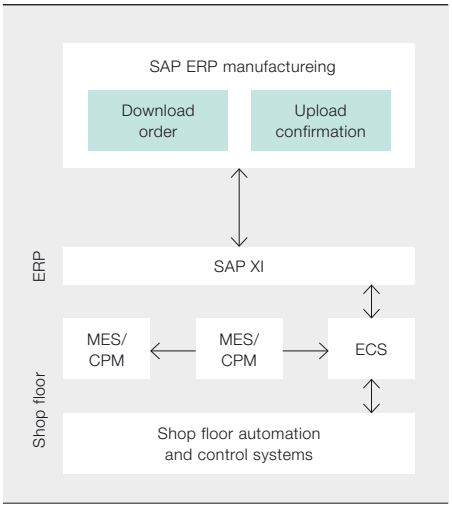
Unfortunately none of these terms has a widely agreed "official" definition and they are often used inconsistently. During the last decades, systems have been steadily improved and extended. Current state-of-the-art systems can no longer be described precisely by these dated terms. New terms are required to better categorize current state-of-the-art systems.

Around 2002, the ARC Advisory Group, a research and advisory firm based in Boston, Massachusetts developed the CPAS vision [1]. This vision is an excellent guideline for the planning, selection, engineering and operation of process automation systems. Since then, many automation vendors have started to market their systems as CPAS. Key principles of the ARC CPAS vision include:

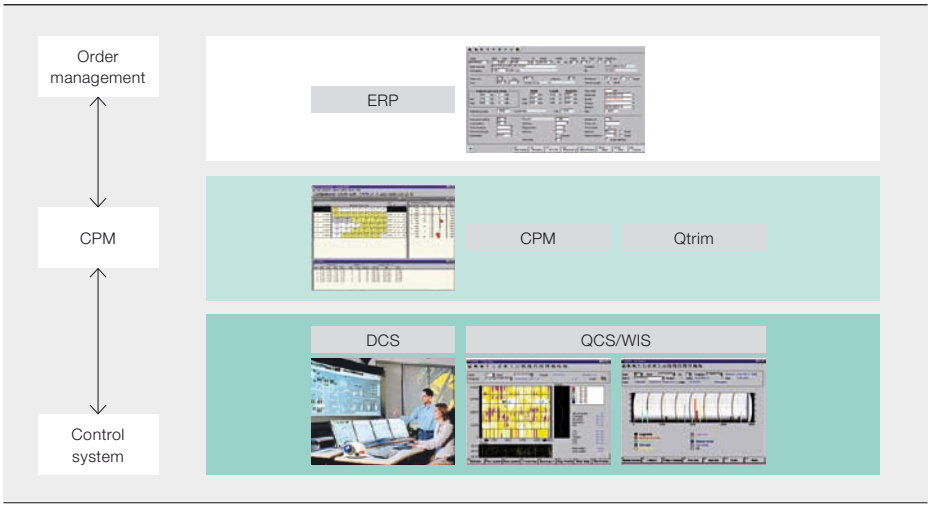
- Continuous improvement
- Common actionable context
- Single version of the truth
- Common infrastructure based on standards

A CPAS architecture must support these principles. A core element of a CPAS is its common object model, which supports reusable and generic solutions. It allows the deep integration of automation controllers from different vendors and different technology generations, fieldbus devices, electrical components (IEC 61850) and higher level operations with management execution system (MES) or enterprise resource planning (ERP) systems. All relevant information is inherently available at all workplaces. ABB System 800xA is based, from the ground up, on the very powerful Aspect Object™ technology. One reason for ABB to create a systematic architecture to enable a common object model was the need to integrate several different classic controller families coming from different parts of the company. The Aspect Object framework organizes standardized access to information to and from every node in the network. It can be seen as a "plant service bus" with analogy to the enterprise service bus (ESB) of business system architectures. It is the basis for the seamless evolution capabilities of System 800xA and allows the integration of previously heterogeneous systems,

2 ECS solution for vertical integration




3 Functional integration overview




eg, process and power automation, through IEC 61850. Each vendor has focussed on different aspects of the vision and some have implemented these better than others.

