ABB
review

3|11
The corporate technical journal

Technology matters

Power and productivity for a better world™

The photograph on the front cover of this issue of *ABB Review* was taken in the coal storage facility of a clean-coal power plant. ABB supplies power and automation components and systems for such plants, raising their energy efficiency and productivity.

The inside front cover depicts Statoil's liquefied natural gas plant on the island of Melkoya in northern Norway, for which ABB provided a complete range of power and automation products.

Efficiency focus

Power and energy

Manufacturing focus

Technology matters

Claes Rytoft
Chief Technology Officer
ABB Ltd.

Dear Reader,

ABB's portfolio is broad and continuously growing. It not only encompasses myriad product families and applications stretching from tiny switches to comprehensive control and electrification systems, but stretches beyond hardware products to system-engineering, diagnosis, service and support capabilities. As the information arm of ABB's research and development organization, *ABB Review* regularly presents reports and insights from across the company's technological spectrum. In the present edition, Technology matters, we are underlying this core aspect of technology by looking at some very different applications.

Photovoltaics have come a long way in recent years. A combination of government incentives, environmental awareness and decreasing prices mean that solar panels on residential properties are becoming increasingly attractive. Besides their smaller size and power rating, one of the main differences setting home installations apart from larger photovoltaic setups is that the average user is not a technician or engineer and hence the interface must be designed to be much more intuitive. ABB's new string inverter does precisely that.

Past editions of *ABB Review* have discussed how power grids will become smarter in view of evolving demands on the transmission and distribution grid. One area of focus involves energy storage as a means of overcoming variations. Pumped hydro storage plants are the only mass-storage technology of any significant scale in existence. The application of modern drives is leveraging the technology further. Looking at a project in Avče (Slovenia), we highlight the contribution these can make.

Further down the distribution chain, an article shows how smart grid technologies can be applied at a distribution level. Stockholm's Royal Seaport is an urban area in which a number of smart grid technologies are being applied. In this article we highlight the impact of adopting intelligent low voltage equipment.

Moving from urban planning to software architecture, we show how ABB is working with methods and tools to make its software sustainable and maintainable. As the functionality of software in products becomes more extensive and sophisticated, the significance of this aspect will increase further.

Remaining in the domain of software, we present a monitoring system that uses artificial intelligence to predict emissions and ultimately to reduce environmental impact. The system has been successfully implemented at one of the largest gas processing plants in the world.

In industrial communications, there is a trend towards the simplification and reduction of wiring. With numerous sensors and actuators distributed across a process plant, wiring is a source of both errors and costs. Wireless communications are already well established, but ABB's new Fieldkey adapter goes one step further and assures wirlessHART connectivity without requiring a separate power supply.

I trust the reading of this issue of *ABB Review* will give you fresh and fascinating insights into the world of ABB's technology.

Enjoy your reading

Claes Rytoft
Chief Technology Officer
ABB Ltd.


ABB

The frugal manufacturer

Part 1, Using energy sparingly

CHRISTOPHER WATTS – As the world leaves a long era of energy abundance and enters an era of constraint, many complex challenges face government, business and society. Among these is resolving the conflict between raising living standards in developing regions by continuing to expand industrial production, and lessening the negative environmental impacts of industrial manufacturing activities across the world. One of the approaches to addressing this challenge is to improve energy efficiency in the core of industry's production processes.

In January-February 2011, the Economist Intelligence Unit surveyed 348 senior executives, mostly in North America, Asia-Pacific, and Western Europe, on their plans to invest in improving energy efficiency in production processes, the issues they face as they consider these investments, and the factors that are likely to influence industrial energy efficiency in the coming years. This is the first of three articles to appear in *ABB Review* based on the results of that survey, as well as on a program of in-depth interviews and desk research on the topic of industrial energy efficiency. In addition, the study is based on a separate comprehensive analysis of the worldwide energy consumption patterns of seven energy-intensive industries, carried out by the energy information and consulting firm, Enerdata.

More than two-thirds of respondents to the survey are executives at director level. Respondents are most likely to have responsibility for strategy and business development, finance, general management, and operations and production. Around 58 percent are from businesses with $500 million or more in global annual revenues. The survey focuses entirely on the manufacturing and power sectors, with manufacturing having the strongest representation.

Title Picture
The Palmachim water desalination/purification plant. The desalination process is energy intensive. ABB has supplied energy-efficient drives for this installation. ABB's contribution to water supplies will be discussed at length in *ABB Review* 4/2011.

1 82 percent of executives in energy-intensive manufacturing segments agree that energy efficiency is critical for profitability. This is a plant of the Qassim Cement Company, whose efficiency is boosted by Electrification, Drives and Automation from ABB.

Sub-optimal efficiency practices are widespread across industry and the potential for saving through improvement in energy efficiency is large.

In addition to the online survey, the Economist Intelligence Unit conducted 15 in-depth interviews with senior business executives, policy makers, and other experts in industrial energy efficiency. The insights from these interviews appear in all three articles.

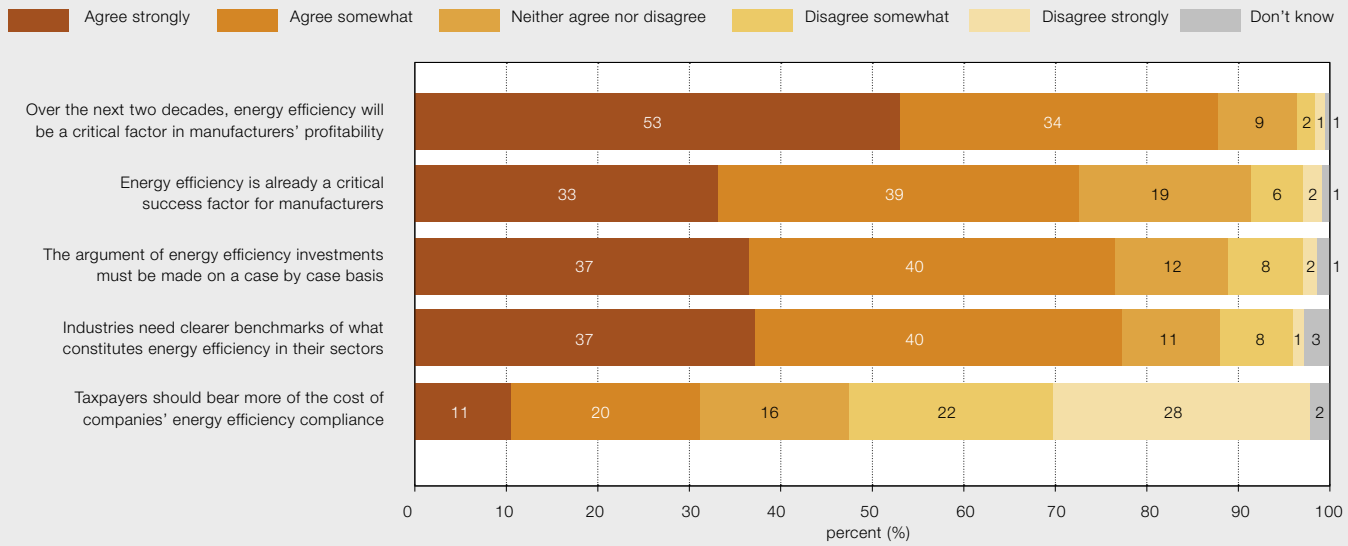
Industry accounts for around one-third of the world's final energy demand; around 60 percent of which is from developing countries. Industry's total energy use continues to grow as a result of expanding production volumes, a trend that is likely to continue in the coming decades as living standards rise in developing regions. Meanwhile, energy efficiency leaves much room for improvement in many parts of the world and in many industries.

Against this background, businesses are facing a future of constraints, including restricted access to energy and curbs on carbon dioxide emissions. As such, improving industrial energy efficiency is no longer optional but a clear pre-requisite for long-term financial growth. Those companies that do not address energy efficiency are likely to find that their long-term financial performance will be negatively affected. Meanwhile, those firms that seek continuous improvement in energy efficiency are likely to steal a march over competitors.

In all, 88 percent of manufacturers say industrial energy efficiency will be a critical success factor for their business in the coming two decades. The reasons are largely related to cost competitiveness, especially for companies in energy-intensive manufacturing sectors. Above all, companies look for financial returns when investing in energy efficiency. Sub-optimal efficiency practices are widespread across industry and the potential for saving through improvement in energy efficiency is large. In making the financial and business case for investments in efficiency, the price of energy is one of the biggest factors, cited by 59 percent of survey respondents.

"In our Indian operations, around 50 to 55 percent of the direct costs to convert raw materials into finished goods is energy," says Satish Agarwal, Chief of Corporate Manufacturing at Apollo Tyres, based in Gurgaon in northern India. That's one of the reasons why, in the past three years or so, Apollo Tyres has invested some $12 million in energy effi-

2 Perception of the need for energy efficiency in industry (survey responses, 348 respondents)



ciency improvements to its plants, including the installation of heat exchange devices for its boilers, flash steam systems to capture and use process heat, and insulation materials to reduce heat loss. These latest investments are part of an ongoing initiative that has so far led to a 40 percent reduction in the firm's energy intensity.

Against a background of intensifying competition, rising energy prices, and closer regulatory scrutiny, Agarwal is not alone in understanding the extent to which energy efficiency is a critical success factor in industry. Indeed, among manufacturing sector managers that responded to the survey, 72 percent "agree strongly" or "agree somewhat" that energy efficiency is a critical success factor for manufacturers today. Looking forward over the next two decades, 88 percent of respondents expect energy efficiency to be a critical factor in manufacturers' profitability.

Variations in these results highlight the diverse backgrounds of companies represented in the survey. For example, among companies in particularly energy-intensive manufacturing segments, such as iron and steel, chemicals and petrochemicals, cement, pulp and paper, and aluminum, 82 percent of executives agree that industrial energy efficiency is a critical factor in their profitability today → 1 (versus 67 percent in less energy-intensive activities). This apparent sharper awareness of the role of energy efficiency perhaps reflects characteristics of energy-intensive segments such as high energy costs as a proportion of total costs; recent energy price volatility and price increases; and relatively thin profit margins → 2.

Seen from a regional viewpoint, executives in developing countries are more likely to agree that energy efficiency is a critical success factor for manufacturers (82 percent) than in developed countries (67 percent). "We believe that, in developing countries, one of the reasons they are more aware of energy efficiency is that energy is a scarce resource," says Pradeep Monga, Director of Energy and Climate Change at the United Nations Industrial Development Organization (UNIDO). Indeed, the survey findings appear to confirm a greater appreciation of energy efficiency in those economies that use most energy → 3 and → 4.

Why are improvements in energy efficiency critical for long-term profitability? For a start, because of the significant cost savings they bring. Doug May, Vice President of Energy and Climate Change at The Dow Chemical Company in the US, says that his firm's energy efficiency efforts since 1994 have contributed total cost savings of some $9.4 billion. "Energy efficiency is a gift that keeps on giving," he says.

The "co-benefits" of improving efficiency

Cost savings are one thing. In fact, behind headline figures such as Dow's, there are further advantages of improving industrial energy efficiency that contribute to long-term financial performance. For example, using less energy in production processes means companies can face relatively higher energy prices without feeling the pinch – a clear competitive advantage. "[Improving] energy productivity is one of the best risk management approaches that a manufacturing company can undertake in the current market place," comments Neal Elliott, Associate Director for Research at the American Council for an Energy-Efficient Economy (ACEEE). Luis Farías, Vice President of Energy and Climate Change at Mexican cement producer CEMEX, agrees: "Energy is a large cost component in cement," he says. "So energy efficiency gives us more predictability in our future earnings and cash flows."

Industry accounts for around one-third of the world's final energy demand; around 60 percent of which is from developing countries.

Leading businesses are scrutinizing the energy efficiency of their manufacturing operations.

3 Emerging markets in the energy spotlight

Over the past several decades, developed countries have seen an ongoing structural shift in their economies – from manufacturing to services. These days, the services sector in most developed economies is significantly larger than the manufacturing sector, and is growing faster, too. Of course, the services sector uses significantly less energy per unit of economic output than the manufacturing sector – so when it comes to energy intensity, developed economies are becoming less energy-intensive.

Today, developing countries dominate global industrial energy use, for a number of reasons. First, the economies in developing countries have shifted from agriculture to manufacturing in recent years. Second, recent economic development has increased demand for infrastructure and buildings, which in turn require large amounts of cement, steel and other energy-intensive materials. And third, developing countries comprise about 80 percent of the world's population.

These basic trends are reflected in economic growth and industrial energy demand statistics from the International Energy Agency (IEA) laid out in the table below and illustrated in → 4.

	GDP growth 1990–2008 (percent)	Industrial energy usage 1990–2008 (percent)
UK	54	-7
USA	66	4
India	205	63
China	485	172

Besides advantages such as these, efforts to improve the energy efficiency of industrial production processes are often associated with further benefits. These include lower plant downtime and longer maintenance cycles; improved productivity; better product quality; compliance with building and environmental codes; employee health and safety; or benefits around research and innovation. These so-called "co-benefits" are not to be sniffed at, according to Elliott: "We typically see non-energy savings benefits being three to five times the value of energy savings," he says.

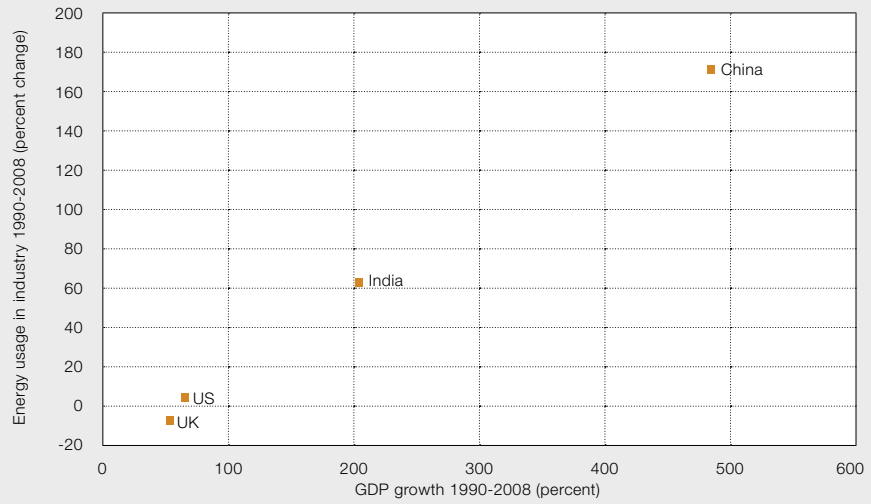
Despite an appreciation of the critical contribution of energy efficiency to long-term profitability among industry executives, relatively low energy efficiency appears to remain the norm in production processes across large sections of industry. In some cases, this is down to inefficient operation of plant and equipment – in its simplest form, leaving motors running continuously, whether they are in use or not. In other cases, it is down to inefficient equipment. Terry McCallion, Director of Energy Efficiency and Climate Change at the European Bank for Reconstruction and Development (EBRD) in London, puts it simply: "In some areas of industry, it seems like pumps and motors have got two modes: On, and Off." Industry experts estimate around two-thirds of global industrial electricity is consumed by electric motors. And yet, market penetration of medium-voltage variable-speed drives – which improve the efficiency of industrial motors by as much as 40 to 60 percent by regulating their speed – was as low as 13 percent in Europe in 2009, according to estimates from market research firm Frost & Sullivan.

It's little wonder, therefore, that the scope for energy savings in industry is so great. According to analysis from UNIDO, the potential for energy savings in production processes is as high as 50 percent of current demand in some industry sectors → 5. In all, realizing these potential energy efficiencies would lead to estimated cost savings of $230 to 260 billion a year. That is equivalent to cutting total production costs by around 3 to 4 percent, according to UNIDO.

The search for financial return

Not surprisingly, given the potential for energy-related cost savings, executives interviewed for the report mostly say first and foremost that they are looking for a demonstrable financial return on any investment they make in improving energy efficiency. Typically, industry executives measure this return on the basis of simple payback period (investment cost divided by annual savings), or internal rate of return. For example, in March 2011, Indian cement producer UltraTech Cement placed an order for $90 million-worth of waste heat recovery systems; L. Rajasekar, Executive President at the firm, expects these will have fully covered their costs after some six to eight years. In many cases, though, the pay-

4 Consumption of industrial energy grows more strongly in emerging economies than it does in mature economies.



Data source: International Energy Agency (IEA)

back period on investments in energy efficiency is as short as six months.

As industry executives weigh up the financial case for investments in improving energy efficiency, several significant external factors come into play. One is the price of energy. Experts reckon that the higher the proportion of energy costs in total production costs, the more financially compelling the investments in improving energy efficiency can be. When asked to name the main factors influencing decisions about efficiency investments, 59 percent of respondents cite the price of energy. Among energy-intensive manufacturers, the figure is 67 percent; among less energy-intensive manufacturers, it's 57 percent ➔ 6.

The investments made by Apollo Tyres are a case in point. As Ajay Mathur, Director General of the Bureau of Energy Efficiency (BEE), a Government of India body, further points out: "For industry in India, the delivered cost of energy is very high. And as far as India is concerned, the energy pressures will only increase. So for those industries for which energy is an essential and a large part of their costs, managing energy becomes amazingly important for their competitiveness." Price volatility and long-term price trends, as much as current prices, are a factor in industrial companies' investment considerations. "The immediate price spikes cause concern," says Steve Schultz, Global Manager of Corporate Energy at US industrial and consumer goods maker 3M. "But the fact that the price trend is upward, and has been upward, helps solidify some of that action."

Besides energy prices, other factors that survey respondents say influence their decisions to invest in energy efficiency improvements include national energy legislation, cited by 27 percent of executives. Some of these policies focus directly or indirectly on industrial energy use. And another factor that influences decisions about investments in energy efficiency is a wish to improve the company's image, cited by 26 percent of executives. This factor appears to be increasingly important as sustainability issues rise in prominence.
Many of these factors vary from continent to continent; from region to region; and from plant to plant – explaining why 76 percent of survey respondents say investments in improving energy efficiency must be judged on a case-by-case ba-

Market penetration of medium voltage variable-speed drives was as low as 13 percent in Europe in 2009.

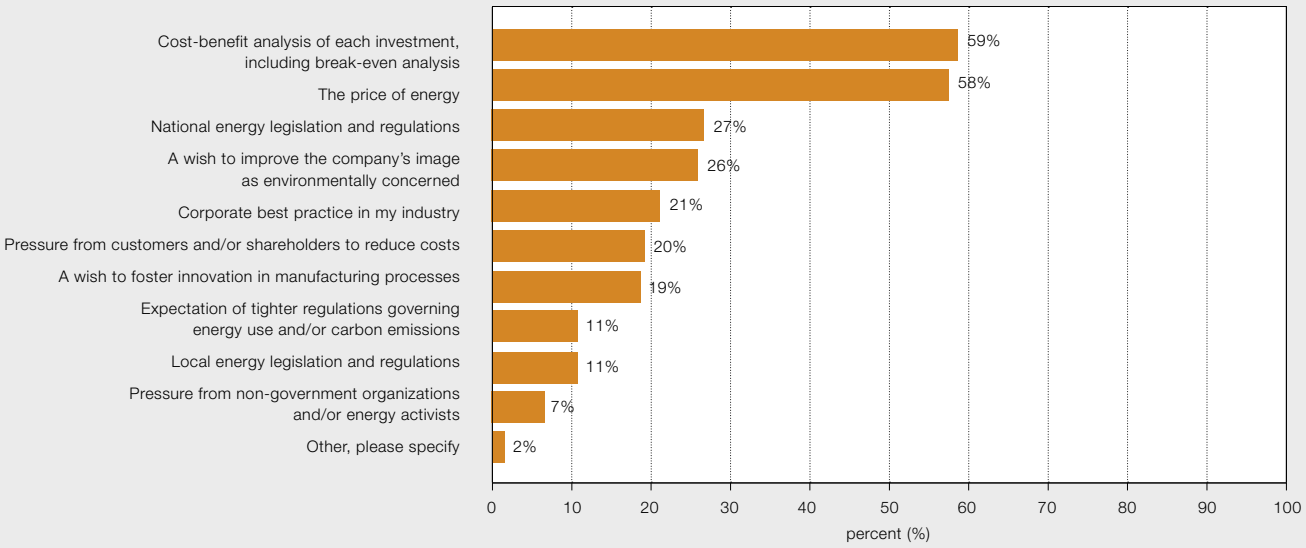
5 Where are the potential savings?

In a November 2010 working paper, Global Energy Efficiency Benchmarking – An Energy Policy Tool, the United Nations Industrial Development Organization (UNIDO) estimates the current energy saving potential in manufacturing industry and petroleum refineries to be some 23 to 26 percent of current total industrial energy demand worldwide.

While the energy efficiency potential in developed countries amounts to approximately 15 to 20 percent, the potential in developing countries is higher at around 30 to 35 percent. Industrialized countries have the potential to save $65 billion or more in energy costs, according to the report. Developing countries have the potential to save $165 billion or more.

Worldwide, the largest potential savings in absolute terms are in the energy-intensive sectors, such as metals, paper, cement, and chemicals. That said, the largest potential savings in percentage terms are in less energy-intensive sectors. In some, given the prevalence of small plants equipped with old technology, savings potential is as high as 40 to 50 percent.

6 Main factors that will influence investment in industrial energy efficiency over the next three years (survey responses, up to three responses per respondent permitted, 348 respondents)



sis. Andreas Genz, Senior Vice President of Energy Services for Finnish pulp and paper firm Stora Enso, is one executive who agrees. "Our machines all look the same, but they are tailor-made," he says. "So you have to define tailor-made measures to improve energy efficiency, too."

As industry faces the challenges of adapting to an era of energy constraints, leading businesses are scrutinizing the energy efficiency of their manufacturing operations. Efforts to measure, manage, and continuously improve energy efficiency save cash in the short term. In the longer term, such efforts enhance competitiveness, foster innovation, and pave the way for companies to meet environmental and other sustainability commitments. In other words, investments in improving industrial energy efficiency are critical not only for short-term profitability, but also for long-term financial performance. Despite the experiences and viewpoints of executives, policy makers and other experts interviewed for the report, sub-optimal practices are widespread. Energy efficiency saves costs and makes companies more competitive. Amid volatile, but rising, global energy prices, efficiency is especially critical for those companies operating in energy-intensive industries, where exposure to cost fluctuations is high, and profit margins are thin. While companies recognize this, many continue to operate inefficient equipment, or to operate equipment inefficiently. A major reason for the gap between awareness of gains from efficiency and actual investment in efficiency is poor information. This includes lack of information on latest technologies and alternative ways to improve efficiency; lack of efficiency benchmarks, and insufficient information on the payback of specific projects.

Another factor that influences decisions about investments in energy efficiency is a wish to improve the company's image.

This article is the first of three parts of the report, The frugal manufacturer: Using energy sparingly. The report was researched and written by the Economist Intelligence Unit and commissioned by ABB. The next article in this series, to be published in a forthcoming issue of *ABB Review*, will discuss in more detail why commitment to improvements in industry remain weak.

The Economist Intelligence Unit bears sole responsibility for the content of the report. The findings and views expressed in the report do not necessarily reflect the views of the sponsor.

For further information on energy efficiency of industry, utilities, buildings and transportation please visit www.abb.com/energyefficiency

The Economist Intelligence Unit would like to thank all survey respondents, as well as executives cited in the report

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Efficiency with usability

ABB's all new string inverter for photo-voltaic systems

JUKKA NURMI – The worries of global warming and soaring oil and gas prices mean the utilization of renewable energy sources looks set to increase to meet growing global energy demands. The planet has always received generous amounts of one source of renewable energy, sun rays. The simplest method of harnessing solar energy is through the use of photovoltaic cells. These cells produce direct current (DC) which needs to be converted into alternating current (AC). This conversion is carried out using an inverter, and ABB string inverters are designed for photovoltaic systems installed primarily on residential and small- to medium-sized commercial buildings. The new inverter series now includes built-in protection functions, which reduce the need for costly and space-consuming external protection devices and larger enclosures.

1 ABB's PVS300 string inverter

Technological developments are continuously improving the efficiency and cost effectiveness of photovoltaic systems. For its part, ABB has long been a leader in inverter and power converter technology and it has been using this knowledge and experience to provide leading-edge and high-quality solutions for photovoltaic power systems. Its portfolio of solar inverters ranges from small single-phase string inverters right up to central inverters with power ranges of hundreds of kilowatts. The latest addition to this portfolio, the PVS300 ➔ 1, has a power range from 3.3 to 8 kW, making it suitable for residential buildings as well as small and medium-sized commercial and industrial buildings. Its all-in-one design makes it reliable, safe and extremely cost effective, especially in installations using multiple inverters.

The heart of the PVS300 string inverter is the intuitive control unit equipped with a user-friendly graphical display that provides three main views: sun meter; solar energy production information; and help/settings menus. The sun-meter symbol indicates the amount of sun shining (10 rays mean full sunshine, one ray means rain) ➔ 2, and at night the inverter goes into sleep mode, consuming less than 1W. The solar energy production information display is designed to provide the necessary data for those interested or involved in the feed-in tariffs [1] provided by many countries for environmentally friendly production such as solar power ➔ 3. The built-in data logger displays and stores the exact daily, weekly, monthly and yearly production for up to 24 years. In addition, the inverter calculates CO_2-emission savings. Detailed technical data are available for those who want more than a general overview of their solar energy production.

A dedicated "help" key and built-in user's manual are provided to explain the different views and setting possibilities. The display platform supports up to 24 languages.

Start-up, guaranteed in just four straightforward steps, is guided by a start-up assistant that is initiated when the inverter is first powered up. Settings can be easily changed thanks to a menu structure with a look and feel similar to that found in everyday devices, such as mobile phones.

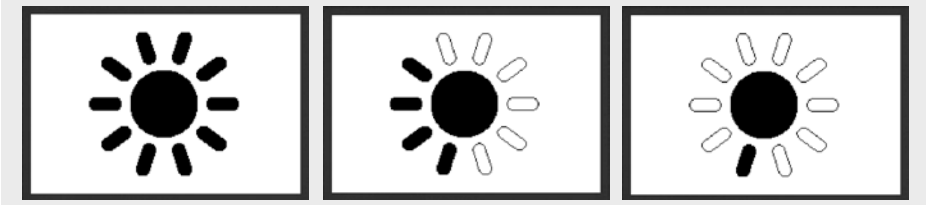
The display can be detached from the inverter ➔ 4 and 5 and mounted separately on a wall to monitor inverter performance from outside the installation room. It can also be wirelessly connected to the in-

ABB's portfolio of solar inverters ranges from small single-phase string inverters right up to central inverters with power ranges of hundreds of kilowatts.

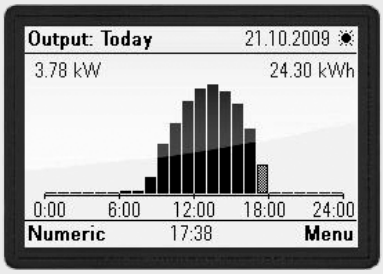
Title Picture
ABB's new string inverter, designed for photovoltaic systems installed on residential and small-to-medium-sized commercial buildings now includes built-in protection functions.

Footnote
1 A feed-in tariff (FiT) is a policy mechanism designed to encourage the adoption of renewable energy sources and to help accelerate the move toward grid parity. Under a feed-in tariff, eligible renewable electricity generators (which can include those in homes and businesses) are paid a premium price for any renewable electricity they produce.

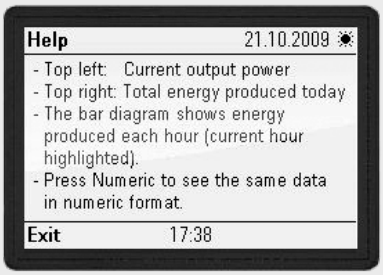
2 Displays even a child can understand



3 Detailed technical information is available for those who want a bigger picture of their solar energy production



3a Solar-energy-production-information



3b A "help" key explains the different views

verter; the wireless transmitter and receiver are already paired in the factory so that the user does not have to play with the complex settings so often needed in wireless connections. The technology and frequency range is similar to that used in wireless weather sensors but it covers longer distances than Bluetooth and consumes significantly less power than Wi-Fi.

Built-in protection

The attention given to the aesthetics, and the internal design and layout of ABB's string inverter were important to fully support system integrators and those installing photovoltaic systems. In particular, the addition of comprehensive built-in protection eliminates the need for the external components used in most traditional photovoltaic systems.

To begin with, fault currents, created in an ungrounded system when two ground faults or a line-to-line fault exist, may damage modules or cause excessive heating in some part of the system. The systems need to be protected against this admittedly rare occurrence by placing string fuses in both the negative and positive legs of the string cabling.

Also solar arrays are subject to atmospheric activity and may be damaged by the overvoltage generated by lightning. To minimize these risks, surge protective devices (SPD) need to be installed on each polarity. The impedance of these devices varies depending on the voltage applied; for example, in normal operation the impedance is extremely high and is only reduced – in the case of over voltage – by discharging the associated current towards ground. Unfortunately,

The addition of comprehensive built-in protection eliminates the need for the external components used in most traditional photovoltaic systems.

standard SPDs do not work properly in photovoltaic systems. Instead specially designed ones are needed for PV systems having high nominal DC voltage

The PVS300 has a power range from 3.3 to 8 kW, and its all-in-one design makes it reliable and safe especially in installations using multiple inverters.

The neutral point clamped (NPC) topology combined with ABB's patent-pending modulation scheme provides an efficient inverter with minimal leakage current and the maximum allowed DC voltage.

4 The PVS300 string inverter is suitable for residential and commercial use

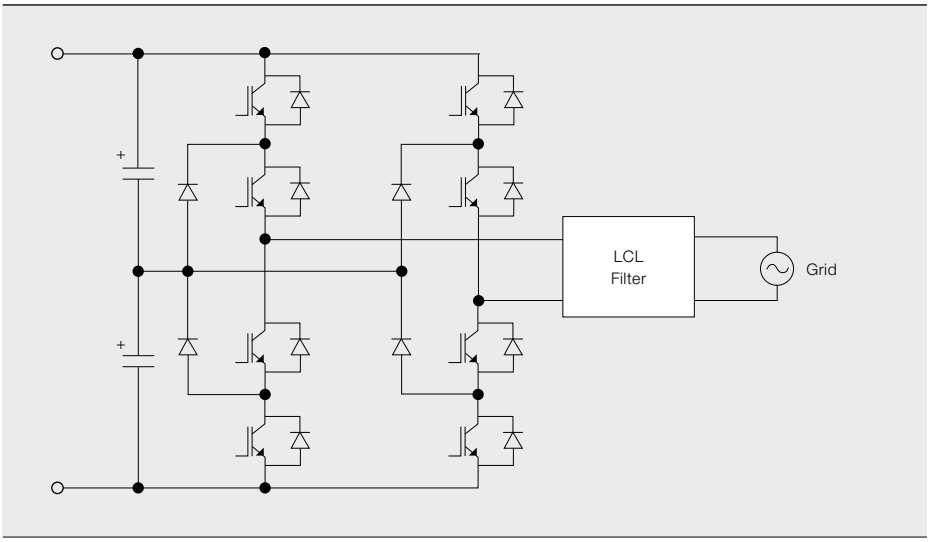
5 PVS300 display can be detached for remote monitoring

6 Integrated DC switch, string fuses and surge protection devices under the main cover

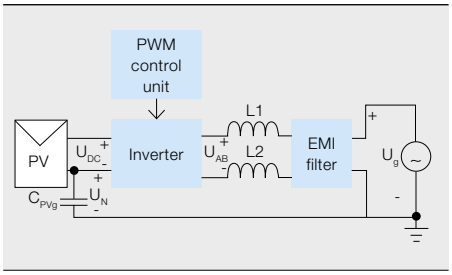
and low short-circuit current capability. Typically, these protection devices are placed in a separate junction box between the solar modules and the inverter.

The built-in protection designed into ABB's PVS300 string inverter avoids the time and cost required to select, design and install external protection devices and enclosures → 6. For system integrators and during installation, a compact integrated solution means space is used much more efficiently, something that is valued especially in installations that use multiple inverters. For end users, the internal design of the inverter significantly reduces troubleshooting and repair time when a problem occurs. For example, an in-built microprocessor monitors internal protection devices (eg, fuses and surge protective devices) and immediately transmits error messages or information to the inverter display and optionally over the Internet as an e-mail in the event of a problem; and components such as pluggable surge-arrester cartridges can be easily and safely replaced. Finally, the reduction in material usage is a major contributor to minimizing CO_2 emissions over the product lifecycle.

7 PVS300 string inverter full bridge neutral point clamped (NPC) topology



8 Photovoltaic system with stray capacitance



Pure performance at the core

The core of ABB's string inverter design is described as a full bridge, neutral point clamped (NPC) topology ➔ 7, which is combined with ABB's patent-pending modulation scheme to provide an inverter that is extremely efficient with minimal leakage current and high maximum allowed DC voltage.

High efficiency comes from simplicity, which is illustrated when certain aspects of a traditional solar inverter design are compared to the PVS300 design. For example, the traditional design uses an additional boost converter in the input or a step-up transformer in the output whereas the ABB string inverter only uses one DC to AC power conversion stage. The elimination of additional power conversion stages not only improves the efficiency but also the reliability of the system. Additional efficiency gains are achieved using intelligent sleep logic and advanced materials, such as amorphous alloy cores in the output LCL filter.

A typical ungrounded photovoltaic system is shown in ➔ 8. Solar modules are always connected to ground through a parasitic capacitance (C_{PVg}). Any AC component present in the voltage U_N will generate a current through this capacitance to ground. If the voltage across the capacitor contains excessively high-frequency components, it can produce equally excessive high-frequency ground currents that can either create electromagnetic compatibility issues, or degrade or damage the solar modules over time. ABB's patent-pending high-frequency elimination modulation scheme eliminates the high-frequency components from U_N that some inverters in the market actually introduce.

The solar-system DC voltage varies depending on the system configuration, temperature and solar irradiation. Due to its wide DC-input range, the ABB string inverter easily accommodates a broad selection of series and parallel configurations and different solar module types. Its high maximum DC voltage allows more modules to be connected in series and this in turn reduces the cost and losses in the DC cabling.

The PVS300 string inverter was introduced to the market for the first time at the 2010 Intersolar fair in Munich, the world's largest exhibition for the solar industry. It follows the successful launch of ABB's central inverter product family for photovoltaic power plants a year earlier.

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The maximum DC voltage allows more modules to be connected in series. This not only reduces the losses in the DC cabling but the cost as well.


ABB
ABB

Advanced power grid protection

Next generation teleprotection solutions

ROMEO COMINO,
MICHAEL STRITTMATTER –

Teleprotection is vital for the reliability and economy of modern electric power systems. With the emerging deployment of non-deterministic Ethernet/IP technology in wide-area communication networks, utilities around the world are concerned that protection signaling, which ensures fast and selective isolation of faults in the power network, might be compromised. Thanks to the company's vast experience in teleprotection and utility communications, ABB has been able to drive the development of new interfaces for its teleprotection platform NSD570, allowing secure, reliable and dependable operation of protection signaling equipment over Ethernet/IP WAN networks for the first time.

Title Picture
Utlities are concerned that protection signaling in substations might be at stake due to non-deterministic Ethernet communication.

Disturbances and faults in power systems can result in severe voltage collapses and power blackouts, affecting entire regions or even countries. Due to its heavy reliance on electric power, modern society cannot accept such power outages – neither for their impact on public life nor for their economical consequences. It is therefore vital to avoid major disturbances by all possible means. A key element for the isolation and fast clearing of faults is a sound protection practice.

> Protection systems must meet sensitivity, time response, selectivity and reliability specifications in order to satisfy fault clearing requirements.

Protection systems must meet sensitivity, time response, selectivity and reliability specifications in order to satisfy fault clearing requirements. Protection schemes, in particular for high-voltage transmission lines, rarely meet all these requirements without using telecommunications.

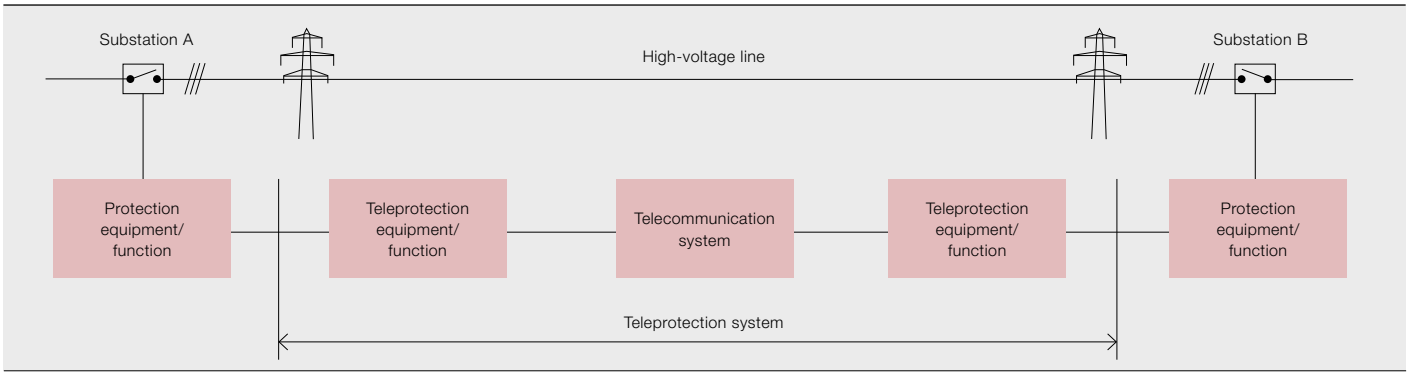
The typical protection-system architecture on a high-voltage transmission line consists of three main components: protection relays, teleprotection equipment and a telecommunications system → 1. Teleprotection acts as a physical interface between the telecommunication infrastructure and the protection relays. It is therefore essential for the conveyance of signals generated by protection relays ("commands"), and to ensure that their response time and selectivity needs are met in case of power system fault conditions.

Performance criteria for teleprotection: security, dependability and transmission time

Since any telecommunication system is subject to various forms of interference and impairment (such as jitter and bit errors in digital networks or corona noise and attenuation variations on a power line carrier channel), the performance of the teleprotection equipment under these disturbed channel

Disturbances may neither simulate a command that was not transmitted (security), nor unduly delay or suppress a command that was transmitted(dependability).

1 Typical protection system architecture



conditions is characterized by the terms *security, dependability and transmission time*.

An important criterion is the available bandwidth on analog links and the data rate of digital or Ethernet channels. The higher the bandwidth or data rate, the lower *the transmission time* that usually can be achieved with the teleprotection equipment.

For the protection system, it is of utmost importance that disturbances in the telecommunication channel must neither simulate a command at the receiving end when no corresponding command signal was transmitted (security), nor unduly delay or even suppress a command that was actually transmitted (*dependability*).

In this regard, all teleprotection equipment must comply with relevant security, dependability and transmission time requirements, as defined in the IEC 60834-1 standard [1].

Security, dependability, transmission time and bandwidth (or data rate) are interrelated parameters. The combination of high security and high dependability with short transmission time and narrow bandwidth (or low data rate) are conflicting requirements. As a result, the emphasis must either be on dependability or on security, or on transmission time, depending on the protection scheme used, ie, whether protection signaling is applied in permissive tripping, direct tripping or blocking schemes.

ABB's next generation teleprotection equipment of type NSD570 is ready to allow Ethernet connectivity by means of a 10/100 Mbps interface.

Another important criterion is the availability of the communication channel itself, in order to perform the required function at any moment in time within a given interval [2]. The availability level for a telecommunication system used for teleprotection should be at least 99.99 percent. To achieve this critical objective, a profound knowledge of the applied telecommunication technology is essential. Moreover, an appropriate network design, implementation of self-healing or recovery mechanisms and necessary redundancy and back-up methods are essential.

Beside the availability of the communication channel, the electromagnetic compatibility (EMC) of the teleprotection system and its immunity against interference from fast transient bursts and other outside disturbances is critical. The entire design of the teleprotection system and respective hardware has to be such that it can withstand interference precisely at the moment of a fault in the power system, ie, at the time when its ability to reliably transmit commands is most required.

Teleprotection via different telecommunication media and channels

Various types of transmission media can be used for teleprotection. As point-to-point communication links are still commonly used, the following media prevail today:

- Power line carrier (PLC) links
- Fiber-optic links
- Copper wires / pilot cables
- Microwave-radio links

The physical property of the interface between the teleprotection equipment and the communication terminal is either an analog circuit with voice frequency bandwidth, or a digital/optical circuit with a certain data rate, eg 64 kbps ➔ 3.

ABB's next generation teleprotection equipment NSD570 offers a complete set of interfaces to the telecommunication system as mentioned above, and enables Ethernet connectivity by means of a 10/100 Mbps interface, which will be discussed later in this article.

Is Teleprotection compromised with deployment of Ethernet/IP based networks?

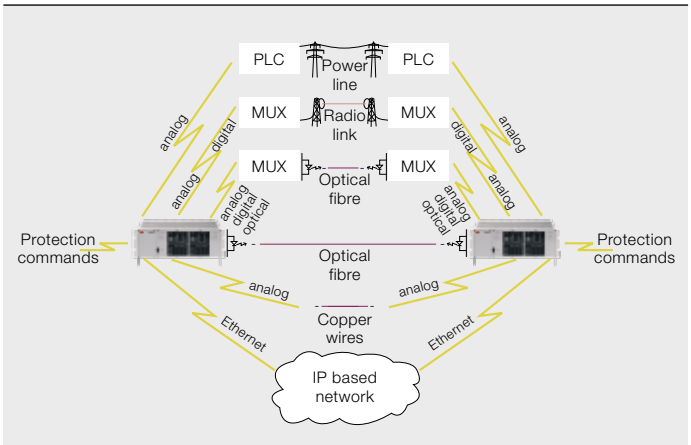
Teleprotection systems rely on telecommunication channels that provide a deterministic signal transmission delay and have a constant bandwidth or bit rate over time, without any delay variation. Static multiplexing techniques such as plesiochronous digital hierarchy (PDH) [1]

Footnote

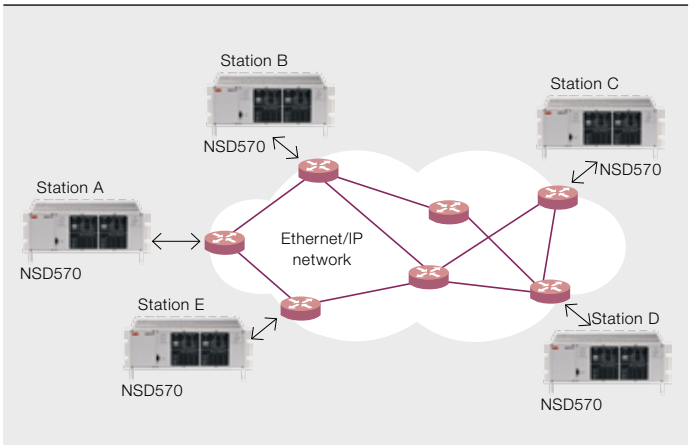
1 A plesiochronous digital hierarchy (PDH) network is a network in which different data streams are nearly, but not quite perfectly, synchronized.

Teleprotection systems normally rely on telecommunication channels that provide a deterministic signal transmission delay and have a constant bandwidth.

3 Transmission media and communication channels available with NSD570



4 The challenge – teleprotection over Ethernet/IP networks



ABB, as leading provider of teleprotection solutions, has developed a new set of interfaces for the NSD570 platform to allow protection signaling and remote management over Ethernet/IP networks.

and synchronous digital hierarchy (SDH) networks comply with this requirement and have been deployed for decades by utilities in their wide-area communication networks.

With the emerging deployment of statistical multiplexing transmission technologies that use bandwidth-on-demand or "best effort" techniques, utilities around the world are concerned that the stringent performance requirements of teleprotection systems might be compromised when using these new communication technologies. This is a particular concern where utilities rely on third-party telecommunication services, for which the communications channels are not under the full control of the utilities themselves.

As a consequence, in situations where Ethernet/IP-based networks are used for protection signaling, a solution is required that allows to monitor the availability and quality of the WAN (wide-area network) communication channel, and to alarm the protection equipment if the reliable transmission of commands to the remote end cannot be ensured ➔ 4.

Innovative solutions for next-generation teleprotection

ABB, as leading provider of teleprotection solutions, has developed a new set of interfaces for the NSD570 platform to allow protection signaling and remote management over Ethernet/IP networks ➔ 2. The innovative solutions consist of the following two modules:

– NSD570 Ethernet WAN Interface type G3LE
– NSD570 Management LAN Interface type G3LM

NSD570 Ethernet WAN Interface type G3LE

– New *line interface* for transferring of up to eight simultaneous/independent commands over Ethernet/IP networks ➔ 3.
– Channel monitoring and alarming functions similar to the existing NSD570 line interfaces (channel quality and availability, end-to-end delay, terminal addressing).