Manufacturers have been forced to optimize production to comply with trends to reduce their carbon footprint. Many forward looking companies want to replicate best-in class solutions to all their production facilities world-wide. Leading production companies have gone along way to implement the CPAS concepts. A CPAS architecture supports the creation of context-independent solutions that can be applied in a wide range of scenarios. This reuse of proven solutions has a high potential for cost savings and ensuring a consistently high quality.

Thus CPAS like System 800xA empower efficient and effective vertical and horizontal integration of data access and system functionalities to serve the ever spiraling and demanding needs. After a discussion of the CPAS common information infrastructure, four examples of typical CPAS functionalities will be presented, many other areas can be found in [2].

A collaborative process automation system (CPAS) is often defined as a method to unify previously diverse systems in order to achieve operational excellence.

## Common Information Infrastructure

CPAS have a common infrastructure, are functionally transparent, logically concise and standards based. Standards like Ethernet, ISA88 and ISA95 as well as IEC61131 should be deeply integrated in a CPAS. Other important standards like OPC (DA, AE, HDA and, more recently UA), IEC 61850 and FDT/EDDL should be used wherever they make sense.

Only few vendors can offer global data access (GDA), which allows access to any information from anywhere to anywhere at any time for any valid purpose ("the five anys" according to Dave Woll) → 1.

In ABB's System 800xA every information item – be it a measurement value or a production schedule – can be published as an Aspect Object property. These properties can be accessed system wide from any interested application in a uniform way, no matter where the original information comes from. Lookup functions exist that allow generic information access, enabling reusable solutions. System 800xA provides a framework that automatically distributes information to all workplaces in the system. For example, an external OPC server can be accessed from all nodes without the need to know on which machine this OPC server is running.

The Aspect Object technology inherent to System 800xA provides the unifying platform base. It allows each application to maintain data in its source application, while providing association to a production asset. This allows access to the data directly from its source in the context of the production asset without the need to know where the data is coming from, and without concern about data integrity and concordance. System 800xA supports late binding: data can be referenced in an abstract and generic way without forcing the engineer to hardcode specific server names or I/O positions. This adds flexibility and facilitates housekeeping when changes are made. Late binding is a very important basis for generic solutions that can be reused in many different contexts. Class concepts known from programming languages like C++ or Java, allow generic solutions to be built.

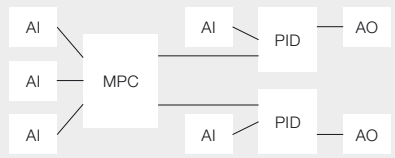
## ERP Integration

ABB's Industrial IT cpmPlus enterprise connectivity solution (ECS) bridges the vertical integration gap between business and manufacturing systems. ECS is fully scalable and includes event handling, transaction handling, error and application logging support and fail-over (fail-safe) support. The main components and their connectivity are displayed in → 2. ECS is the information broker that connects to the MES, to the control system on the shop floor and to the ERP system via SAP's [1] external interface SAP XI.

**Footnote**

1 SAP is the leading ERP software company.

4 Schematic of MPC configuration




AI analog in
MPC model predictive control
PID proportional integral derivative
AO analog out

Full data integration enables various novel applications. One such cross application, which combines the online quality information with offline planning and customer order data, is the ABB quality-based retrimming solution (qtrim). qtrim complements ABB's fully integrated production management suite for the paper industry. The suite includes state-of-the-art technology, such as leading quality control (QCS) and web imaging (WIS) systems.

The qtrim solution comprises a mathematical model [3] that is able to consider quality profiles along the paper jumbo-

ABB's Industrial IT cpmPlus enterprise connectivity solution (ECS) bridges the vertical integration gap between business and manufacturing systems.

reel as well as the customer order requirements attached to each paper roll. Thus, the solution provides a complete geometric representation of the trim-loss problem. The model can generate cutting plans, which reduce the quality loss significantly. Quality loss is the economic loss based on degraded quality. Better cutting plans result in reduced energy and raw-material consumption, that is, a minimized environmental load, improved reliability for customers and, finally, higher profit through lower total production costs.