NSD570 Management LAN Interface type G3LM

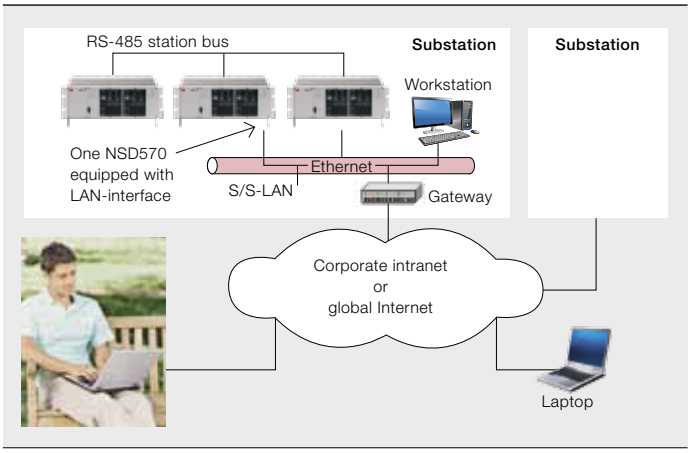
– Successor of existing *management interface* for remote access, with additional features such as SNMP (Simple Network Management Protocol) and VLAN (Virtual Local Area Network) support, improved cyber-security measures such as authentication and logging.
– For the remote supervision/management of the teleprotection units in a rack and further units accessible via the RS-485 station bus. The latter permits several racks to be interconnected ➔ 5.

Both modules offer an electrical port (10/100 Mbps) and an optical port (100 Mbps) with exchangeable small form-factor pluggable (SFP) transceivers for connection to the Ethernet/IP network ➔ 6.

NSD570 Ethernet WAN interface (G3LE) –– reliable protection signaling solution over Ethernet/IP networks

Instead of simply converting the existing synchronous 64 kbps channel of the

5 Secure remote access of NSD570



6 New G3LE/G3LM plug-in module for ABB's teleprotection platform NSD570

NSD570 digital system to Ethernet packets, a protocol was developed in order to *reduce latency and bandwidth requirements*.

Beside the actual teleprotection commands, the payload content of such a packet comprises several data fields that enable the measurement of various key performance parameters including transmission time and packet loss rate.

The entire payload is protected by an authentication algorithm (patent pending), which addresses various cyber-security issues.

Channel supervision continuously monitors quality and availability

A packet-switched network is vulnerable to various factors that can negatively affect transmission time.

The NSD570 Ethernet continuously monitors the channel's availability and quality using "guard" packets that are sent at user-configurable intervals. Alarms are generated if the measured transmission time or packet-loss rate exceeds user-configurable thresholds, or if the channel is lost completely.

Ensure dependable command transmission

As soon as a command is received from the protection relay, the NSD570 Ethernet WAN interface starts sending multiple "tripping" packets at short intervals. This ensures fast reception of packets at the remote NSD570, even under very bad channel conditions (ie, high packet loss). Following this initial sequence, the NSD570 Ethernet continues to send tripping packets, but at the lower rate set for guard-packets. If the command is removed by the protection relay, guard packets are sent from then on.

The reception of only one correct tripping packet at the remote NSD570 trigger the configured relay interface outputs in accordance with the commands received in the packet.

Priority settings for time-critical teleprotection commands

As teleprotection commands are time-critical, they should be transmitted as fast as possible through the network. Both IP and Ethernet offer means to set priorities and handle high-priority traffic accordingly. The NSD570 Ethernet supports Ethernet/IP priority settings with the following parameters: ToS – setting the type of service field on IP layer 3, and VLAN tagging – ID and priority setting of the Ethernet frame on layer 2.

Proven performance under severe network conditions

The worst-case requirement for security (referred to as P_{uc} or probability of an unwanted command) of tripping commands transferred in digital communication systems according to IEC 60834-1 is P_{uc} < 1E-08. For the new protocol implemented in the NSD570, a P_{uc} of < 1E-18 can be proven mathematically.

Comprehensive tests were conducted on the new G3LE type NSD570 Ethernet interface in a network built up of ABB's Ethernet type AFS switch family. Even with simulated burst traffic of varying packet size and traffic overload on sections of the network, the transmission time did not exceed 4 ms, and averaged approximately 2.5 ms.

To verify reliable operation even under severely disturbed Ethernet/IP network conditions, ie, with packet loss rates (PLR) of up to 10 percent and above, the dependability (referred to as P_{mc} or probablility of missing a command) was measured. At various PLR levels, a significant number of tripping commands were sent, the number of commands not received within a specified transmission time (T_{ac}) was recorded and thus the resulting P_{mc} was calculated. For comparison, the measurement of the dependability is based on the bit error rate (BER), which can be derived from the corresponding packet loss rate PLR → 7.

All user activity is logged in order to detect security relevant system manipulations at an early stage.

These test results, in conjunction with additional field trials in utility Ethernet/IP networks, confirmed that ABB's innovative Ethernet WAN interface type G3LE meets and exceeds the requirements as set for "Digital" teleprotection equipment according to IEC 60834-1.

An appropriate Ethernet/IP network design is a prerequisite as is engineering that guarantees the requested maximum packet loss rate and minimum latency.

7 Excerpt of test results (NSD570 Ethernet WAN interface, type G3LE)

Dependability	P_{mc} <	1E-02	1E-02	1E-03	1E-03	1E-04
Channel condition – Packet Loss Rate	PLR <	1%	2%	3%	10%	10%
Channel condition – Bit Error Rate	BER <	1.1E-05	2.3E-05	3.5E-05	1.2E-04	1.2E-04
Max. actual Transmission time	Tac ≤	4 ms	5 ms	6 ms	8 ms	10 ms

Assuring reliable command transmission requires both an appropriate Ethernet/IP network design and a setup guaranteeing the specified packet loss rate and latency between the two NSD570 terminals are not exceeded. If this requirement is not satisfied, NSD570 will immediately report the network impairment.

NSD570 management LAN interface (G3LM) – secure remote connection and monitoring

Together with the G3LE Ethernet WAN interface, a new NSD570 Management LAN interface type G3LM was also introduced, enabling remote access on NSD570 teleprotection equipment over Ethernet/IP networks. The integrated SNMP agent serves network management stations with alarm and equipment information using the open standard SNMP interface.

At the same time, several features were integrated to achieve the highest possible level of cyber security and enable customers to operate the NSD570 teleprotection system supporting new standards such as NERC CIP. A technique called Secure Socket Layer (SSL) is used for encryption and authentication of the user access. Furthermore, a new user administration system now allows individual user accounts to be set up and access rights to be assigned to users individually. All user activity is logged, in order to detect security-relevant system manipulations at an early stage.

NSD570 ready for future applications of IEC 61850

The introduction of IEC 61850 [2], the international standard for substation communication, has driven the implementation of Ethernet-based local area networks in substations.

Currently, IEC 61850 intra-substation Ethernet bus communication is used for control and automation signals only. Protection signals are still hard-wired from relay to relay or from relay to teleprotection device. However, the new NSD570 module type G3LS has been designed to accept "GOOSE messages" [3] according to IEC 61850-8-1 from protection relays with GOOSE interface in future.

Moreover, new IEC working groups have been formed to discuss and define the extension of IEC 61850 for inter-substation communication. In March 2010, a technical report for this WAN communication was released under IEC 61850-90-1 [3].

Solution is fully integrated, ie no external devices that need their own power supply and user/management interface are required.

As per the "gateway approach" described in this report, the GOOSE protection signals in WAN communication can be transferred to the remote NSD570 via any analog, digital/optical or Ethernet channel ➔ 3.

Mixed operation of "legacy" and IEC 61850 protection relays is possible with G3LS GOOSE LAN interface:

GOOSE and contact type commands can be signaled in parallel over the same NSD570 link. Additionally, GOOSE messages from one substation can be released via contact type command outputs in the remote substation.

Acronyms

BER	Bit Error Rate
CIP	Critical Infrastructure Protection
EMC	Electromagnetic Compatibility (EMC)
GOOSE	Generic Object Oriented Substation Events
IEC	International Electrotechnical Commission
IP	Internet Protocol
LAN	Local Area Network
MUX	Multiplexer
NERC	North American Electric Reliability Corporation
PDH	Plesiochronous Digital Hierarchy
PLC	Power Line Carrier
PLR	Packet Loss Rate
SDH	Synchronous Digital Hierarchy
SFP	Small Form-factor Pluggable
SNMP	Simple Network Management Protocol
S/S	Substation
ToS	Type of Service
VLAN	Virtual Local Area Network
WAN	Wide Area Network

Thus, ABB's NSD570, with its open architecture, is ready to evolve in line with both the IEC 61850 standards for intra- and for inter-substation communication.

Summary

With ABB's latest innovations, NSD570 offers a future-proof platform that can be integrated into Ethernet/IP WAN or into a substation LAN network by simply replacing/adding one module. NSD570 is a true all-in-one system for communication line and protection interface requirements.

The solution is fully integrated, ie no external devices that need their own power supply and user/management interface are required.

The large installed base of "legacy" protection relays with contact-type command inputs/outputs can be used over all existing communication media, even in parallel with new IEC 61850 "GOOSE" protection relays via the same NSD570 link. In this respect, NSD570 also supports the step-by-step retrofit of substations with IEC 61850, ie the interconnection of "legacy" substations with IEC 61850 substations via existing NSD570 teleprotection channels.

Customers planning to migrate their WAN communication network infrastructure to Ethernet/IP based networks are well supported by the NSD570 architecture. They can use digital and Ethernet line interfaces in parallel for example, to build up confidence in the new medium. For this purpose, a cost-efficient "1+1" path protection operating mode is provided, with no need to duplicate the relay interfaces to the protection devices. The setup requires only a second line interface for the redundant path, plugged into the same rack.

With the latest innovations of ABB, NSD570 offers a future-proof platform that can be integrated into Ethernet/IP WAN networks or into a substation LAN network by simply replacing/adding one module.

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[2] Protection using Telecommunications, Cigré Joint Working Group 34/35.11, August 2001
[3] IEC publication 61850-90-1 "Use of IEC 61850 for the communication between substations".

Footnotes

2 See also the *ABB Review* Special Report on IEC 61850, downloadable from www.abb.com/abbreview
3 GOOSE: Generic Object Oriented Substation Events is a control model defined by IEC 61850 for transferring event data.

Power on tap

A pumped storage solution to meet energy and tariff demands

STEVE AUBERT – The latest developments in power electronics and machine technologies open a new trend for large hydro pumped storage applications. Pumped storage power plants (PSPP) with variable speed units offer several advantages compared to the conventional fixed speed solutions. Variable speed can be achieved with doubly fed induction machines controlled by AC Excitation systems. These systems feed the rotor circuits of the machines with low frequency three phase currents and control the speed or active power and reactive power of the machines. The pumped storage power plant Avče, in Slovenia, is the first variable speed installation in Europe with a state of the art three-level Integrated Gate-Commutated Thyristor (IGCT) Voltage Source Converter system. ABB Switzerland Ltd's MV Power Converter Systems department provided electrical and mechanical engineering, installation and commissioning of the PCS 8000 AC Excitation system, including an excitation transformer. After the successful completion of commissioning, the unit has been handed over to the customer SENG d.o.o. and has been in commercial operation since April 2010.

The Slovenian power generation mix is provided by approximately two thirds nuclear and coal fired power plants and one third hydro generation, mainly run-off river power plants. These generation capacities supply mainly base load and intermediate electrical energy. Under these circumstances the control of electricity production, according to demand, is difficult to achieve. The country faces a lack of peak energy capacities for covering high demand and over-capacity during low demand periods, especially overnight or during weekends. With a large electricity price gap between peak and low consumption hours, this situation leads to a negative influence on the overall energy price. At the same time, with cross-border connections to Italy, Croatia and Austria, Slovenia is located at the crossroad of international energy flows in the new European transmission operation network. The Slovenian network must bear its share of responsibility for international energy transfer. To satisfy the needs and expectations of consumers, adequate interconnections between regions and sufficient generation capacities must be ensured. For continuity of electricity supply and to prevent blackouts, transmission network rules also have to be respected.

Based on these considerations, Soške Elektrarne Nova Gorica d.o.o. (SENG), an affiliated company of the Slovenian Energy Group HSE (Holdinga Slovenske Elektrarne) d.o.o., decided to invest in the first PSPP in the country. Hydro pump storage facilities offer the possibility of absorbing large amounts of energy during low price periods, especially at nights and during weekends, by transforming electrical energy into the form of potential energy using a pump. In the high consumption periods, when the electricity prices are high, the plant uses the accumulated water to generate electricity. With this storage generation process, nuclear and coal fired power plants can be run at the optimal operating point continuously, even during low demand periods. Costly and inefficient variations in generation set points for steam power plants can so be reduced.

> The main advantage of the variable-speed solution is the possibility for active power regulation in pumping mode.

The location of Avče, near the city of Nova Gorica, at the western border of the country, has the advantage of providing existing low reservoir facilities on the

Title Picture
View on the upper reservoir of the Avče pumped storage power plant, and the landscape.

Hydro pump storage facilities offer the possibility of absorbing large amounts of energy during low price periods. In high consumption periods, the plant uses the accumulated water to generate electricity.

1 The Avče power house located on the Soca river side, looking over the lower reservoir

Soča river, but also a large geological variation in elevation ➔ 1. Additionally the switchgear station connects the powerhouse electrically to the existing 110 kV Northern Primorska loop, which is also connected to a cross-border transmission line to Italy, some kilometers away. The pumped storage power plant will also support the development of conventional hydro generation facilities in the region. To realize the pumped storage power plant, the upper-water reservoir, headrace tunnel, surge tank, pressure penstock and the powerhouse were built. The powerhouse, sitting on the left bank of the Soča River, is made of an 80 m deep powerhouse shaft and an overhead section. Inside the shaft, the reversible pump-turbine and motor-generator are installed with their auxiliaries. The powerhouse building is equipped with the excitation system device as well as circuit breakers, transformers, diesel generator, batteries, mobile cranes, etc.

Optimized pumped storage operation

With the focus on a most efficient pumped storage operation, SENG decided to install a 195 MVA reversible variable-speed unit. This variable-speed pumped storage setup provides several advantages when compared to the traditional solutions with fixed speed. In classic fixed speed solutions with synchronous machines, only the reactive power can be adjusted by the excitation unit. While generating, active power can be adjusted only mechanically, using the guide vane. In pump mode no adjustment of the absorbed active power is possible at all. With a variable-speed solution, the active and reactive powers of the machine are adjusted through the AC Excitation system during both pump and generation operations. This leads to several technical advantages resulting ultimately in economic advantages.

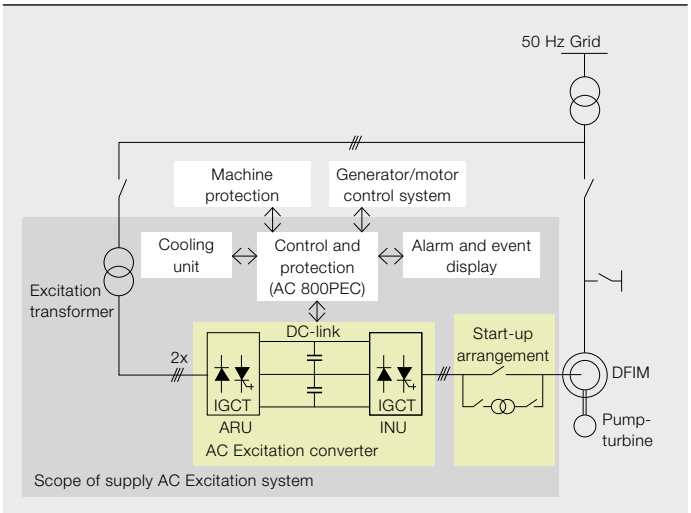
The reversible Francis pump-turbines are usually designed for nominal head and rated machine power. With continuous changes of the effective head, practical operation points with fixed speed are usually operating in the region of, but not exactly on, the design point. Therefore pump-turbines with fixed-speed units usually run below their optimum efficiency. In generator mode, the pump-turbine efficiency can be improved for partial load operation by adjusting the speed according to the required power and actual head. Whereas in pump mode, the pump-turbine can be operated either at optimal efficiency according to actual head or according to available power from grid. This leads to a broader operation range during pump and generation periods, with an improvement of the pump-turbine cycle efficiency of up to more than 77 percent at the Avče pumped storage power plant.

The control algorithms used for rotating frequency converters have been improved continuously for more than thirty years.

The main advantage of the variable-speed solution is the possibility for active power regulation in pumping mode, in the case of Avče within the range of 65 to 100 percent of rated power. The possibility of controlling the absorbed active power in pump mode allows flexible energy storage according to the available power on the electrical network, even though the available power fluctuates depending on the gap between production and demand. This flexibility is a good fit for optimized storage behavior, increasing the amount of stored energy in a similar time, but also reducing drastically the number of start-stop sequences compared to fixed-speed units. In addition, active power regulation allows for contributions to the primary grid frequency control (ancillary service) even in pumping mode. With conventional fixed- speed units this service has to be performed separately by running a generator unit during low consumption and electricity prices. Clearly, generating when energy prices are low is not financially sensible, so variable-speed pumped storage units allow the maximization of economic advantages: generating higher revenues through optimized pump-generation operation and services to the network.

The power regulation of the variable-speed machines will also generally play an important role in the integration of

2 Single-line diagram of AC Excitation system



3 ABB PCS 8000 AC Excitation system in its containerized solution installed in the power house

even larger amounts of wind and other renewable energy sources. Even for those renewable production facilities whose production may be predictable, their production can not be allocated according to the demand. Hydro pumped storage provides the largest and most cost efficient solution for the integration of intermittent generation sources into the actual electrical network. Moreover, additional greenhouse gas emissions from peak energy generation from gas turbine power plants can be avoided.

ABB AC Excitation

The variable-speed pumped storage unit incorporates a doubly fed induction machine (DFIM). Doubly fed induction machines have a three-phase slip ring connection to the wound rotor. By applying low frequency AC currents from the so called AC Excitation system to the rotor, variable-speed operation is achieved. The frequency of the rotor currents is related to the difference between the actual rotational speed and the synchronous speed, dependant on grid frequency. The PCS 8000 AC Excitation actually controls the rotor slip compared to the synchronous speed. At the same time, vector control of the excitation currents allows not only for the speed/active power control but also control of the voltage/reactive power for the machine. This latter control is done similarly by a conventional DC Excitation like ABB Unitrol® for a synchronous machine. The startup/breaking sequence of the machine is achieved with the same PCS 8000 AC Excitation system. No additional starter is required.

Based on the fact that variable-speed units control active and reactive power separately, additional contributions to grid stability can be achieved. Variable-speed power plants do not need any power system stabilizer (PSS) functionality. Active power control of the machine improves stability and enables fast reactions to perturbations from the grid. The variable-speed units act as damping elements for the whole network, which means: absorbing the power oscillations created by synchronous generators. Electronic speed control reduces the response time drastically in comparison to mechanical control by the hydraulic guide vanes equipment. As the speed of the unit does not need to be synchronous to the grid, one could see a variable-speed power plant also as fly-wheel storage for short term phenomena. These superior control capabilities can be utilized to stabilize long transmission lines.

ABB's PCS 8000 AC Excitation

For the Avče project, ABB's scope of supply was the AC Excitation converter, together with its control unit and converter protection, excitation transformer and start-up arrangement ➔ 2. ABB was responsible for engineering, project management, manufacturing and factory acceptance test, as well as installation and commissioning on site. The whole project was realized and conducted from the production site of ABB's Automation Products division based in Turgi, Switzerland. The production site in Turgi is responsible for PCS 8000 AC Excitation systems worldwide.

The AC Excitation was delivered as a containerized solution, including the converter, control and protection cubicle and the water cooling unit ➔ 3,4,5. The whole arrangement was assembled and fully tested at ABB premises in order to provide a reduced installation and commissioning time on site. The control software, including protection functions for the converter and the excitation transformer, were factory checked before commissioning on a real-time hardware-in-the-loop simulator. Once more, this drastically improved the commissioning time on site, avoiding waiting time during test periods.

The ABB AC Excitation system is based on state of the art, three-level, voltage source converter (VSC) topology. Power electronic frequency converters from ABB have a long-standing tradition. The first generation was delivered in 1970s. The VSC technology is used by ABB for several applications such as railway grid interties, static reactive power compen-

Greenhouse gas emissions from peak energy generation from gas turbine power plants can be reduced.

4 View inside the power house with the ABB PCS 8000 AC Excitation system

6 PCS 8000 AC Excitation IGCT converter arrangement inside the container

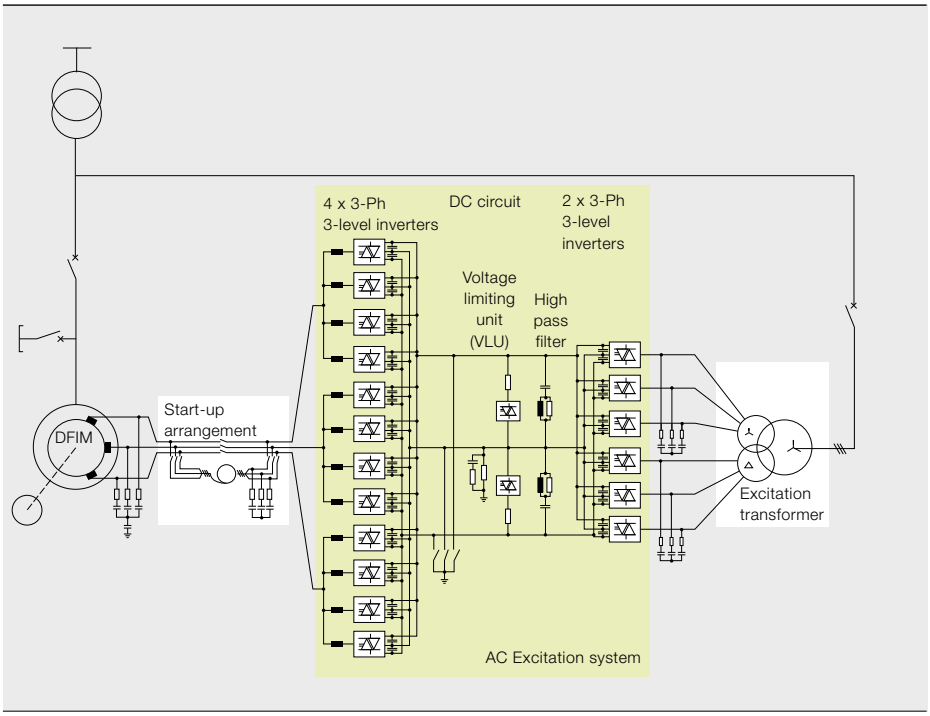
5 AC Excitation Transformer with the 3 bus ducts (yellow on the left) for primary windings supply and the 6 bus connection to the 12 pulse ARU

sators (STATCOM), static frequency converters for energy supply applications and also, since the early 1990s, AC Excitation for DFIM for rotating frequency converters. With more than twenty installed AC Excitation converters, ABB offers a wide range of experience with DFIM applications. The control algorithms used for rotating frequency converters have been improved continuously for more than thirty years. This large range of proven field experience has helped to guide the specific requirements for pumped storage applications and ensures a reliable and safe implementation and operation of the machine. The ABB voltage source converter topology is based on IGCT semiconductor elements assembled in so-called three-level power electronic building blocks (PEBB) → 6. From these PEBBs, the converters are assembled. For the Avče project requirements, the PCS 8000 AC Excitation system setup contains two three-phase systems on the active rectifier unit (ARU) and one three-phase system on the inverter unit (INU) connected by a single DC link → 7. The so- called "12-pulse ARU topology" has typical advantages in regards to harmonics performance. The INU has four phase legs in parallel, in order to supply the required rotor currents for rated operation, including reserve for transient situations. The coupling of the two voltage inverters via a DC link provides a very high operational flexibility. Frequency, voltage and power factor can be controlled independently on both sides, and no reactive power supply to the excitation system is necessary. The DC link is equipped with a voltage limiter unit (VLU). The task of the VLU is to ensure that the DC link voltage is kept within limits.

IGCT semiconductor elements are a leading technology in high power converters because they provide the advantages of gate turn-off (GTO) combined with the advantages of insulated gate bipolar transistor (IGBT) semiconductors. The conducting losses are low, as in GTOs, and the state transitions are comparably fast, as with IGBTs. Due to the monolithic structure, IGCTs show the same overload behavior as thyristors and GTOs. In case of a semiconductor failure, the current will establish a conducting channel in the silicon wafer. Under fault conditions this behavior ensures the mechanical integrity of the semiconductor housing, as well as the conducting path for the rotor circuit in variable speed applications, avoiding dangerous rotor overvoltage. Not all other semiconductor types available on the market tend to show the same fail-safe behavior.

The control system of the AC Excitation is based on ABB's AC 800PEC platform, specially designed for high-speed control of power semiconductors. The control cabinet contains the AC 800PEC controller hardware as well as all the necessary I/O devices from/to generator/motor control system, AC Excitation converter, excitation transformer, cooling system and voltage/current transform-

7 Detailed diagram of the PCS 8000 AC Excitation system with its single DC Link unit for improved system stability and optimized footprint



8 The dam and the beautiful countryside around the Avče power plant

ers. The AC 800PEC controller belongs to ABB's widely established 800xA family, and combines a very powerful CPU and large field-programmable gate array, which suits the AC 800PEC to control demanding power electronics systems.

As the speed of the unit does not need to be synchronous to the grid, the variable-speed plant can act as short-term fly-wheel storage.

The ABB control algorithms comprise loops for speed/active power and voltage/reactive power controls, DC link control, startup/braking and synchronization sequences, as well as control of the system auxiliaries, such as water cooling units, cooling fans, etc. Furthermore, the AC 800PEC (control PEC) manages the communications with the superimposed unit control system and the excitation/governor control, providing the operation set points. The monitoring and protection of the converter and excitation transformer are programmed in a separate AC 800PEC (protection PEC) controller. Nevertheless, in order to ensure the safety of the equipment, the main protection functions are programmed as a backup in the control PEC as well, providing redundancy for the main protection scheme.

By means of a service PC, all necessary software maintenance and diagnostics are possible by local by ABB personnel or, with an appropriate internet connection, also from remote locations. This remote access function allowed ABB to actively support the double feed induction machine tests, performed on site during commissioning of the motor-generator, from the office. ABB could set power and speed set points according to on-site test requirements which were simply given by phone. This reduced the number of ABB specialists on site therefore reducing the cost of commissioning. The startup/braking sequences of the machine are achieved with the same PCS 8000 AC Excitation system and no additional starter equipment is required. The startup function in motor mode is fully integrated in the PCS 8000 AC Excitation software, as well as the synchronization and the breaking sequences. A start-up unit, increasing the rotor voltage during start-up phase is installed. This allows the machine to start-up and to synchronize in less than four and a half minutes for pump operation. In generator mode, the process is similar to synchronous machines. Nevertheless, in both cases, as the motor/generator is an asynchronous machine, the synchronization of the unit does not have to take place at synchronous speed. Only the stator voltage and the phase's angle difference on both sides of the generator breaker must be considered.

All round beauty

The variable-speed pumped storage power plant at Avče, with ABB's PCS 8000 AC Excitation voltage source converter equipment, brings very important benefits to the site operator SENG d.o.o. and the grid operator. It matches perfectly the electrical network requirements, the geographical situation and the economic aspects → 8. It produces peak energy shifted from low demand periods, offers flexibility of operation in the open electric energy market and provides primary reserves for network control service, in the mean time stabilizing energy transmission lines around the site. With its fast startup time in turbine and pump mode, the DFIM at Avče is, even when offline, set as the stand-by unit by the network operator, ready to start instantaneously in case of any sudden unbalanced situation in the network. Unquantifiable benefits are also provided by the tourist development on the upper reservoir area which increases the attractiveness of the beautiful countryside in this region of Slovenia.

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Intelligent application

Applying intelligent equipment to bring increased benefits to power distributors and residential customers

PETR GURYEV, ENRICO RAGAINI – Stockholm Royal Seaport is one of the first large smart grid projects in Sweden. An urban area of three districts, including the port, will be rebuilt based on new smart city criteria. Local generation of renewable energy, life in smart houses and the use of electric vehicles (EV) are only some of modern technologies which will be used for the sustainable city. ABB is working together with Fortum, one of the biggest Nordic heat and electricity production and distribution companies to help redesign the approach to power distribution. Fortum is exploring the different possibilities for this project which now exist because of the smart grid. A typical need in projects such as this is for a cost/benefit analysis, in this case, of smart grid technologies which can be used to improve network reliability and reduce downtime. Such analyses show that the benefits of intelligent equipment in terms of reduced profit losses and penalties justify the capital investment expenditure.

With changes to legislation in Sweden and regulations becoming stricter generally across Europe, distribution companies must now solve outage problems in the distribution networks more quickly. The frequency and length of power interruptions are typically measured using the system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) reliability indicators. The fewer and shorter the power interruptions, the lower the indexes are and the less penalties and compensations a distribution company has to pay.

Design criteria for the Stockholm Royal Seaport project include improvements of the power supply quality and reductions in power interruptions. In the development of the project, the following requirements were used:

- Load shedding to avoid blackouts when the power system is in a critical condition
- The possibility to avoid outages due to overload

Title Picture
Artist's impression courtesy of City of Stockholm and Aaro Designsystem

1 Comparison of LV substation solutions

Summary	Traditional design (no supervision, no redundancy)	Breakers/switches with supervision /control	Redundant feeders with advanced selectivity and supervision/control
Simplicity	+	-	-
Initial investment	Very low	Moderate	High
Time for fault identification	Long	Short	Short
Time for power restoration	Very long	Long*	Very short
Remote monitoring	–	+	+
Remote control	–	+	+

* - depends on the configuration of the circuit breaker, use of parallel breaker and type of the outage

Remote monitoring and remote control of equipment brings a significant reduction of outage time in many situations.

– Minimum consequences from short circuit outages
– Minimum cost of ownership (including initial equipment purchase, operation, maintenance and malfunction compensation)
– Short payback period

Improving on the traditional

Traditional low voltage (LV) installation designs have inherent advantages and disadvantages. The traditional design of a medium voltage (MV) and LV transformer station for non-industrial customers is typically based on fuses, which protect each of the outgoing LV feeders, and generally radial feeders are used. The advantages of this design are the low cost and reliable protection from short circuits and overloads. On the other hand, due to a lack of remote supervision and control, manual power restoration is required which can sometimes take a long time. In fact, that a fault has occurred may remain unknown to even the operator for several minutes or even hours.

Alternative design schemes employ electromechanical circuit breakers instead of fuses, which in some cases results in better coordinated protection. Larger stations may use two transformers instead of a single one. All such “traditional” designs can also suffer the consequences of manual fault management and a lack of supervision.

However, traditional designs can be improved by modern technologies, particularly in the field of electronics and communication. In smart grid applications, such as at the Stockholm Royal Seaport, LV network design employs apparatus and switchgear with remote monitoring and remote control. In addition, power system design is based on redundant feeders with advanced protection coordination.

Remote monitoring and remote control of equipment brings a significant reduction of outage time in many situations. In case of a short circuit, information about the fault is immediately transmitted to the operator, who can then take action. Transmitted information can include data about fault currents and voltages, which are useful to locate the fault. In addition, remote supervision allows optimized operation of the power system. In case of overload or in a situation close to a blackout, when power consumption becomes too high, some loads can be disconnected. Power produced by renewable sources, such as solar panels, can be monitored in real-time.

Remote supervision allows optimized operation of the power system.

A wide range of ABB products are available for the remote control and supervision of LV networks, such as power meters that can communicate, which can be installed together with electromechanical breakers or fuse switches. Such a solution is especially good for retrofitting existing substations. One innovative solution, which offers the maximum compactness, is the circuit breaker with integrated power measurement unit. The

2 ABB's Tmax XT4, designed for smart grid applications

unit includes protection, measurement and communication all in a single item.

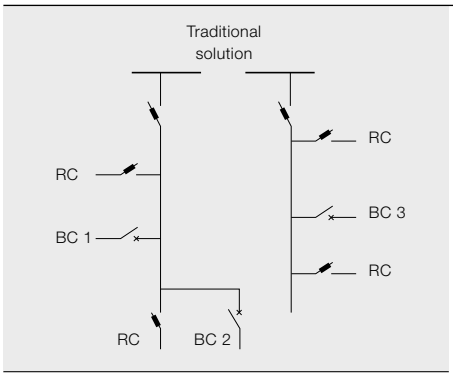
Remote monitoring can reduce detection time and time to power restoration. However, in case of a short circuit power may not be restored until a repair crew has identified and removed the cause of the fault. In a traditional design, radial feeders offer no redundant path for power: if a fault occurs in one portion of the feeder and is then cleared by the relevant protection device, all of the downstream part of the feeder is disconnected from the power, potentially blacking out several customers. Since it is now also required that the number of customers affected by the fault be minimized, a specific design strategy based on new technologies such as redundant feeders and advanced circuit breaker protection can be applied to achieve this. Significant improvements can be achieved if redundant feeders are used in the design of the LV network because two alternative paths become available to connect any given customer to the power system. Plus, each feeder is split into sections, separated by breakers or switches. Only the sections where the fault occurs will be disconnected from the power. Together with the advanced selectivity schemes implemented by intelligent circuit breakers, this design makes it possible to restore power in a very short space of time to all the loads which are not directly connected to the faulty section of the feeder ➔ 1.

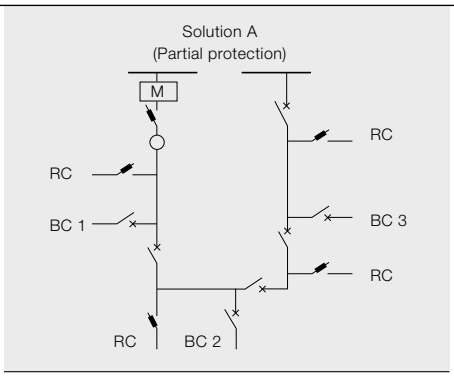
Redundant feeders are normally used in MV distribution, where feeders designed as rings that can be fed from both ends are common. Each feeder is split into segments, separated by circuit breakers or switch-disconnectors. The feeder can be operated as a closed loop, ie, with all breakers closed, or as an open loop ie, with one of the breakers open, which actually creates two radial feeders, each fed by one of the end stations. When a short circuit is detected, depending on the fault location,only a defined subset of circuit breakers open, so that the faulty section of the feeder is disconnected from the power system, while keeping all the other loads connected.

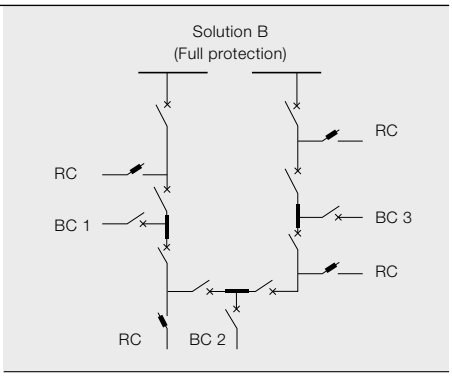
Closed loop operation provides the maximum operational advantage in terms of reduced outage time. It makes it possible to automatically identify and disconnect the faulty section of the feeder, without any power interruption

Significant improvements can be achieved if redundant feeders are used in the design of the LV network.

3 Traditional and suggested designs for the LV substation and distribution network







4 Share of outage consequences in comparative scenarios

Outage type	Expenses in case of outage %	Traditional solution	Solution A	Solution B
Overload	Compensation to residential customers	50 %	0 %	0 %
	Compensation to business customers	50 %	0 %	0 %
	Repair crew work	100%	0 %	0 %
Short circuit	Compensation to residential customers	50 %	33 %	33 %
	Compensation to business customers	50 %	33 %	0 %
	Repair crew work	100%	100%	100%

Breakers are able to identify where a fault has occurred and disconnect only that specific part of the network.

to all the remaining sections of the feeder. This requires protection elements with directional sensing, which is becoming more and more common in MV installations.

In order to gain similar advantages for LV feeders, circuit breakers with directional protection and logic interlocking can be used. Each breaker recognizes the direction of the fault current and sends a trip block signal, ie, a signal that prevents opening, to the upstream breaker. The blocking signal is then propagated from one breaker to the next, all the way up to the feeding station. The breaker directly facing the fault receives no blocking signal, hence it immediately clears the fault. If the feeder is powered from both ends, the same occurs in both directions. The final result is that the two breakers immediately facing the fault open, while all the other breakers remain closed, maintaining power to all loads not directly affected by the fault. LV breakers with directional protection and logic interlocking are technology that is exclusive to ABB. Originally designed for critical power applications such as marine installations, this technology is now finding new applications as a building block of smart grids. Integrated directional protection is available in all of the ABB LV air circuit breakers, such as the Emax E1 to E6 and X1, with a minimum rated current of 630A [1].

The most critical requirement to reduce unnecessary blackouts and minimize the consequences of any faults, is selectivity. In other words, the ability of breakers to identify where a fault has occurred and disconnect only that specific part of the network. The is a very challenging requirement, particularly for smaller feeders, where molded case circuit breakers are typically preferred, due to their compact size , reduced interruption time, and more efficient limitation of fault energy. Until recently, no zone selectivity system existed for such devices. In order to prevent breaker trips, fault detection and signal processing should take place in less than 1 ms, which was not feasible for existing embedded protection units.

A recent major breakthrough in LV technology was the development by ABB of a dedicated protection system with fast interlocking, which allows breakers to automatically identify and disconnect the faulty section of the feeder in less than 5 ms. This protection, called early fault detection protection (EFDP), is available on Tmax moulded case circuit breakers T4 to T6, rated 250A to 1000A → 2. When EFDP breakers are used, zone selectivity is ensured. Each breaker which detects a

short circuit sends a trip block signal to the upstream ones, ensuring that only the breaker directly facing the fault will open. In turn this reduces, as much as possible, the portion of the network which is disconnected from the power system.

Business case and payback time

During the pre-study phase of the Stockholm Royal Seaport project, ABB developed a decision tree of several business case scenarios for feeder automation solutions based on customer profiles and the functionality required.

To illustrate one of the business case scenarios, show its benefits and estimate the payback period, the following assumptions were made about outage related expenses. These expenses can be partially or fully avoided:

Compensation to business customers

Assuming that a business customer is either a corner shop or a small restaurant the normal working day of the business customer will be at least 12 hours. This means that it can have a maximum amount of 12 hours power loss a day. The compensation to business customers will be among the biggest of all the potential expenses, which can be partially or fully avoided by the solution.

If the outage can be avoided, repair crew work will not be necessary.

Compensation to residential customers

Assuming that there will be residential customers that will require compensation according to the legislation of Sweden, this applies if the outage is longer than 12 hours. The value of the compensation for residential customers is fixed and moderate in the scope of the overall avoidable expenses.

Maintenance crew work

If the outage can be avoided, repair crew work will not be necessary. The value of the repair crew work is moderate, but accumulates for every hour of the outage length and is the second biggest cost in the range of overall avoidable expenses.

Advanced feeder automation for LV substation and distribution network

To meet the requirements set by the project, two possible designs for the LV substation and distribution network were suggested → 3. The suggested designs have the lowest possible price and meet the set requirements.

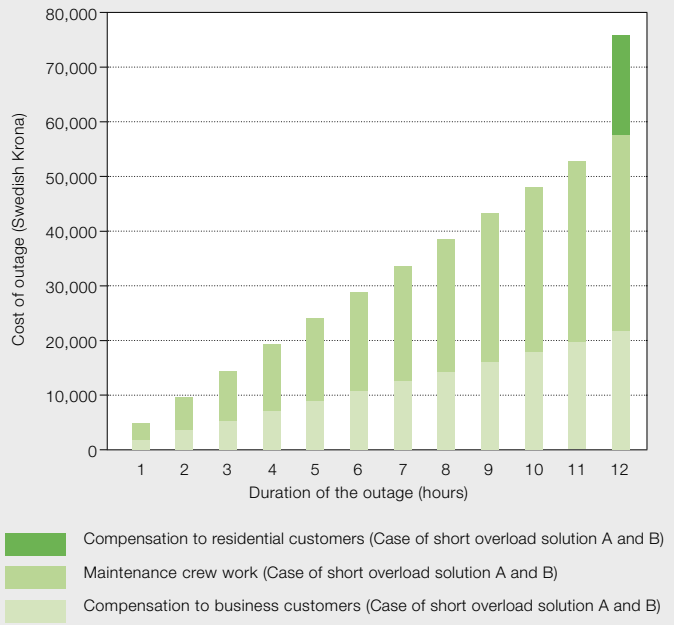
The traditional scenario is used here as a comparison against the advanced feeder automation solutions A and B. Three business customers are shown in the traditional scenario, which are located in two non-redundant feeders. A distribution company is not required to compensate for outages caused by customers, but has to compensate if it was a result of a damaged cable supplying the customer. If a short circuit or overload happens in any section of any feeder, the average compensation a distribution company will pay is 50 percent of overall compensation if all three business customers lose power.

Solution A illustrates the design of the redundant feeder, with junction boxes used for the connection of redundant feeder sections. This solution gives full protection from overload and partial protection to business and residential customers from short circuits, meaning that outages can happen in one of three sections of the redundant feeder and only residential and business customers in this section will lose power. Thus the average compensation paid to both residential and business customers will be only 33 percent of the potential total compensation if all customers had lost power.

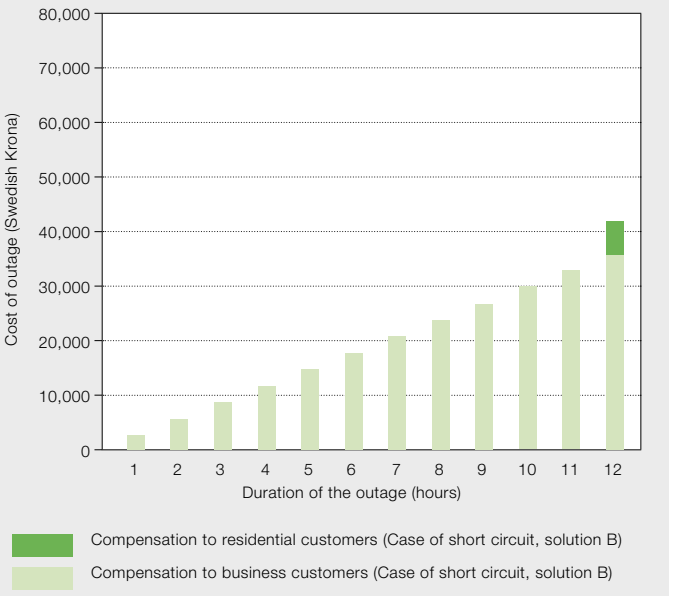
Solution B illustrates the design where business customers are connected to the redundant feeder by means of small kiosks with bus bars. Two infeed circuit breakers are used in each kiosk, allowing each busbar to be supplied in both directions. In addition, intelligent breakers with directional protection are used all the way to the feeder station. This solution also gives full protection from overload, partial protection from short circuits to residential customers, and full protection to business customers. The possibility of a short circuit on the busbars inside the kiosk is

Breakers using EFDP send a trip block signal to the upstream ones, ensuring that only the breaker directly facing the fault will open.

5 Cumulative expenses which can be avoided if outage lasts from 1 to 12 hours, when applying solution A or B



6 Cumulative expenses, which can be avoided if outage lasts from 1 to 12 hours, when applying solution B



Selection of the appropriate solution is based on the likelihood of the different kinds of faults, and on the amount of compensation to be paid in each case.

generally very low. If a short circuit happens in one of three sections inside of redundant feeder, the distribution company will pay to residential customers an average of 33 percent of the potential total compensation if all customers had lost power and no compensation at all would be payable to business customers.

A summary of the outages and compensation paid by a distribution company applying different solutions are shown in figure ➔ 4.

Selection of solution A or B for a specific installation is based on the likelihood of the different kind of faults (overloads versus short circuit), and on the amount of compensation to be paid in each case. In case of a short circuit, solution A will result in much longer outage times for business customers on average, compared to solution B, so solution B may be preferable. While both solutions are substantially equivalent for overloads. If the network has a low probability of short circuit because, for example, the cables are installed in conduits with physical protection, and probability of overloads is high, solution A can be advised. These factors have to be weighed against the cost of the equipment, which is lower for solution A.

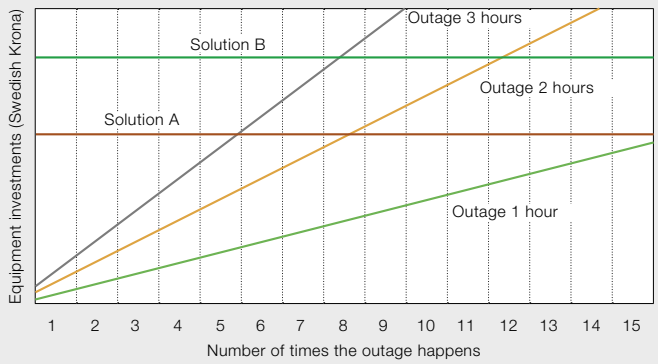
According to the business case assumptions, a summary of cumulative expenses which a distribution company can avoid in case of overload, applying solutions A or B in comparison to the traditional solution, are shown figure ➔ 5.

Cumulatively avoidable distribution company expenses that can be gained from applying solution B, in the case of a short circuit, when compared against the traditional scenario, are shown in figure ➔ 6. If the network has no business customers, or business customers who are only due small compensation in case of power loss, the recommendation is to apply solution A.