The key enabler of such a solution is data availability. During the paper-making process, quality information is collected by the QCS that performs continuous scans along the paper reel. Properties such as moisture, caliper and brightness are measured frequently. Even for small paper machines, there may be tens of thousands of measurement points for each quality property per jumbo reel.

In the WIS, a number of high-speed cameras track all visual defects (holes, cracks, wrinkles) and the images are efficiently analyzed using neural network-based methods. These methods ensure fast and reliable processing of data to classify and determine a defect's type. The challenge is to handle large amounts of data and to ensure that the actual information can be extracted efficiently.

These very specialized systems are fully integrated and the solution will work silently in the background creating additional profit to the customers. The most important issue is to put everything together into one robust and uniform concept that will deliver the best results. The functional components and their integration are shown in ➔ 3. The measurement data of the quality systems are provided with geometric information from the control system. Customer order quality requirements are collected from the order management system and compared with the actual quality. Potential customer roll positions are mapped to the actual produced roll; this mapping is then used as "raw data" for optimization. Information can flow in all directions through well-defined interfaces, and the intelligent solution ensures that the current planning is always up-to-date with respect to the known quality data. Summing up, the cross-application integrates all levels (ERP, CPM, DCS) seamlessly and contributes to an economically and environmentally optimized production process.

## Advanced Process Control

In an automation hierarchy following the ISA 95 standard [4], advanced process control (APC) corresponds to coordinated control of a production unit or parts thereof.

In principle, APC means any closed-loop control, using automatic feedback from process measurements, which is more advanced than using decentralized PID controllers. However, in recent years APC has become more or less synonymous with model predictive control (MPC).

MPC is a multivariable controller, which optimizes future process variables every time new measurements are available, using the model as an equality constraint. The MPC's popularity is due to a range of properties, which no other control method can match: When executing the optimization process MPC can take account of:

- Constraints on both manipulated as well as predicted process variables
- Future known changes of the set-points

Traditionally MPC has been implemented in a PC separate from the control system, communicating with the control system using, for example, OPC. The output from the MPC is usually connected to the setpoint of underlying PID (proportional integral derivative) controllers. However, there is a lot to be gained if the MPC is an integrated part of the CPAS. In particular if the configuration can be made by drag and drop in a IEC61131 editor. For a schematic of an MPC configuration with three process variables delivering two manipulated variables to two PID controllers see ➔ 4.

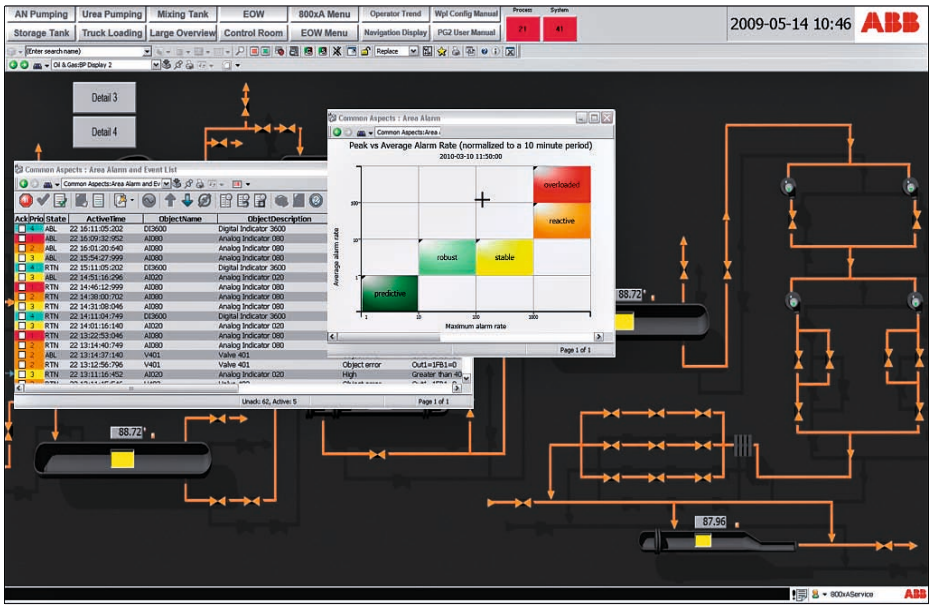
To appreciate the benefit of this, one needs to understand that a line connection in ➔ 4 may represent the bi-directional flow of information. For example a line between the MPC and a PID, in addition to sending the setpoint to the PID, receives the following information back to the MPC:

- Logical flags, if the PID output is saturated or not (high and low limit respectively)
- The mode of the PID (manual or automatic)
- If the PID is using an external (ie, from MPC) or internal (ie, from operator) setpoint
- If PID uses an internal setpoint then the MPC also receives the value of this setpoint

All this information is needed to properly take the state of the PID into account when running the optimization.

By having the actual execution integrated in the CPAS, benefits like automatic

5 Continuous improving alarm system




backups, automatic re-start when CPAS is re-started, possibility of redundance, etc, can be achieved. This may however, still be in a PC server belonging to the CPAS. Execution in a hardware controller carries potential additional advantages like faster and more secure communication.

## Plant Asset Management

Plant asset management (PAM) is a multidisciplinary task that spans organizational and structural boundaries. PAM focuses on various aspects of operations, maintenance and production management.

Recent NAMUR and VDI/VDE GMA publications have established a widely shared definition and understanding of PAM [5,6]. In particular, relevant PAM functions have been described in a common model framework. The three main aspects of this framework are asset monitoring, information processing and information management. Each of these areas may represent complex functionalities depending on whether a complete PAM-system or a single function is targeted.

Implementing PAM as part of a CPAS, benefits from self-evident collaborative properties as described previously. One main feature of CPAS is the easy connection to a large variety of data sources. PAM strongly relies on this connectivity in order to receive information such as real-time process data, historical asset information, plant topology, economic information and maintenance work orders. This information, which is available to the PAM system, forms the background for asset monitoring. Asset monitoring is the supervision and assessment of the most vital plant equipment such as reactors and heat exchangers. It needs to host both simple and as advanced algorithmic functionality in order to cope with the large number of different assets to be monitored. Monitoring is performed with respect to both performance and condition. Performance relates to high energy and material consumption due to asset deterioration and the impact of poorly performing assets in production. Condition relates to the identification of harmful operating conditions and diagnosing as well as predicting relevant asset faults.

PAM has often disappointed users because it tends to generate a high number of noncritical asset alerts. In order to generate useful asset information, powerful information concentration and aggregation has to be applied to the basic asset monitoring data. This can only realistically be achieved if plant topology information is used together with asset monitoring results and maintenance history. Such a procedure is well supported by a CPAS architecture that enables simple and flexible access to different kinds of information from various data sources.

The third aspect of PAM is the user-specific delivery of information. Since information is unique and accessed flexibly, different users may efficiently use the system based on their requirements. Operator information differs significantly from maintenance information and each is delivered according to their specific needs. Integration of PAM into enterprise-level applications such as CMMS (computerized maintenance management system) is enabled by the consistent use of standards for vertical integration. Any maintenance-related information can thus be transferred efficiently from shop floor to top floor.

## Alarm Management

Originally the word alarm meant an important event that required an urgent reaction. In today's plants many so-called alarms are completely meaningless for plant operation. During the last decade it has become apparent that many automation systems generate so many nuisance alarms that human operators can't handle them any more. If most of the generated alarms have no meaning for the operators, this reduces their vigilance and trust in the alarm system. Even important alarms are ignored or overlooked during a flood of nuisance alarms. This means that many alarm systems are of low quality and provide the operators with little support. Guidelines like EEMUA 191 and ISA 18.2 show how alarm systems can be systematically engineered to create a high-quality alarm system. One important reason for the low alarm system quality of many automation systems is that a high quality configuration of alarms requires lots of expertise and effort. The high upfront investment cost has in some cases impeded better alarm configurations. Sometimes the information required for a perfect alarm configuration is not available before operational experience exists.