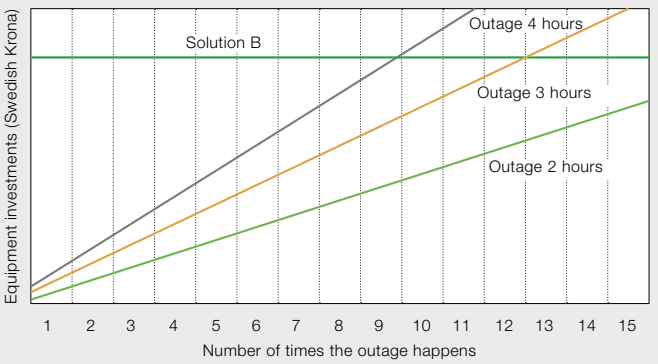
Payback period

To assess the payback period of the equipment it is important to bear in mind that the business case is based on the risks factors of if and how often a certain type of outage can happen. For existing networks with low power quality indexes, a historical record of outage types and lengths can be used to understand the expected payback period. In this case, by applying solution A or B, a distribution company will have as many outages as in the past but will reduce the financial consequences. The overall payback period of the equipment depends on frequency and length of the outages, which occur in a particular redundant feeder in case of overload ➔ 7. The payback period for applying just solution B in case of short circuit is different when compared

7 Payback period of solutions A and B by avoiding overloads of different lengths and frequency



8 Payback period of solution B by avoiding short circuits of different lengths and frequency



to evaluating solutions A and B together because of certain unavoidable losses ➔ 8. The illustrated payback periods depend on the number and type of customers located on the redundant feeder and price of the equipment. The assumptions made about customers are considered to be typical for the Swedish market. The assumptions also use list prices for the equipment which means that the overall payback period could decrease significantly depending on any discount that a customer negotiates when purchasing the equipment. A decision to apply advanced feeder automation solution A or B is always based on an outage risk assessment. However, when it is appropriate to apply solution A or B, the offered solution brings "insurance" to the distribution company, that in case of any outage, compensation, penalties or expenses will be either avoided or significantly reduced.

Applying intelligent technology in the scenarios considered for the Stockholm Royal Seaport project brings savings and reliability advantages for the power distributor.

The suggested advanced feeder automation solutions have a relatively short payback period and can significantly increase the power quality indexes of existing LV distribution networks. Such solutions fit very well to the needs of smart grids, allowing remote monitoring and control together with high reliability and minimum consequences from outages. This type of solution is recommended for grids with a high probability of overloading and high compensation costs to business customers in case of outages. The equipment has a life time of 20 years, which makes it a worthwhile and significant improvement for LV networks, and with a relatively fast payback period which is not typical for this type of power distribution equipment. Applying intelligent technology in the scenarios considered for the Stockholm Royal Seaport project brings savings and reliability advantages for the power distributor, but of course enables residential customers to go about their lives and businesses with the minimum of power supply disruption.

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[1] Viaro, F. Breaking News: User-Friendly products that satisfy new customer requirements and reduce environmental impact. *ABB Review* 3/2004, 27–31.

Further reading

More information on EFDP protections is available in ABB Technical Application Paper, "Low voltage selectivity with ABB circuit-breakers", document number 1SDC007100G0204.

Software architectures that last

Intelligent software architectures create value and safeguard product investments in the short, medium and long term

ALDO DAGNINO, PIA STOLL, ROLAND WEISS – **The proportion and complexity of software in almost all ABB products is now higher than at any time in the past – a trend that is accelerating. Indeed, some products are purely software. As such industrial software has become ever more sophisticated, and critical, its long-term maintainability and sustainability have become very important factors for a good return on investment over its entire lifetime. Therefore, it is essential that it is founded on an appropriate and durable architecture.**

The world in which we live is based on an incredibly intricate spider's web of technology: Our power grids delicately balance a huge range of generation and distribution assets and effortlessly provide us with guaranteed power at the flick of a switch; a fantastically complex chain of technological wonders transports an oil molecule from a subsea reservoir to the nozzle of the pump at our local gas station; every item we buy and consume reaches us through a amazingly complex series of co-ordinated actions, mostly hidden to us. As individuals, we directly interact with only the tip of this technology iceberg.

ABB supplies many of the products which, unseen, provide this material structure of our society. At the heart of much of this, by now often essential, infrastructure is software. And the proportion and complexity of this software is now higher than ever before – a trend that shows no signs of abating, quite the reverse, in fact.

Some ABB products are purely software. In others the software and hardware components work together intimately and in yet others the software is embedded in the product hardware itself. They are found in almost all applications in the industrial world: in utilities, in process industries (such as pulp and paper, oil and gas, petrochemical, pharmaceutical, chemical, etc.) and in all kinds of manufacturing plants.

Such a high degree of software content makes products very adaptable, imbues them with powerful decision-making capabilities and fosters a higher degree of system autonomy. This has, in turn, shifted the operators' role from one in which they use their expertise to manually set control values, to one of supervision, fine-tuning and fault finding. A modern industrial system can nowadays control a process with minimum operator inter-

> To obtain a compelling return on investment, an industrial software-intensive system must be fully sustainable over decades.

Title Picture
Sophisticated software lies at the heart of much of the seen and unseen technology which supports our daily lives. Under the surface of this cityscape, for instance, is an entire world of complex and indispensible software systems. But whether the system is a building management software controlling a 100-storey building or a global share trading package running in one of the companies housed there, they all have one essential quality in common: a solid and robust software architecture.

The architects need to have an understanding of how the stakeholders' evolving business environment can influence software architectural requirements.

vention and autonomously interact with a multitude of other systems in the plant.

Further functional synergy is created when software components interact with each other in a way the hardware parts could not. In short, all this software content creates significant additional value for ABB's customers.

However, there is one very critical aspect of such a sophisticated software system: its maintainability and sustainability. To obtain a compelling return on investment for both the customers and the development organizations, an industrial software-intensive system must be able to be maintained in a cost-effective way and stay operational, in a fully-supportable way, for decades, ie the system must be fully sustainable.

Over such a long time, this sustainability will face challenges: new, and perhaps radically changed, technologies; new stakeholder requirements; new organizations and re-organizations; key expertise emigration; and changing business goals. In addition, software-intensive systems often have an inherent legacy heritage that significantly impacts software architecture and design going forward. If the organization in the past accurately predicted today's stakeholders' needs and adapted the development to suit, the incorporation of today's concerns in the system should be fairly straightforward. In the same fashion, today's organization should predict future stakeholders' needs and select the most important concerns to address.

To do this, the architects need to have an understanding of how the stakeholders' evolving business environment can influence software architectural requirements. For example, industrial software-intensive systems are often impacted by company mergers and acquisitions, where two or more systems have to be consolidated into one or perhaps share a core part.

Furthermore, stakeholders can include customers, end users, developers, project managers, product managers, maintainers and others, each with different and often conflicting expectations. The architect must reconcile these and balance them with technical and economic constraints.

Sustainability is, therefore, related not purely to software structures and their interactions but also to their environment in terms of enterprise aspects such as organization, business, tactics and scope [1].

To meet all the challenges described above and thus preserve the integrity of sophisticated software systems over, potentially, many decades, one very important prerequisite must be fulfilled: the systems must sit on a very solid software foundation. And this is where the role of the software architect becomes crucial.

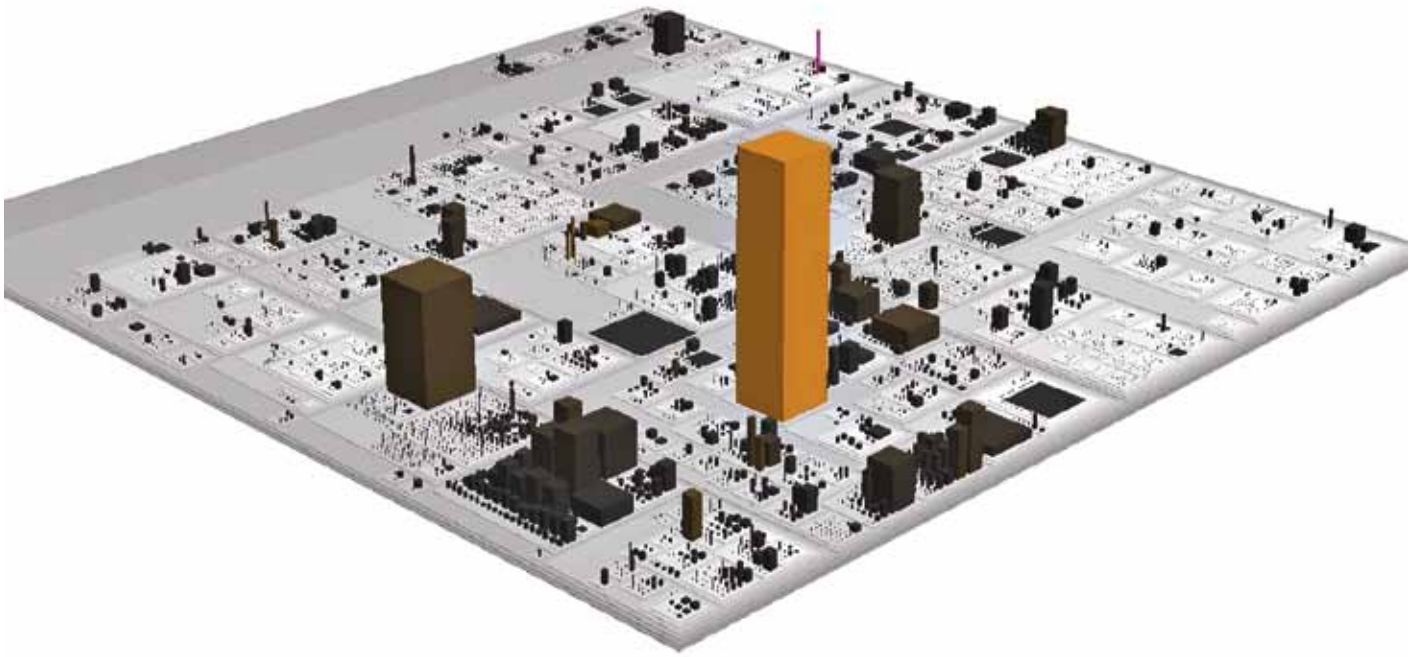
Software architecture

The study of software architecture is, in large part, a study of software structures and their interactions. This began in 1968, the year in which the term "Software Engineering" was introduced when Dijkstra presented his work with the THE-multiprogramming system. Dijkstra showed a layered software structure that supported the testability quality of the system, thereby connecting the software quality "testability" to software architecture structures [2]. Twenty years later, Shaw described different architecture styles [3]. She wrote:
"... important decisions are concerned with the kinds of modules and subsystems to use and the way these modules and subsystems are organized. This level of organization, the software architecture level, requires new kinds of abstractions that capture essential properties of major subsystems and the ways they interact". Shaw describes common ways to solve specific problems and concepts to solve a particular problem. An example of the latter is the "Blackboard" architectural model, where a common knowledge base, the "blackboard", is iteratively updated by a diverse group of specialists, starting with a problem specification and ending with a solution. This was applied, for example, to solve early software problems in speech recognition.

"We shape our buildings; thereafter they shape us".

WINSTON CHURCHILL, TIME, SEPTEMBER 12, 1960

1 System architecture and code visualization using the city analogy



On the formal side, the ISO/IEC 42010:2007 standard defines system architecture as: “The fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution”.

Software architecture can be visualized as if the constituent components were buildings in a city. In the physical world, a secure building could, for example, be realized by allowing only one road, guarded by a watchman requiring a password, to lead to it. The software corollary would allow only one access possibility, from secure, authorized sources, to a software component. Software architecture researchers are constantly seeking innovative ways to design their “city plans” in order to positively influence software usability, security, performance, reliability or energy efficiency.

This “city” analogy has indeed been used in architecture visualization, where components/packages are represented by districts and classes by buildings whose sizes are determined by code metrics, eg code size or cyclomatic complexity (codecity.inf.usi.ch) ➔ 1.

Architecting a system is a process because a sequence of steps is prescribed to produce or change the architecture within a set of constraints. Architecting a system is a discipline, too, because a body of knowledge is used to inform practitioners as to the most effective way to design within a set of constraints. System architecture is primarily concerned with the internal interfaces between the system’s components or subsystems and the interface between the system and its external environment, especially the user.

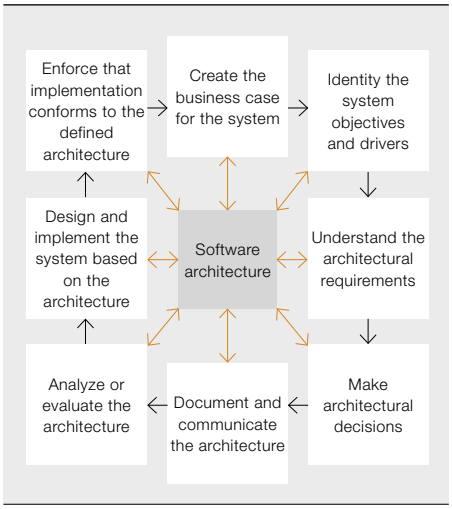
Architecture patterns of ABB’s industrial software systems

Christopher Alexander is a building architect researcher. In the book “The Timeless Way of Building”, published 1979, he describes common architectural patterns in space, events and human existence, at all levels of granularity. According to Alexander, “each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution”.

Alexander’s thinking regarding building patterns has inspired many of the software community’s architects. Software architecture patterns describe the core of a solution to software problems that occur over and over again. While Alexander focuses on the usability quality, namely the user’s experience of the building, the software architecture patterns address software qualities, such as

Software architecture can be visualised as if the constituent components were buildings in a city.

2 Software architecture methodology.



3 Graphical user-interface

security, performance, reliability, availability, maintainability and so on.

ABB's industrial software systems exhibit different types of architecture patterns. Some commonly observed ones include: client-server, event-driven, multi-tier and data-centric. These are briefly explained below.

Client-server

Client-server computing is a distributed application architecture that partitions tasks or workloads between service providers (servers) and service requesters, called clients. Often clients and servers operate over a computer network on separate hardware components. A server computer is a high-performance host that runs one or more server programs that share its resources with its multiple clients. A client does not share any of its resources, but requests a server's content or service function. Clients therefore initiate communication sessions with servers which await the incoming requests from the clients [4].

Event-driven architecture

An event is defined as a significant change in a particular system state, eg incoming information from I/O components. Event-driven architecture may be applied by the design and implementation of systems that transmit events among loosely-coupled software/hardware components and services. An event-driven system typically consists of event generators and event consumers. Event consumers have the responsibility of instigating a reaction as soon as an event is presented. Such an architecture facilitates more responsiveness because event-driven systems are, by design, more normalized to unpredictable and asynchronous environments [5]. Many ABB systems operate in such a way that external input is continuously received, processed and appropriate actions are taken, eg process control or manufacturing.

Multi-tier architecture

Multi-tier architecture, or n-tier architecture, is a client-server architecture in which the user interface, the system processing capability and the data management are logically separate processes. For example, middleware which services data requests between a user and a database employs multi-tier architecture. The most common is three-tier architecture. The concepts of layer and tier are often used interchangeably, though many subscribe to the view that a layer is a logical structuring mechanism for the elements that make up the software solution, while a tier is a physical structuring mechanism for the system infrastructure [6].

> Software architecture evaluation and development at ABB is framed by important principles constituting an established methodology.

Data-centric architecture

Here, databases play a central role as such systems typically use a Database Management System (DBMS) as a major system engine. These contain a set of stored procedures that run on the database servers and have table-driven logic. The database-centric approach primarily leverages the indexing, transaction processing, integrity, recovery and security capabilities provided by high-end database systems [7].

Software architecture principles employed at ABB

Software architecture evaluation and development at ABB is framed by important principles which constitute an established methodology [8] → 2:

Create the business case for the system

The business case constrains requirements and provides a guide for determining the software qualities.

Identify system objectives and drivers

Guided by the business case, a system's objectives and primary drivers have to be identified, eg in a Quality Attribute Workshop. These drivers have to be taken into account when analyzing the system requirements and when making architectural design decisions.

Understand the architectural requirements

These have typically two components: the functional and the non-functional (or quality) elements. Architectural functional requirements define the basic functionality of

4 Mission critical system

the system and the architectural non-functional requirements, or quality attributes, define the behavioral and quality requirements, eg usability or performance.

Make architectural decisions

The desired quality attributes of a system determine the shape of its architecture. Specific tactics that address these are embedded in the system.

Document and communicate the architecture

To be an effective element of the software design, the architecture needs to be clearly documented and efficiently communicated to all relevant stakeholders, bearing in mind the diversity of their backgrounds (developers, testers, customers, managers, etc.) This documentation should also illuminate the decision-making process which leads to the target architecture.

Analyze or evaluate the architecture

The software architecture must be evaluated for the qualities that it supports to ensure the system satisfies the needs of the relevant stakeholders. Scenario-based techniques are effective tools to evaluate software architectures.

Design and implement the system based on the architecture

Having a well-documented and clear set of architecture documents is imperative for software designers and developers to remain faithful to the defined architecture.

Ensure implementation conforms to the defined architecture

The culture of the organization should support the maintenance of both the code and the architecture, especially once the system is in maintenance mode.

Use of software architectures methodology at ABB

The methodology described in → 2 is used at ABB in different ways. Firstly, to evaluate if the architecture of a current product still meets the quality attributes that the market expects, especially as customers' expectations evolve over time. Secondly, to evaluate new and emerging technologies that could be employed to re-develop or enhance an existing product. Thirdly, to develop a new or revised product architecture to meet the quality attributes and functionality expected by the customer. Finally, the architecture methodology can be employed to verify and validate a newly-created product architecture by evaluating the architectural scenarios generated. Examples of these four cases are provided below, based on projects conducted by ABB Corporate Research together with various ABB Business Units.

Evaluate architecture of existing product

The Architecture Tradeoff Analysis Method was developed by the Software Engineering Institute (SEI) in Pittsburgh, USA. ABB employs the method to evaluate architectures of both new and existing software products. The strength of the method lies in the analysis result, which shows how different quality attributes trade-off with each other and what business case they support. In the case described here, the ATAM review's customers had questions related to the usage of a code-generating tool for embedded code modules. It was not clear if

The culture of the organization should support the maintenance of both the code and the architecture.

The business goals and benefits to the customer of replacing the GUI included reduction in maintenance costs, enhancing the system's scalability and improving the system's performance.

the tool produced code modules that were optimized for performance, since the developers of the tool's generation engine had focused on the portability of the code modules.

However, by using the ATAM it was possible to demonstrate to the customer that the tool's generation engine produced code with an architecture that could be slightly more performance-efficient, at the cost of being less portable. The ATAM review of the customer's business case showed that the portability was no longer prioritized in the same way as it was at the time of the tool's development. This showed the customer that they could target optimization of the software's performance instead of software portability without losing business.

Evaluate emerging software technologies

Yet another project evaluated emerging software technologies that could be used to create a new, replacement Graphical User Interface (GUI) ➔ 3 for an operations management software system. The business goals and benefits to the customer of replacing the GUI included reduction in maintenance costs, enhancing the system's scalability and improving the system's performance. All these directly translated into the software qualities employed to create architecture and technology options and evaluate them. An analysis of the system architecture associated with the selected technologies was conducted. A set of architectural requirements was elicited in conjunction with the business unit that guided the evaluation of these technologies. A subset of the requirements identified was selected together with the business unit and this subset was used to create a scenario which was, in turn, employed to evaluate the technologies through the development of prototypes. Based on the results obtained in the creation of the prototypes, two competing technologies and corresponding architecture options emerged, one of which was eventually chosen after a subsequent prototype stage.

The customer saw that they could target optimization of the software's performance instead of software portability without losing business.

Develop new architecture

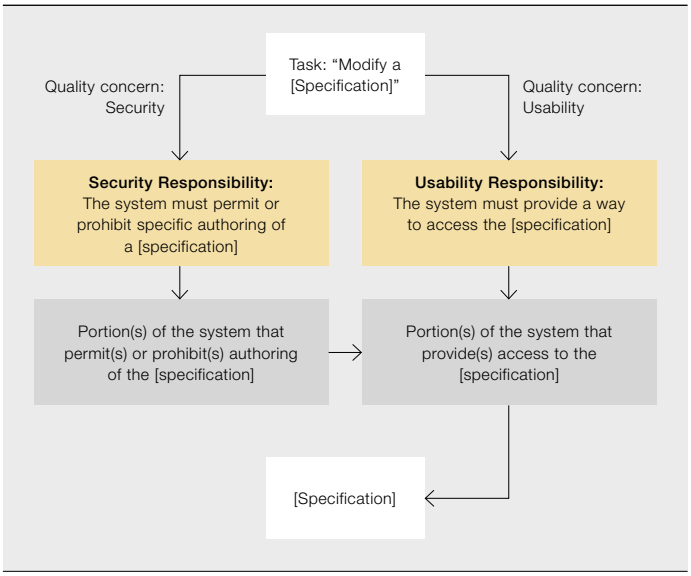
Attribute-driven Design Methodology

A system that integrated a mission-critical ABB product ➔ 4 with a wide array of third-party applications used at customers' sites, and that extracts data from these applications for later use, was architected using the attribute-driven design methodology [9]. Several drivers guided the development of the system's architecture: First, the system should integrate with a wide range of third-party applications seamlessly. Second, the system was to have the capability to collect large amounts of data from the third-party applications. Third, it was necessary that the system was perceived by its users as being very fast. These drivers were used to define the primary quality attributes for this system as integrability, scalability, performance and security. The quality requirements were then utilized to create the scenarios needed to build and evaluate the architecture options for the system and select the best one. Once the system architecture was selected, a system prototype was built and demonstrated to customers. This served as an excellent way to obtain their input so the final system could be developed.

Usability-supporting architecture patterns

The next example of new architecture development deals with supporting usability. One user task in a software system can have multiple quality concerns ➔ 5. Often security and usability have to be traded off. Security is all about preventing inappropriate user access and usability is all about facilitating appropriate user access. In the Usability-Supporting Architecture Patterns, USAP, the term "responsibility" is used for the general sub-tasks the software system has to support to ensure the usability quality of the main task. For each responsibility the USAP provides architectural implementation instructions ➔ 6.

5 Multiple quality concerns of one task [1]



6 Screen shot of the USAP tool

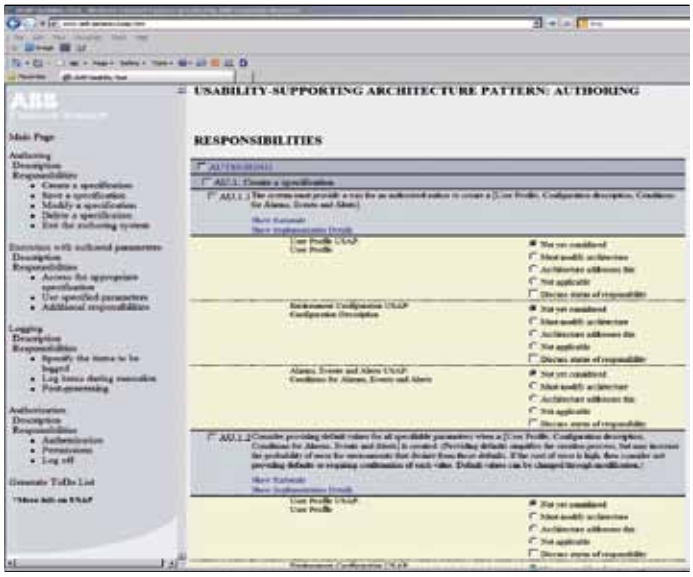


ABB undertook a USAP study in the domain of sustainable industrial software systems and contributed a description of an enhanced research method and a software tool that visualizes the method's constructed responsibilities.

The tool, visualizing the responsibilities, acts as an experience factory [10] housing reusable architectural knowledge for a set of system environment interaction scenarios in the form of a check-list. Three scenarios were hosted with a check-list of forty-two architectural responsibilities describing how the architecture can be revised to accommodate the usability requirements. One of the scenarios was the "Alarm & Event" interaction between the system and its environment. Two ABB architects who used the tool for six hours estimated that this time spent saved them five weeks' effort by allowing them to understand the usability requirements early on [11]. Three aspects of this study are significant:

- The usability-supporting patterns are primarily described at the level of responsibilities. These are independent of implementation and lead the architects to think about how a particular responsibility relates to their current system design
- Using textual descriptions for implementation instructions rather than diagrams was well received by the architects at ABB. In the study's first group, the architects showed some reluctance with respect to diagrammatic instructions. Using textual instructions, the tool enables the architects to investigate one aspect of the pattern at a time instead of forcing them to overlay an entire visual diagram of a pattern on their design to identify gaps.
- Using a tool to encourage the architects to examine all of the items in the checklist makes the architect go through all aspects of the patterns.

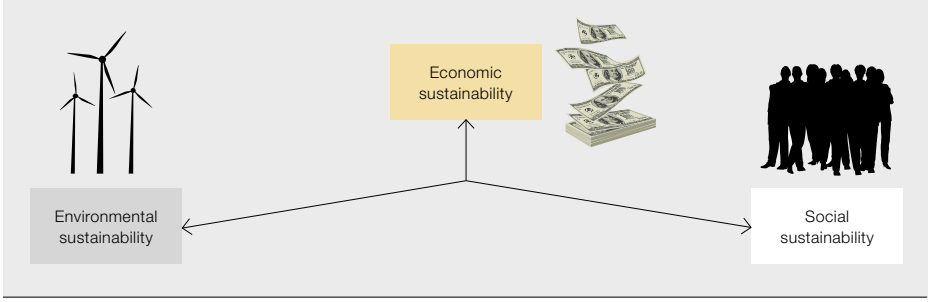
In addition, there is nothing in the USAP delivery tool that is specific to usability patterns. Any quality attribute where the requirements can be expressed as a set of responsibilities, eg security, could probably be included in the tool. The same portions of a system could then be represented from both the security and the usability responsibilities implementation points of view.

Verify and validate new architecture

A development team responsible for a major update of an ABB software system spent significant effort creating a new architecture for this next system version. As ABB Corporate Research was part of the architecture creation process, a neutral entity was asked to conduct an architecture evaluation. This external company used the architecture documentation from the project team and the results of a Quality Attributes Workshop to baseline the demands on the system's qualities. They then interviewed all relevant stakeholders, including Business Unit (BU) management, product management and system architects. After

Two ABB architects who used the tool for six hours estimated that this time spent saved them five weeks' effort by allowing them to understand the usability requirements early on.

7 Triple bottom line of corporate sustainability



> "When we build, let us think that we build forever."
>
> JOHN RUSKIN 1849

analysis of the material and interviews, the external reviewers presented their findings. The key results were:

- The main architectural decisions around the new architecture were sound and address the project's primary objectives.
- The architecture documentation was not precise enough in some areas and needed further refinement to avoid erroneous design decisions.
- The reasoning behind design decisions was not part of the architecture documentation. This makes future evolution more difficult and leaves room for deviations from the target architecture.

Overall, the workshop and the subsequent external review provided the BU stakeholders with the necessary confidence in the proposed new architecture and also pointed to topics that needed more attention and further elaboration.

Focusing on sustainable software architectures

It is evident from the preceding discussion of software architecture that the discipline has expended much effort to lay sustainable architectural foundations. But what particular aspects demand attention so that sustainability is maximized?

In 1849, John Ruskin wrote, "when we build, let us think that we build forever." Ruskin, then, was referring to the architecture of buildings, but the saying is as relevant today in the software world.

Within a sustainable architecture there is a focus on the process as well as the end product and while the product may "wear out" over time, the process remains. This process can then be repeated without resort to major external inputs. In the building industry, sustainable architecture brings together at least five key characteristics:

- Technical sustainability: can skills be introduced and passed on to others, and are the required tools accessible?
- Organizational sustainability: is there a structure that allows one to bring together the different stakeholders without, for example, needing to call on outside expertise on each occasion?
- Financial sustainability: can money or service exchange be accessed to pay for the work that needs to be done?
- Environmental sustainability – does the approach avoid depleting natural resource bases and contaminating the environment?
- Social sustainability: does the overall process and the product fit within, and satisfy the needs of, society?

Economic sustainability represents one of the "triple-bottom-lines" [12] of corporate sustainability → 7. From the economic sustainability point of view, three of the characteristics above are important in software-intensive systems: technical, organizational and financial sustainability.

Technical sustainability in a software-intensive system is achieved by selecting a technology that not only provides the required qualities but also provides a platform for future maintainability and evolution of long-lived systems. Issues such as developers' skills and compatibility with other company's products are important factors.

Organizational sustainability ensures the right resources (people and tools) will be available to ensure development is conducted in the most efficient way.

Financial sustainability ensures the organization meets its expected revenues from the developed software. It is impor-

tant to ensure that the right processes are implemented and followed to reduce non-value added costs such as re-work, cost of poor quality, etc.

Software architectures can also contribute to the environmental sustainability axis → 7. This is impacted by the software system's structures and inter-operations. Software architecture designed to limit the energy consumption of the product increases environmental capital. Social Sustainability can be increased if the architecture is structured in a way that simplifies the developers' daily work and stimulates and motivates them.

Outlook

The importance of systematic software architecting has been identified within ABB development organizations. Most development units have established the software architect's role and increasingly adopt software architecture methodologies such as attribute-driven design.

At the same time, ABB continues to investigate ways to improve the architecture discipline in areas with potential for ABB, by, for example:

- Identifying and cataloging best practices for developing systems with sustainability as a high-importance quality attribute, like ABB's distributed control systems.
- Evaluating the benefits and applicability of software product line architectures as a basis for software development within ABB, as well as fostering systematic and coarse-grained software reuse.
- Developing methods for making design decisions early in the development process, eg not relying on extensive prototyping. In this regard, ABB has participated in the publicly funded research project Q-ImPrESS (www.q-impress.eu) that targeted predictions of changes to the performance, reliability and maintainability quality attributes.
- Deriving concepts for future automation systems for increased modularity, maintainability, scalability and portability.

Most development units have established the software architect's role and increasingly adopt software architecture methodologies such as attribute-driven design.

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Smarter recovery

Integrated Operations – Enabling safe and profitable operation of remote and mature assets

KATRINE HILMEN AND ESPEN STORKAAS – As existing oil and gas fields mature they become more marginal and reservoir and fluid characteristics become more complex. In turn, newer fields are typically located in more remote and harsh environments. These challenges have triggered new approaches to oil and gas recovery both in subsea development and downhole technology as well as in new and leading concepts in remote monitoring, asset management and maintenance. Integrated Operations (IO) addresses these challenges and ABB offers a wide range of solutions in this area.

The upstream oil and gas business continues to face challenges that make safe operation with sensors, computing power, diagnostics and communication technologies and work processes less profitable. As fields mature they become marginal, resulting in increasing operational costs. Newer, remote fields in harsh environments, such as arctic or deep water, provide their own set of challenges. Drivers for change are, then:

- Economy (reduced operational expenses, increased reservoir recovery and production capacity increase).
- Geography (harsh environments, remote locations).
- Safety and environmental surveillance (exposure to hazards, integrity, emissions).

Technology advances are also changing the game by continually expanding the technical capability envelope.

The challenges, combined with the advances in the enabling technologies, have triggered new approaches to oil and gas reserve development. Examples are satellite fields and subsea tie-ins,

Title Picture
To get the maximum return from industrial plant, be it offshore assets or the complex processing plant shown here, it is essential to harness all available relevant data and make it work for you.

1 The various phases, roles and responsibilities related to the enhanced production target

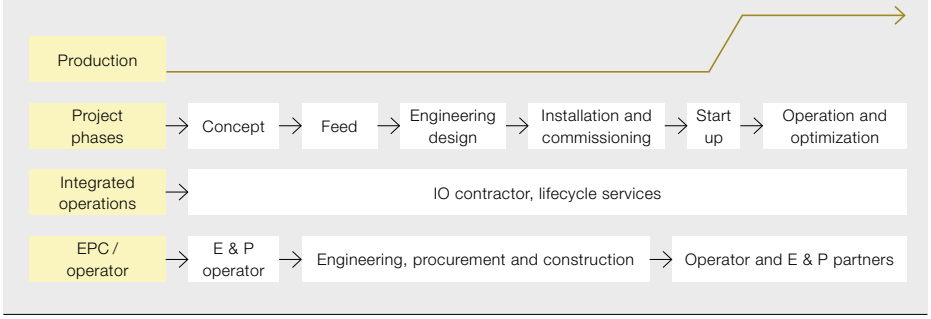


ABB offers a portfolio of technology and services to optimize production and facilities operation and maintenance from wellbore to export.

smart wells and light well interventions, as well as an increased interest in remote monitoring, organizational models with integrated asset management and adoption of world class maintenance principles.

Integrated operations (IO) is a collective term that addresses some of these challenges, and is embraced by the main players in the oil and gas sector under such names as “smart fields”, “digital oilfield”, “intelligent energy” and so on. IO concepts and solutions can be utilized from the earliest phases of field development right up to production tail-end.

ABB has developed a suite of IO solutions, methodologies and services targeted at safety, health and environment and increased production. → 1 illustrates the various phases, roles and responsibilities related to the enhanced production target. Faster startup, leaner manning, improved execution and readiness for operation can be provided by ABB as an IO contractor or engineering services provider, supplementing the more traditional project execution. Examples include life-extensions where ABB brings operational experience into early phase concept selection, design engineering, commissioning, startup and optimization. Process control strategies, alarm management, control room design, use of lifecycle simulation, system functional integrity, flow assurance and optimization are other examples where ABB can provide value.

The elements of Integrated Operations

ABB offers a portfolio of technology and services to optimize production and facilities operation and maintenance from wellbore to export. Key components are → 2:

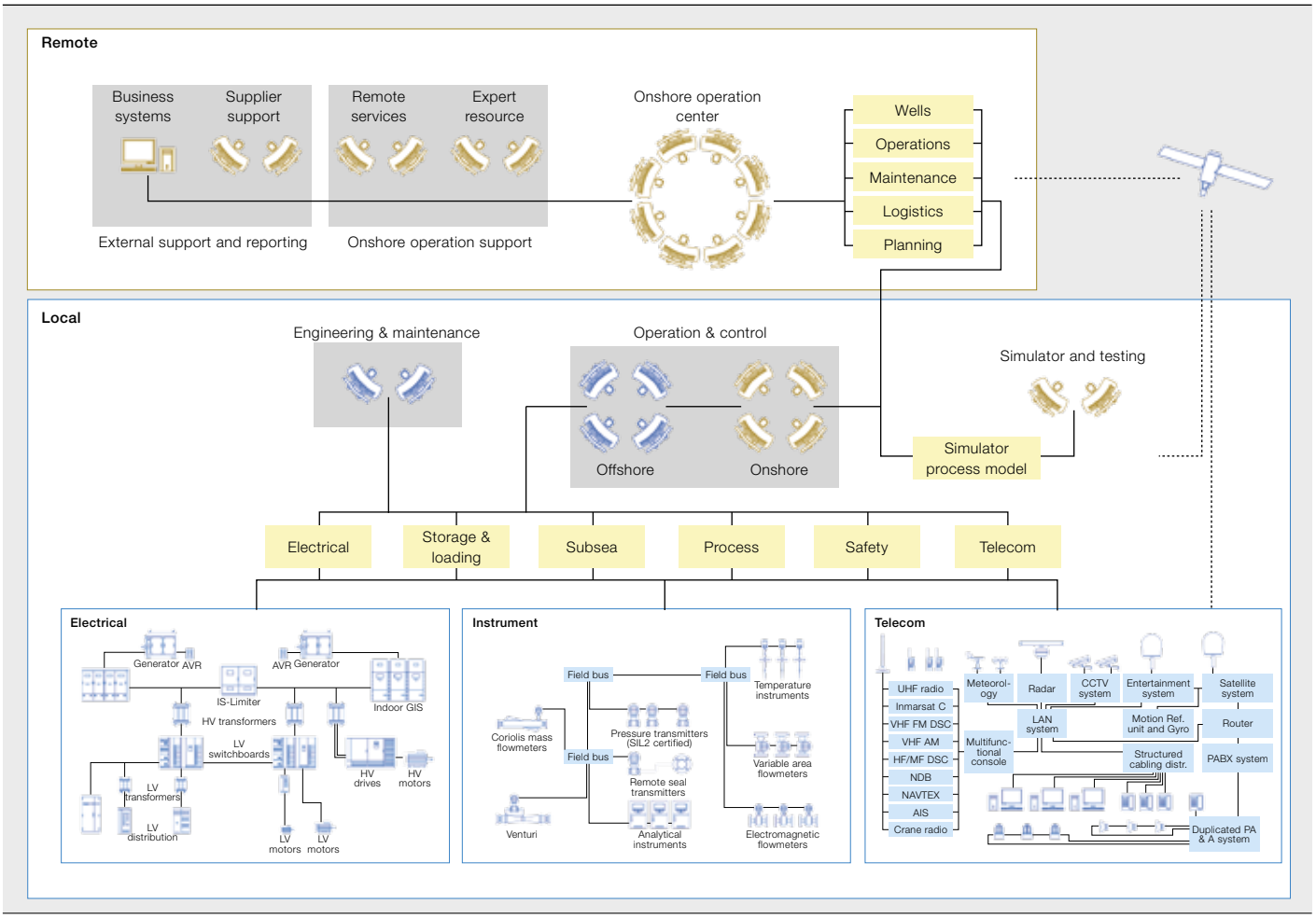
- ICT infrastructure and security
- Data capture and access, including software applications for remote support
- Production and operation intelligence and optimization
- Condition monitoring, diagnostics and reporting

ABB intends to be a lifecycle partner and integrated system vendor in this context. Integrated Operations Products and Solutions Center has developed solutions and support offerings that supplement both third-party and ABB technologies for upstream oil and gas use, in particular for offshore and subsea operated assets. To fully benefit from these offerings, multidisciplinary team thinking is required as well as knowledge and training in petroleum technology and operation.

The solutions specific to the oil, gas and petrochemicals industry cover areas such as:

- Production and process optimization and control
- Safety integrity and alarm management
- Integrated systems for remote control and operation
- IT security and communication network infrastructure
- Condition monitoring systems and services
- Emission monitoring and energy efficiency improvement
- Multiphase flow assurance and optimization
- Subsea intelligence
- Data capture and storage and collaborative work environments
- Process control performance lifecycle services
- Wireless sensor systems

2 Remote support and IO are enabled by proper asset infrastructure and facilities design. In particular, integration of the instrumentation, automation, information and communication technologies (ICT) with the operation and maintenance management systems is critical.



Integrated Operations: the benefits

Added infrastructure investment cost is generally paid back in the operational phase. The value potential of IO can be summarized as:

- Increased production (3–5 %).
- Reduced production losses, deferment or Increased Oil Recovery (20–40 %).
- Reduced operation and maintenance costs (15–30 %).
- Improved safety through risk reduction and improved work environments; logistics and transport benefits.
- Reduced emissions, better energy efficiency and improved environmental surveillance and marine operations monitoring.

ICT and system topology

The principal components in a system facilitating Integrated Operations for an offshore operated asset comply with the ISA 95 Level 5 hierarchy standard → 3:

- An efficient historian and data integration infrastructure with associated connectivity and interface solutions to gather and distribute all relevant data.
- An efficient and secure IT and communication networks infrastructure that facilitates remote access, monitoring and collaborative support.
- A comprehensive asset management system giving both maintenance and performance measures of all key systems and processing units.
- Daily operations and optimization applications.
- A common user interface.
- Collaboration rooms and workstations.

In addition to these technical components, associated work processes, appropriate operational philosophies and an organization with a mindset and culture suited to Integrated Operations are all required to fully exploit the opportunities provided by Integrated Operations. Cross-disciplinary decision-making processes and collaboration between different parts of the organization, or even between the operating company and suppliers and service providers, are all essential ingredients.

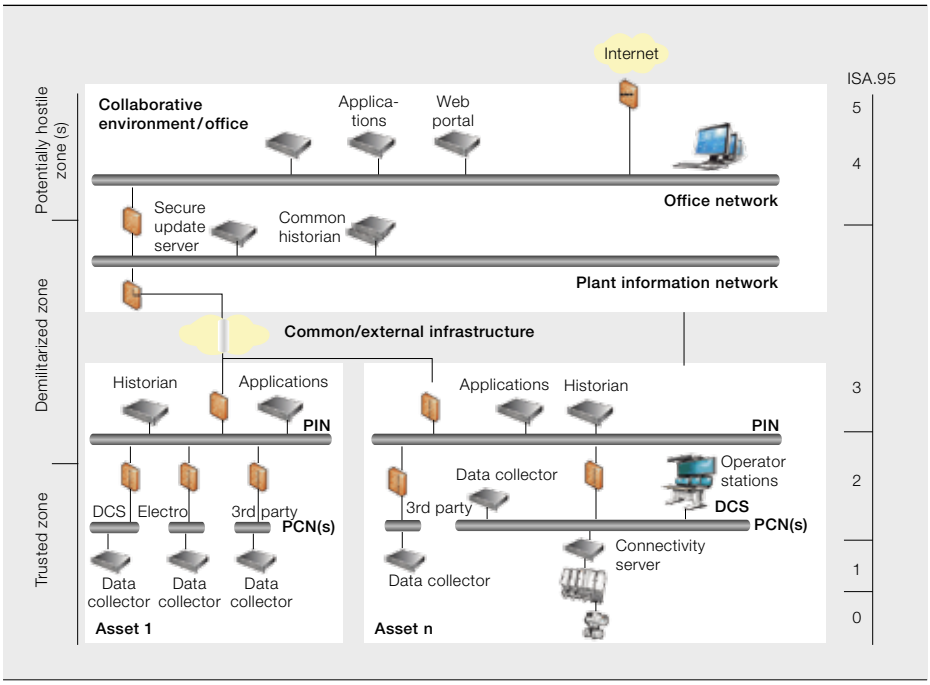
Some ABB highlights in the areas of production optimization, asset management and safety may now be described in more detail.

> Integrated Operations is a subset of solutions, methodologies and services targeted at increasing oil & gas production.

Production optimization

Subsea developments are becoming ever more important for the upstream oil and gas industry, both in deepwater

3 Principal IT topology showing layers of integration related to ISA.95.



and for tying-in smaller fields to existing infrastructure to make up for production decline. One of the main challenges to subsea field operation is production optimization; reservoir recovery for subsea developments are typically 10–15 % below that of platform wells, for example.

The Flow Assurance and Optimization System (FAOS) is an ABB control, monitoring and optimization and flow management product. The key components are:

– Control: ABB's patented Active Flowline Control (AFC) controls and stabilizes wells and pipelines to ensure stable and uninterrupted production. AFC also very accurately controls wells and pipelines during well test, thus providing invaluable information for production optimization. AFC's other control functions include protecting wells against rapid pressure changes during start-up and protecting downstream equipment against overload.
– Production monitoring: Well and pipeline monitoring is of vital importance, especially in preventing blockages due to hydrate formation. Apart from these frozen mixtures of hydrocarbons and water, there is also a wide range of other detrimental flow phenomena, such as wax formation, deposition of solids and slugging, that must be guarded against. Real-time mathematical models can predict many of these problems as well as provide inputs to production optimization programs.

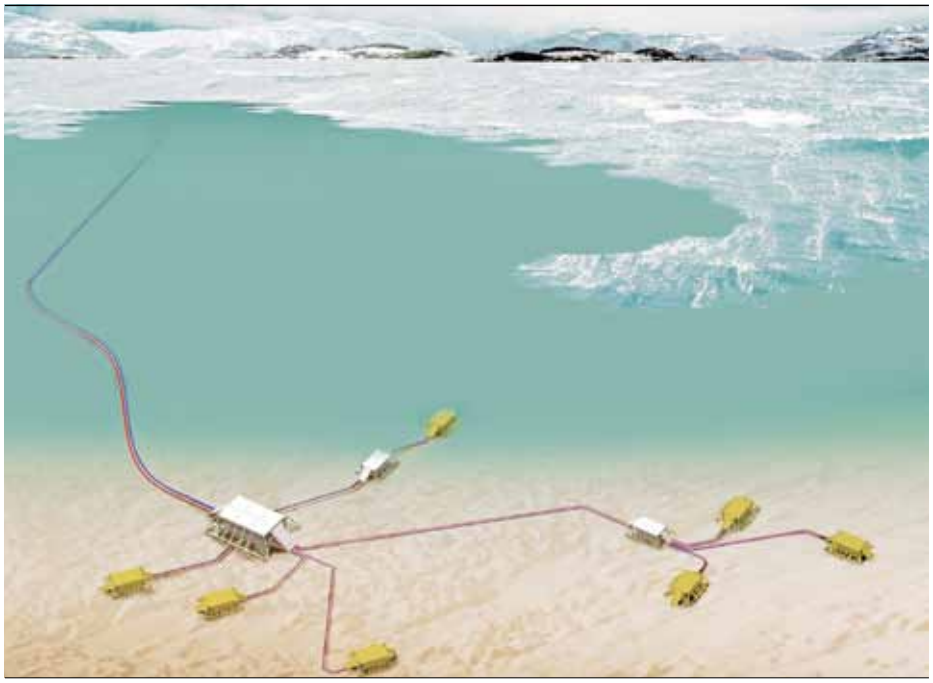
For simpler cases, ABB has its own model-based Well Monitoring System (WMS) for monitoring pipelines and wells. This is based on steady-state models and can be used to calculate production rates throughout the system as well as warn of potential flow problems. For more complex systems, where dynamic behavior can be of great importance, OLGA Online, the leading multiphase flow simulator (delivered by ABB's collaboration partner SPT Group) should be utilized.

– Optimization: With control and monitoring functionality in place, optimization, utilizing both primary (physical) and secondary production measurements, can proceed. Optimization strategies range from targeted solutions, for example gas lift optimization, to generic model predictive control solutions, such as ABB's "cpmPlus Predict & Control". For optimization on longer timescales, production monitoring can give invaluable inputs to reservoir simulations (Eclipse) and optimization.
– Maintenance management: Due to the severe consequences of any equipment error and the expense of intervention with ROVs or workover vessels, seabed equipment maintenance requires careful planning. Therefore, timely detection of emerging faults and maintenance requirements can be a critical success factor. FAOS provides extensive tools to ensure optimal maintenance management.