Some companies report good results from continuous improvement activities,

ABB's System 800xA help manufacturers stay competitive by implementing world-class process automation.

6 The CPAS book


where the operating team continuously monitors the quality of the alarm system. System 800xA supports such continuous improvement processes by providing easy-to-configure monitoring tools fully integrated into the operator environment. During regular meetings, operating teams can go through preconfigured alarm management reports, which help them to pinpoint the most urgent alarm management problems. In the light of this philosophy, an alarm is always a call for action: either to fix an operational problem, to repair a faulty component or to reconfigure a suboptimal alarm configuration. A perfectly running plant should produce no alarm at all → 5.

This kind of continuous alarm management system provides a kind of plant hygiene, like brushing teeth each day. It is a nice example of how System 800xA supports the continuous improvement culture of the CPAS vision.

## Meeting the challenge

Modern CPAS like ABB's System 800xA help manufacturers stay competitive by implementing world-class process automation. As the goals of the CPAS vision are very ambitious and broad, there is still much work to be done until we see automation systems fully supporting all aspects of this vision. ISA has published a book on CPAS (see http://isa.org/CPAS) edited by ABB's Martin Hollender. It contains chapters explaining modern aspects of CPAS like security, engineering, operator effectiveness and much more. Dave Woll has contributed a chapter describing the original ARC CPAS vision → 6.

ARC is currently updating the original vision and calls this CPAS 2.0 [7]. The introduction of OPC-UA [8] will have a large impact on the technological front. In the first phase OPC-UA will supersede the classic OPC standards. This will remove the headaches some systems had with the flawed DCOM and enable the use of OPC on systems running without Microsoft Windows, eg, many intelligent field devices. In a second phase, the use of standardized information models, eg, the DI specification for devices will be the basis to provide more generic functionality without the need to specify every little detail differently for each system. Complete process of manufacturing automation systems can be described even more with Automation ML [9], and their interaction and date exchanges described by applying a specific automation XML dialect. Examples are loop monitoring and asset management functionality that can be specified at a very abstract level, which then works for all connected systems independent of vendor or technology generation. As hardware becomes cheaper and powerful digital fieldbuses become available, there are fewer and fewer reasons to run control algorithms in a central location. IEC 61499 extends IEC 61131 to include object-orientation and event-driven execution and is therefore a good candidate for truly distributed control scenarios. The upcoming field device integration (FDI) specification [10] will harmonize and unify the existing field device tool (FDT) and electronic device description language (EDDL) standards. It will improve easy access to value-added functionality of modern field devices like calibration and diagnostics. Other features that future CPAS will offer are a very tight integration of telecommunication, workflow and video supervision systems.

ABB's System 800xA provides a framework that automatically distributes information to all workplaces in the system.

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# Aspects of productivity

For the end user, the best technology is often technology that is operationally invisible. It performs the tasks for which it was designed without drawing attention to itself. If intervention is required, this should be in a predictable manner rather than being dictated by malfunctions or outages.

Robustness can be increased by making installations more tolerant to disturbances, errors and unexpected situations. This can be through overall design considerations, making the system more resilient and flexible. It can furthermore be supported by adding "smart" functionality. Self- and remote-diagnosis can provide information on the condition of a device and enable a shift from reactive to proactive maintenance.

Productivity can also be improved by focusing on the human machine interface (HMI). Automation and control systems collect and process a lot of data. Raw data, however, is not the same as actionable information. Enabling an operator to take the best possible decision at all times involves providing a higher quality of information.

In the past, the fourth issue of *ABB Review* of every year focused on innovations. This theme is now being moved to edition one. Issue 4 of 2010 will look at ways in which ABB can uplift productivity in different situations and areas of application.

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