FAOS delivers all the above, and more, in an integrated system. This ensures that the synergies between the various elements are fully utilized. For example, virtual measurements from the monitoring system can be used as (secondary) control variables by AFC. Also, AFC can serve as the implementation platform for the set-points sent from the optimization module. Furthermore, such integration ensures a unified user interface, for both a quick overview of key data and for detailed analysis by expert users. FAOS resides within ABB's integrated operation infrastructure and all information can be accessed through the client's corporate network.

As regards client data security, ABB offers a comprehensive set of security consulting services that focus on protecting the confidentiality, availability and integrity of the local asset information and automation system network. Corporate, national and international standards are adhered to and good technical and procedural solutions are developed. Also

4 Predictive maintenance is increasingly seen as key to cost-efficient operation of complex assets, like these subsea production units.



FAOS ensures that the synergies between the various elements are fully utilized.

offered are standard pre-packaged security solutions to help establish baselines for addressing the risks associated with plant automation systems.

Asset management system and lifecycle services

Predictive maintenance is increasingly recognized as the key to cost-efficient maintenance → 4. The method implies that maintenance operations are managed according to reliable prognosis of the equipment wear and tear. Predictive maintenance also ensures the reliability and integrity of the equipment. This is particularly appreciated at offshore and remote installations where personnel and travel costs are considerable. The method also provides cost reduction by reducing unplanned downtime, allowing operation closer to the design limit and by facilitating more structured maintenance planning. A key to condition-based maintenance is real-time monitoring and reporting technology.

ABB's Integrated Asset Management system provides a common infrastructure to integrate maintenance data from individual systems. All major ABB electrical, instrument and control and telecoms systems components are available with intelligent monitoring and diagnostics functions suitable for inclusion in the Asset Management System. Long-term monitoring functions deliver important information on equipment status, tasks due and possible performance improvements. Third-party systems can also be integrated.

The Asset Management System allows real-time access to these functions, supports monitoring and diagnostics and integrates planning and enterprise-wide ERP connectivity.

The main advantage lies in the ability to display all relevant maintenance data in a uniform user interface. This allows for more informed decision-making as overlapping monitoring functions can easily be compared.

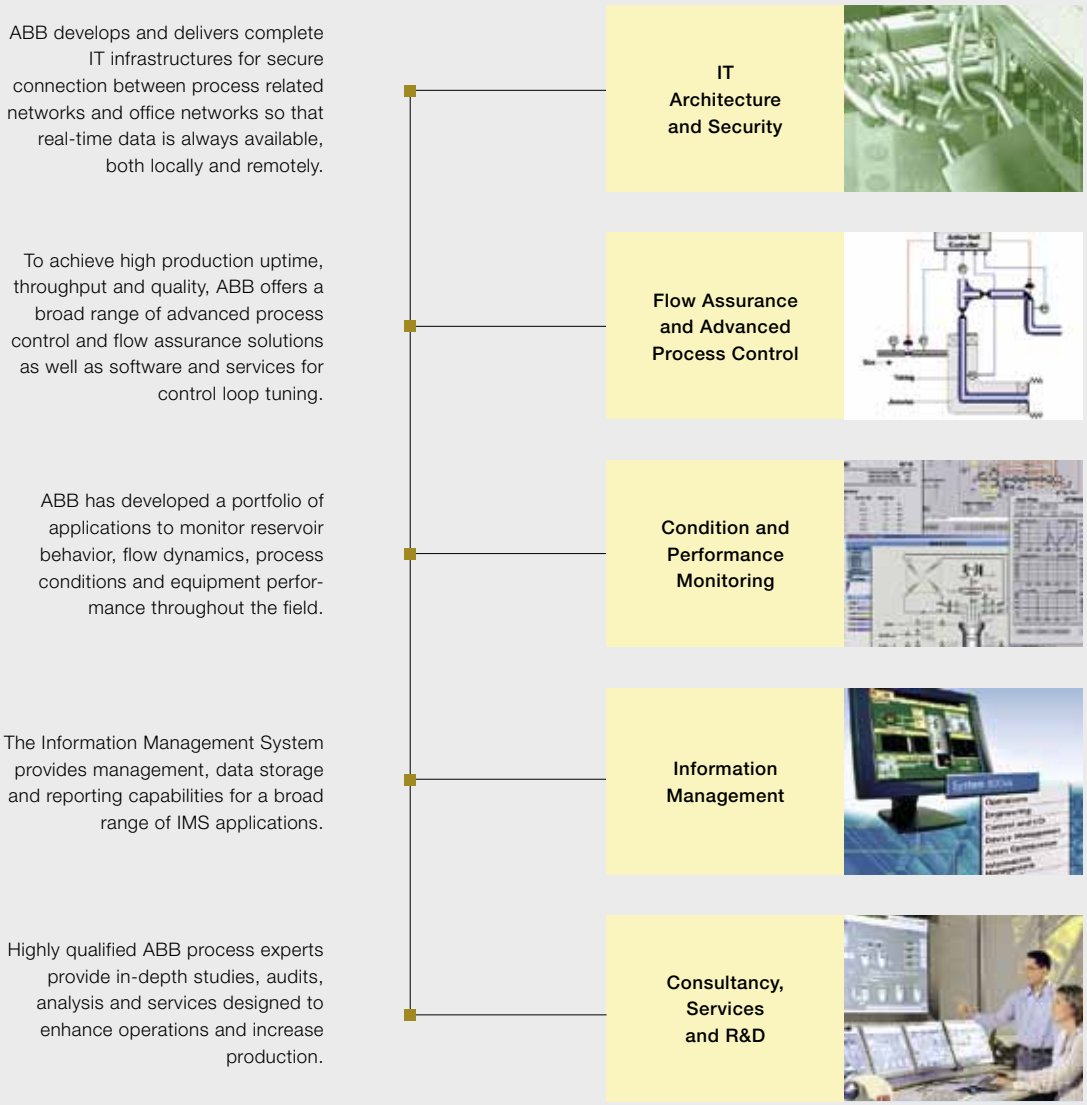
Safety

ABB has a complete portfolio of lifecycle solutions and service offerings within the area of safety and alarm management, including awareness training and performance benchmarks, improvement projects and services, reporting applications and system maintenance as well as integrated safety and control system installations. These all follow industry standards and best practices.

Importance of the "soft factors"

Integrated Operations experience so far has indicated that organizational change and the mindset of individuals, especially as they strive towards acquiring new knowledge and skills, play a critical role

5 Overview of ABB's Integrated Operations in the oil and gas arena



Predictive maintenance is increasingly recognized as the key to cost-efficient maintenance.

in the success of the enterprise. In fact, more than 80 % of the effort involved resides in this area.

Swallowing your own medicine

The drive towards Integrated Operations has changed ABB too. ABB Services itself is adapting to this shift in the industry via client partnering and the adoption of new service concepts, as well as improving IO-enabling products and services. New contract strategies such as performance contracts, with full-service at the extreme, are an emerging business area. Electrification and subsea intelligence solutions are other examples.

Delivering value

An early adopter of Integrated Operations saw the lifting cost of a small, tail-production North Sea field significantly reduced. The main contributor to reduced operational expenses and an extension in production forecast was the 'soft IO', ie organizational change, which was eagerly embraced by staff keen to see their facility have a longer life. ABB was a partner for the operator in the whole change program, conducting interviews and handling change management in addition to installing enabling remote operation support technology. Since then, this very significant customer has established standard work processes, roles and responsibilities and introduced a new offshore organizational model based largely on this pioneering work.

More recently, work carried out by a team specializing in process and production optimization from ABB Integrated Operations has made a big impact at the Shell Ormen Lange facility in the areas of pro-

cess control performance services, simulation and tuning, commissioning and startup support. Benefits were delivered in terms of on-stream days, less fluctuations, energy efficiency and reduced emissions. Uptime was “increased by four to five days per year". The magnitude of the financial savings here can be guessed at by taking into account that, at its plateau production, Ormen Lange will process some 20 billion standard m^3 of gas per annum – equivalent to Norway’s entire energy consumption.

Statoil, too, has benefitted from ABB partnering and technology development targeting production optimization: following an Integrated Operations initiative to improve sand management at the Gullfaks field in 2003, $300 million was added (15,000 barrels per day of the retention volume). In 2004, a further $190 million was added (3.8 million barrels). A key factor was the establishment of an erosion management system based on process and production data combined with choke models allowing active

In the Ormen Lange facility uptime was “increased by four-to-five days per year”.

sand control. Statoil reported further, in SPE 94511 [1]: “During 2004 a total of $95 million (1.9 mill. barrels) of additional revenue was achieved on the Statfjord field.” These immense sums are based on a $60/ barrel oil price; more recent Integrated Operations successes are valued considerably higher. The safety gain of having more accurate sand monitoring and erosion estimates, and adapting the permitted sand to various well conditions, is invaluable in itself for such a mature field. This is an excellent example where the combination of enabling technology and actual operational change adapting to a new strategy have delivered value.

Integrated Operations for the future

ABB’s portfolio for enabling Integrated Operations → 5 is tailored to increase throughput, decrease energy consumption and decrease the cost of operation by advanced use of available data, such as real time process data and asset condition monitoring. Integrated Operations provides an opportunity to significantly optimize reserve exploitation. Integrated Operations has already proven itself in financial terms and it will continue to grow in importance in the oil and gas sector as the industry moves forward.

During 2004 a total of $95 million (1.9 mill. barrels) of additional revenue was achieved on the Statfjord field.

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Model-based emission monitoring

PEMS: a monitoring system that uses artificial intelligence to reduce environmental impact

NUNZIO BONAVITA, FEDERICO CALLERO – Acquiring proper, reliable and timely information about actual emission levels is crucial in order to deploy adequate control actions to keep emissions inside law-enforced limits. This, combined with the need to comply with the ever-increasing demands coming from regulatory bodies, means process industries have started to equip themselves with Environmental Management Systems (EMS) that monitor, collect and process environmental data. In principle several types of monitoring systems are available but the most efficient and reliable one is the Continuous Emission Monitoring System (CEMS), where a continuous stream of data is acquired by rapid-response instruments and displayed in real time. Recently, another system, known as the Predictive Emission Monitoring System (PEMS) has been attracting attention. A PEMS uses an empirical model to predict emission concentrations based on process data, and it has been successfully implemented as part of a comprehensive EMS in one of the largest gas processing plants in the world.

According to ISO 14001, the goal of an Environmental Management Systems (EMS) is "to enable an organization to establish, and assess the effectiveness of procedures to set an environmental policy and objectives, achieve conformance with them, and demonstrate such conformance to others" [1]. In accordance with this, a typical EMS is designed to provide a number of functions, including:

- Collecting and processing environmental-related data
- Providing key environmental performance indicators
- Providing environmental performance evaluation planning
- Emission calculation and reporting
- Record keeping and audit trail functionalities

A well-known and reliable monitoring system is the Continuous Emission Monitoring System (CEMS), which is composed of sample extraction and transport hardware, an analyzer, and data recording and processing hardware and software. CEMS can be broken into three types of methods [2] ➔ 1:

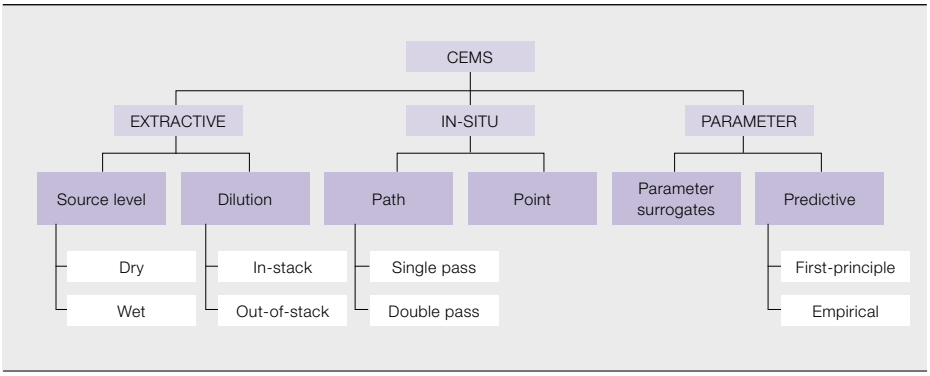
- Extractive, which involves the physical extraction of the sample from the chimney stack
- In-situ instrumental, which are automated instrumented techniques employing various detection principles for continuous or periodic emission measurements
- Parameter-based methods are possible alternatives to the installation of conventional CEMS

They are two classes of parameter–based methods: surrogate and predictive. Surrogates may be used to determine the compliance of a source with the emission standard. However, acquiring the parameter values usually requires extensive testing and validation. On the other hand, predictive parameters are applied in cases where the relationship between process conditions and emission levels is such that it cannot be properly described by a single parameter. Predictive class parameters involve the concept of modeling, which nowadays plays an important role in emission management systems ➔ 2.

A Predictive Emission Monitoring System (PEMS) – also known as an inferential analyzer – cannot measure emissions directly but uses an empirical model to predict emission concentrations based on process data, such as fuel flow, load, operating pressure and ambient air temperature. In fact PEMS can provide the only way of obtaining a continuous stream of (estimated) emission values in process units where CEMS' are not present and where either in-situ (ie, periodic) analysis or the campaign approach is implemented. In such cases the plant is allowed to lease a portable CEMS to

Title Picture
Statoil's liquefied natural gas (LNG) plant at the island "Melkoya" near the city of Hammerfest, in northern Norway. ABB has delivered a complete range of power and automation products and systems to this gas processing plant. Gas from the "Snohvit" (Snow white) gas field is recovered through subsea templates, transported in pipelines to the plant, where the gas is cooled down until it becomes liquefied and ready for transport by ship.

1 Typical continuous emissions monitoring system (CEMS) configurations



Acquiring proper, and reliable information about emission levels is crucial if adequate control actions to keep emissions inside law-enforced limits are to be deployed.

gather sufficient emissions data to build and validate the models. Once the models have been certified, the CEMS is removed and replaced by the inferential-type system [4]. PEMS can also be used as a back-up if a CEMS is in place, and irrespective of which role it plays, it provides numerous benefits in different applications ➔ 3.

Many applications have proven that software systems are just as accurate as the hardware-based CEMS. In addition, virtual analyzers offer other functionalities that can [5]:
– Identify the key variables that cause emissions
– Automatically validate sensors
– Reconstruct emission levels from historical data when the hardware device fails
– Complement and enhance process optimization strategies

Actual regulation requirements insist that periodic tests need to be performed at the stack as well as continuous emission monitoring in order to prove compliance with the legal limits and track eventual violations. A conventional CEMS, however, cannot anticipate pollutant limit violation. A PEMS, on the other hand, could allow plant engineers to directly correlate the relationship between varying operational parameters, predict plant emissions in advance and take action to adjust emissions before violations occur. The mood around the world regarding the methods used to monitor emissions is changing: Many European regulations now explicitly call for software-based redundancy emission monitoring systems while in the US, several states allow artificial intelligence (AI) technologies based on models like PEMS as an alternative monitoring technique.

Underlying technology

As a mainly software analyzer, the successful implementation of PEMS depends largely on a powerful model-building and model-implementation tool. This tool has to ensure the availability of efficient and reliable modeling technologies together with all the required functionalities for data acquisition, data processing, model testing, etc.

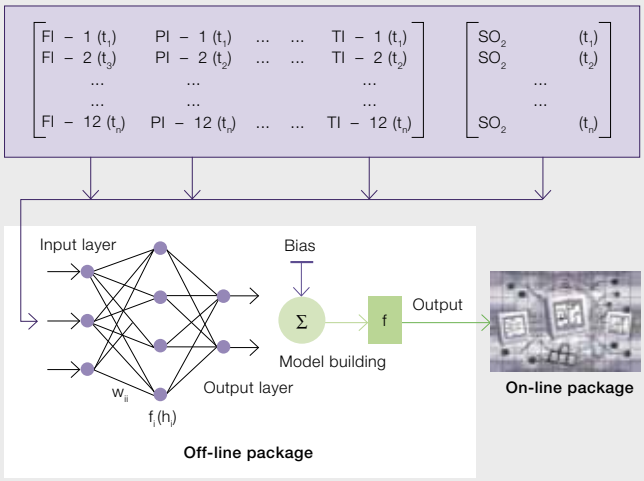
One such tool, the Inferential Modeling Platform (IMP), is an innovative ABB proprietary software package for the development and deployment of data-driven advanced applications. IMP is based on two separate environments:
– IMP Model Builder for application design and development
– IMP Online for online project deployment and monitoring

The IMP features the latest generation of data analysis and modeling-building technologies (eg, neural networks, genetic algorithms, multiple linear regression, calculation scripts) including AI-derived algorithms and tools, all of which can exploited through a broad collection of highly sophisticated tools [6]. These tools are embedded into an intuitive working environment based on the latest HMI concepts. The IMP is loaded onto a PC that communicates through OPC with the distributed control system (DCS) containing the process variables and analyzer data (if PEMS is used as a back-up). Using real-time process data, the models output the estimated value of the relevant emissions, which can be either monitored via a dedicated HMI or sent back to the DCS operator interface.

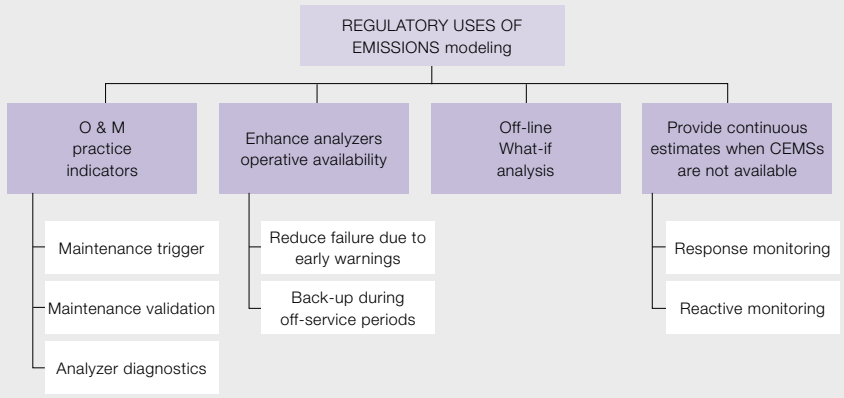
2 Modeling plays an important role in emission management systems.

Modeling is used to develop compact mathematical expressions that describe the behavior of a process or equipment. There are two main approaches: theoretical and empirical [3]. A theoretical model is derived from scientific principles, such as the conservation of mass and energy, and the laws of thermodynamics, while an empirical model is mathematically derived from plant-specific process data. In general, modeling is able to provide an accurate real-time estimate of difficult-to-measure quantities; exploit otherwise hidden or neglected correlations; and provide a deeper insight into the process. Estimated quantities are often referred to as inferential variables and the model is also called an inferential model. Advanced process control strategies usually employ inferential models.

The relationship between the input data (ie, available measured variables) and output data (ie, the variable that needs to be estimated) is determined during the model building stage. Dedicated software is used to import, pre-process and filter out historical datasets, which must include all the possible samples of the quantity that needs to be estimated. The resulting model has to be extensively tested and validated on the widest possible range of operative conditions. When this is completed, the model can be placed online where it is fed with real-time process data. This data is generally pre-processed to identify transient states and filter out possible outliers and bad qualities. The model output is also pre-processed to increase its reliability and accuracy.



3 Potential applications areas for PEMS



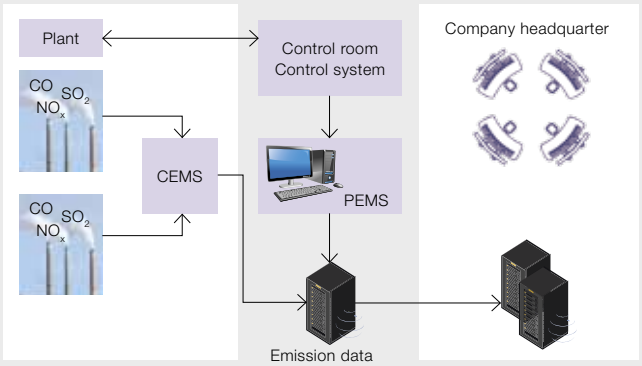
PEMS could allow plant engineers to directly correlate the relationship between varying operational parameters, predict plant emissions in advance and take action before violations occur.

PEMS at work in industry

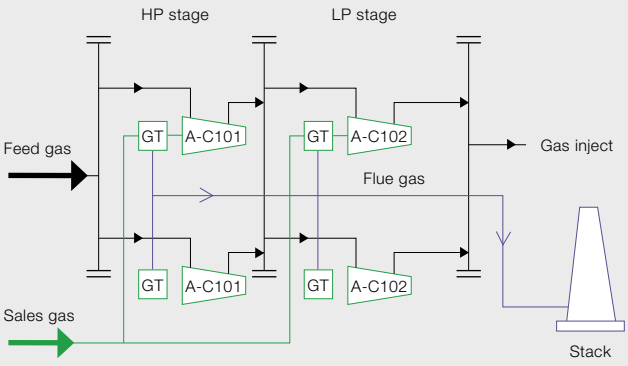
In 2007, ABB was awarded a contract to supply a comprehensive EPA-compliant EMS for a primary plant of a major gas provider in the Gulf region. The plant, one of the largest gas processing plants in the world, has eight gas-processing trains and two gas-injection trains with a feed gas capacity of 3,500 billion standard cubic feet per day. The plant produces network gas, natural gas liquids (NGL), condensate and sulphur. The project required the installation of CEMS (on a temporary basis), PEMS and a dedicated data acquisition system to provide emissions measurements to ensure health and safety compliance and for process improvement purposes → 4.

In the field, the two gas-injection trains, A and B, are configured in parallel and each has two two-stage axial compressors, C101 and C102 → 5. Each compressor is driven by a gas turbine (GT), whose emissions are monitored by a PEMS. Sales gas is used to drive the high-pressure (HP) and low-pressure (LP) stage turbines. The HP turbines operate in all cases at constant speed, ie, very close to 100 percent of the maximum speed. The speed of the LP turbine can vary depending on the plant operating conditions, but it is mainly dependent on the availability of sales gas. In most cases the two trains are operated together, close to their maximum load. However, during times of little or no gas production, one of the two trains is operated at a lower load or speed. In summer

4 An overview of the required environmental management system (EMS)



5 The turbo compressor unit configurations



when ambient temperatures are very high, the overall efficiency of the system is reduced in order to reduce excessive stress on the equipment.

At this plant PEMS has a crucial role in emission monitoring as it works solely for gas turbines. To design the most appropriate model for PEMS, a temporary CEMS analyzer was used at each stack unit to acquire proper emissions data, while simultaneously process data were collected directly from the plant DCS through an OPC protocol. Data collection lasted about six weeks to cover the widest range of process conditions. Model design and validation, data processing and site implementation activities were executed using ABB's IMP. Data processing is a key step during the development of an empirical model. To begin with, both the input variable set and optimum pattern for the plant model were defined using sophisticated statistical and mathematical techniques. Identifying the optimal sampling rate for modeling purposes was critical because it has to satisfy two purposes: allow the identification of process dynamics and conditions; and provide an adequate number of suitable data sets to create good and accurate models.

> The EPA assessment and certification process required 18 test runs lasting 30 minutes each at two different operating conditions.

IMP provides a user-friendly environment for applying Principal Component Analysis (PCA) → 6, a powerful technique that allows engineers to represent and analyze the variability of the system from which they can identify a minimum subset of the most representative variables from a wider range of process parameters. Another advantage of PCA is that it identifies different process settings and abnormal operating conditions, as well as the mutual influence between input (ie, process variables) and output (ie, emissions).

Once the data processing phase was completed, a set of around 1,700 records (ie, a set of process and emission values sampled on an hourly basis) and 35 variables were identified as suitable for creating effective models. Included in this dataset are:

- The main process parameters, such as air and gas inlet low, feed flow, compressor load, turbine inter-stage and exhaust flue gas temperature
- Important weather-related measurements, such as air temperature and humidity
- Pollutant emission measurements, such as NO_x, SO_2, CO, CO_2 and flue gas flow

Of the several options available in the IMP tool, feed-forward neural networks (FFNN), a powerful AI modelling technique was deemed to provide the most accurate, reliable and robust models. Each set of models was characterized by the number of hidden-layer structures, input variables such as the key process variables mentioned above and number of varying parameters. In order to avoid any over fitting and guarantee the right model robustness, the 1,700 input values were split into three subsets: training (50 percent); testing (25 percent); and validation (25 percent). A dedicated IMP feature was used to access the sensitivity of a single input variable on the estimated emission type.

The system was integrated with the DCS and the estimated emission values were configured to be written to the EMS via the serial protocol Modbus.

Results and achievements

Once installed, the system was subjected to an Environmental Protection Agency (EPA) assessment and certification process by an authorized third-party company from the United States. The process required 18 test runs lasting 30 minutes each at two different operating conditions (ie, nine at 95 percent of compressor load and the rest at 100 percent).

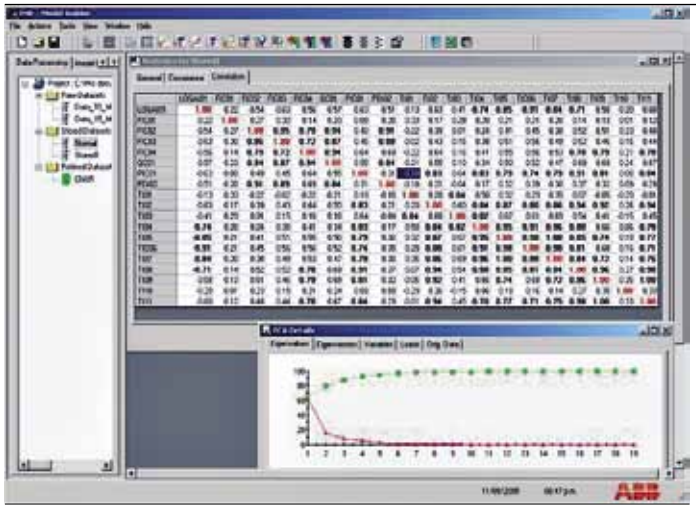
After each test run, the emissions estimated by PEMS were compared to the values measured by CEMS, enabling the relative accuracy [1] of the PEMS system to be determined. As the performances for each emission were compliant with EPA regulation, the system was certified and then finally accepted by the customer → 7.

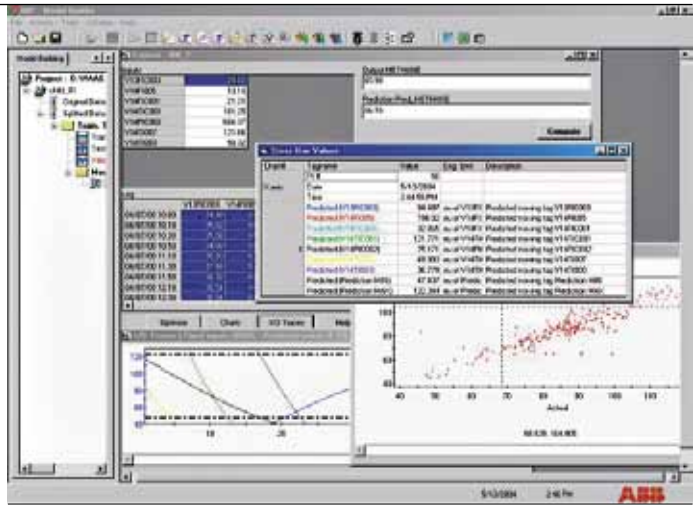
Footnote

1 $\text{Accuracy} = \frac{1}{n}\sum_{j=1}^{n} \text{abs}\,(Y_j - Y_j^*)$

Where: Y_j is the PEMS estimation, Y_j^* is the actual composition and n is the number of samples used in the comparison.

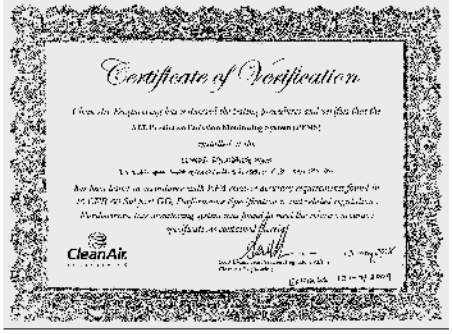
6 ABB's Optimize^{IT} IMP model builder for data processing and PEMS modeling





7 PEMS project results and resulting certificate

Property	Ra 95% Load	Ra 100% Load
Oxygen	< 10%	< 10%
NOx	< 10%	≈15%
SO_2	undetected (<1ppm)	undetected (<1ppm)
CO	< 10%	< 15%
CO_2	< 10%	< 10%



The innovative PEMS described above represents the first EPA validated system based on predictive technologies in the Gulf region, and its success is opening the way for further applications in that area. Currently PEMS technology is being tested by another major oil and gas player for government acceptance in other Gulf and Mediterranean countries. Many see the advantages of having an easily adaptable "smart" system:

– Its performance is accepted by internationally recognized environmental agencies.
– A predictive system can improve traditional CEMS availability.
– PEMS can actually replace traditional analyzers in cases where CEMS are not available or usable.

In addition to these advantages, the simulation features provided by the ABB solution allows plants to investigate possible operation improvements in a non-invasive environment and determine best practices to run the process. They also enable the advance testing of optimization systems to satisfy local environmental regulations.

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The innovative PEMS application represents the first EPA validated system based on predictive technologies in the Gulf region.

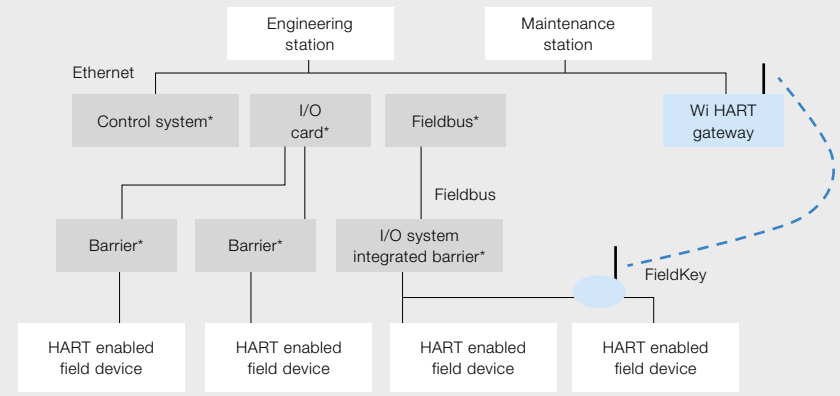
Efficient harvesting from the 4..20mA loop

Low-power design of ABB's FieldKey wireless adapter

YANNICK MARET, STEFAN U. SVENSSON, TILO MERLIN – Many of the 4..20mA current-loop field devices used in industrial automation applications today include highway addressable remote transducer (HART) communication capabilities. Because these capabilities are very often used only during commissioning, valuable information, such as process or diagnostic data, is stranded or unavailable during runtime. In order to transmit this information to an engineering and maintenance station without affecting the instruments already installed on the 4..20mA loop, ABB developed the FieldKey adapter, which adds wirelessHART capability to installed HART devices. The FieldKey adaptor transmits data via a wireless gateway and as such is the first WirelessHART adapter listed by the HART foundation. Although it is self powered by extracting the required energy from the current loop in which it must interact, there are circumstances when the available power is limited. To overcome this, ABB has developed techniques that aim at reducing the power consumption of the FieldKey and limiting its impact on the existing 4..20mA loop.

Title Picture
ABB has developed techniques to reduce FieldKey adapter power consumption that in turn will benefit many industries.

1 HART capability in a typical process industry application



* HART communication capability needed to access field device information from engineering or maintenance station

The analogue signaling technology, the 4..20mA current loop, is typically composed of a voltage supply and a signaling device that transmits measurement or control values by modulating the current between 4 and 20mA. Any device connected in series with the loop can read the current and incidentally the transmitted value. Many 4..20mA current-loop field devices include highway addressable remote transducer (HART) communication capabilities [1].

The HART communication protocol is designed to complement the analogue signaling technology by superimposing digital signaling capabilities based on a frequency shift keying (FSK) scheme on top of it. Implementing complete HART communication capability (ie, back to a control and monitoring system) in installations in hazardous areas, such as those in the process industry, is simply too costly → 1. As a result HART communication is often only used during the set up and commissioning phases, and important information, such as process or diagnostic data remain stranded in the field device. Indeed many components, such as barriers, are only designed to transport the 4..20mA to a control system during runtime.

Even though recent HART installations have a pathway back to condition monitoring applications, the fact remains that 80 percent of the installed base do not. To use HART information from field devices for predictive maintenance or asset management, most of the installed input/output components and associated wiring would have to be exchanged and redone. To avoid such a costly endeavour, ABB developed the FieldKey wireless adapter, which provides a cost-effective and secure communication pathway back to remote process and condition monitoring applications without affecting the standard 4..20mA operation [2]. In other words, it acts as a bi-directional bridge between wired HART data and wirelessHART.

The FieldKey adapter can be connected anywhere within the 4..20mA loop used by the device, and to minimize installation and maintenance costs, it is self-powered. In other words, it automatically adapts to the available power. Therefore, if connected in series to an installed 4..20mA loop → 2, the adapter should be able to extract enough power to supply itself by creating a voltage drop across the current loop. This voltage drop actually represents an additional voltage loss for the loop and should therefore be small enough not to disturb other devices. However, minimizing the loop voltage loss actually constrains the available power. To overcome this, ABB has looked at ways of limiting its impact on the existing 4..20mA loop and reducing the power consumption of the FieldKey adapter.

ABB has developed techniques that aim at reducing the power consumption of the FieldKey adapter and limiting its impact on the existing 4..20mA loop.

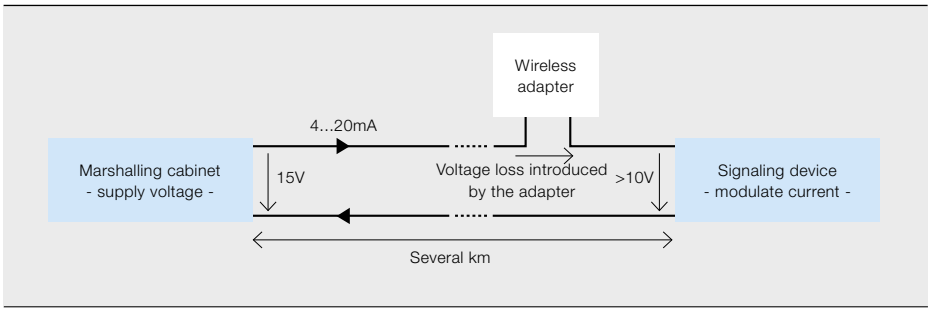
To limit the impact of the adapter on the 4..20mA loop, a novel adaptive voltage-drop regulation method has been developed that uses a new blocking barrier circuit and enables the inclusion of a "virtual" communication resistor. Reducing the power consumption of the adaptor can be achieved by power-optimizing the design and in particular by decreasing the leakage current of the large capacitor bank used to even out the power peaks.

Current-loop impact limitation

Voltage loss optimization

The central idea of adaptive voltage-drop regulation is to adapt the voltage loss caused by the FieldKey adapter according to the current flowing into the loop. Because the current is defined by the signaling device and the adapter needs a constant power of about 5 mW to operate, it actually requires less voltage to operate at higher signaling currents than at lower ones. Additionally, the resistive voltage loss introduced by the wiring is maximal at higher currents. Therefore, the voltage available to the field device is minimal at 20mA and maximal at 4mA. In practice the wiring is often close to the maximal allowed length, resulting in a field-device voltage that is nearer to the lower limit accepted by the device. The voltage drop created by the FieldKey

2 Retrofitting of a FieldKey wireless adapter



adapter is thus made larger at low currents than at higher currents ➔ 3.

An important contributor to DC voltage loss in the 4..20mA loop is the series communication resistor, which is required to convert current to voltage and vice-versa. This resistor incurs a DC voltage loss of up to 2.5 V. The FieldKey adapter replaces this communication resistor by a "virtual" one that acts as a resistance of 240 Ω in the HART frequency range and 0 Ω at DC.

Both adaptive voltage drop regulation and the effect of the virtual communication resistor are achieved through analogue signal processing in order to minimize power consumption. The block diagram of the implemented electronics is depicted in ➔ 4.

The wired front-end primarily consists of a HART modulator and DC voltage regulator. The HART modulator takes care of the HART protocol modulation and also regulates the DC voltage drop created by the adapter. The DC regulator creates a stable DC voltage that can be fed to the DC/DC step-up converter.

Power consumption reduction

Capacitor bank leakage optimization

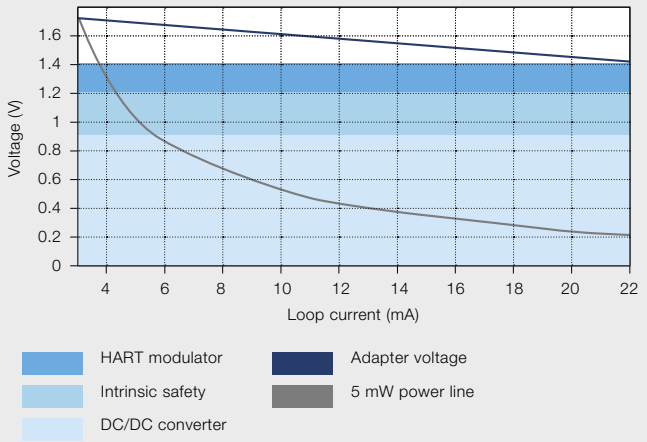
The FieldKey adapter is nothing more than an energy harvesting device ➔ 5. However, it has to harvest its required power from a process (ie, the 4..20mA current loop) that is simply not designed for that purpose. The wireless HART chip requires more peak power than can be extracted from the 4..20mA loop (eg, up to 100 mW for a flash memory write, which can last for 30 ms or 75 mW for a wireless data transmission, which can last 5 ms). The actual power available is the product of the minimum loop current and the voltage loss across the loop caused by the adapter. Therefore a voltage loss of 1.5 V results in 6 mW of available power. Since the voltage drop ought to be minimized, the power available is constrained.

A large capacitive buffer of 6 mF is needed to average out peak power, but such a large buffer will incur a leakage current at high temperatures and thus power losses. Only electrolytic capacitors can achieve 6 mF within a reasonable footprint. Some special aluminum electrolytic capacitors exhibit very low leakage current but are ruled out because of intrinsic safety (IS) requirements ➔ 6, ie, no liquid electrolyte is permitted [3]. The alternative is solid electrolyte and therefore mainly tantalum-based and niobium-oxide capacitors. However, direct current leakage (DCL) is not a primary optimization target in the solid electrolytic capacitor market in contrast to equivalent series resistor (ESR) or capacitance. The smallest leakage current for tantalum capacitors is obtained by operating the capacitor at a ratio of about 30 to 40 percent of the rated voltage [4]. At a lower ratio, the leakage current is mainly due to dielectric absorption whereas it is dominated by fault current at a higher ratio. Therefore, for an internal voltage supply of 3 V, the capacitor should be rated at 10 V.

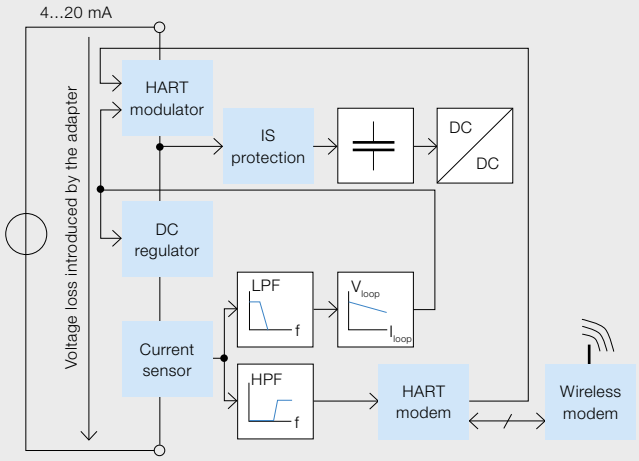
As an energy harvesting device, the FieldKey adapter has to harvest its required power from a process that is simply not designed for that purpose.

A device complying with intrinsic safety (IS) can be operated in the presence of explosive gases without requiring costly sealed housing.

3 Voltage drop created by the FieldKey adapter



4 Block diagram of the wired front end



A suitable capacitive bank could be formed using twelve Kemet 470 µF/10 V capacitors [1]. Incidentally, the leakage current for these capacitors is much lower than that documented in the datasheets. For example, at an operating voltage of 10 V, the leakage current is specified to be 14 µA per capacitor (p.c.) at 25 °C and increases by a factor of five at 85 °C; at 3.6 V operating voltage, the derating graphs specify a maximum leakage current of 8.5 µA p.c. at 25 °C, which also increases by a factor of five at 85 °C. However, measurements performed by Kemet on several samples reveal values of only up to 5.1 µA p.c. at 85 °C at an operating voltage of 3.6 V and values of up to 55 µA p.c. at 85 °C at 10 V operating voltage → 7. These values correspond to a decrease in leakage current of about 90 percent for 3.6 V operation and only 20 percent for 10 V operation, results which corroborate the ones previously reported in [4] by another capacitor supplier.

The smallest leakage current for tantalum capacitors is obtained by operating the capacitor at a ratio of about 30 to 40 percent of the rated voltage.

Low voltage reverse-current blocking barrier

To comply with IS standards, large capacitors must be encased within a protective enclosure and connected to the outside electronics through a reverse-current blocking barrier [3]. This limits the thermal and electrical energy that could be transferred from the capacitors to parts outside the protecting enclosure in the event of a failure. According to the

Footnote

1 The capacitors in question are Kemet B45197A2477K509.

5 The FieldKey (NHU200-WL) mounted on field instruments

6 Intrinsic safety (IS)

A device complying with intrinsic safety (IS) has the significant advantage that it can be operated in the presence of explosive gases without requiring a costly sealed housing. On the other hand, the regulations on IS limit the energy that can be accidentally delivered by the electronics. One of the consequences is that only relatively small capacitors are allowed. For example, if the voltage on the capacitors is limited to say 5V, the sum of all capacitors should not exceed 100µF for devices that are allowed to operate within the most volatile gases. There are two ways of limiting the energy delivered by capacitors: add a serial resistor; or impede the flow of energy back to the hazardous area by means of barrier diodes. Unfortunately, the first technique implies important resistive losses while the second adds a severe voltage drop.

There is one drawback of a power optimized and intrinsically safe 4..20 mA loop interface: it increases the theoretical probability of interfering with the loop current in case of a device failure. The FieldKey adapter is used to extend diagnosis capability but reduced reliability of the system is not acceptable. A failure modes, effects and criticality analysis (FMEDA) is used to help calculate the mean time between failure (MTBF) of different designs.

standards, the energy stored in the required 6 mF capacitive buffer is too large and therefore some form of barrier is needed.

Conventional solutions, such as diode-based circuits, induce a large voltage loss while complex circuits, eg, integrated circuits, are not allowed by certification bodies because faults are difficult to analyze, and when something goes wrong the protection system has to operate without a power supply. For these reasons, ABB have proposed a new near zero-power barrier that performs better than the diode-based solution.

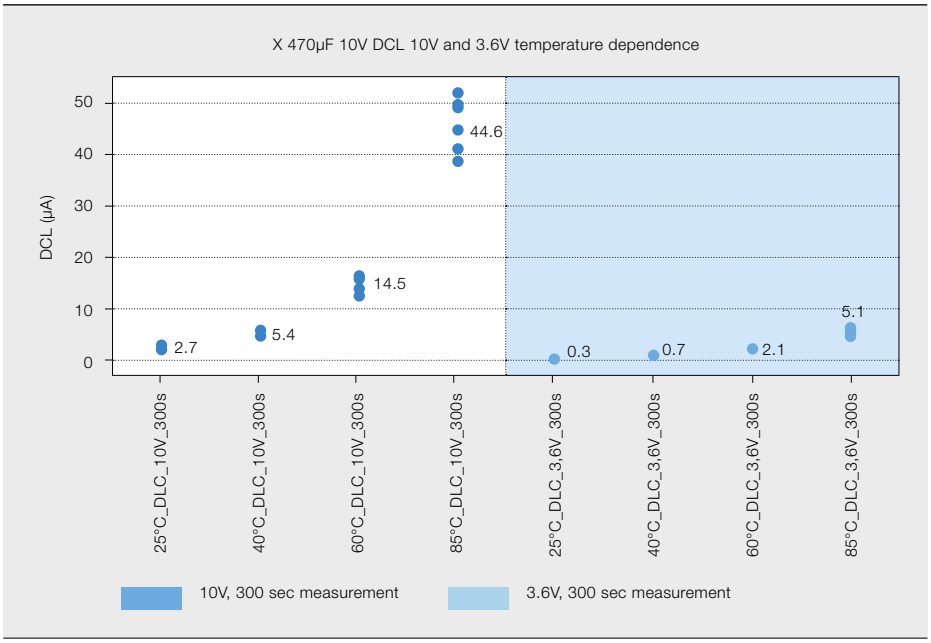
The conventional approach consists of a number of silicon diodes connected in series [5]. In some regions around the world two diodes are enough while in others three are mandatory. To minimize voltage losses, Schottky diodes are used. The total voltage drop caused by three series Schottky diodes at room temperature is around 0.5 V. However, when the temperature decreases there are fewer charge carriers and the voltage drop increases for a given current. When this happens the voltage loss can grow up to 1 V at –40 °C.

The proposed ABB solution (for three protection stages) is shown in ➔ 8. In the forward mode ($V_i > V_o$), only the lower transistors and resistors define the behavior of the protection circuit – the upper transistors are reverse biased and therefore non-conducting. The lower transistors are forward biased in such a way that they are in forward-active mode and saturated. The total voltage drop caused by the three transistors is therefore very low at any temperature value. Since the transistors are saturated, the required base current is much higher than for normal forward-active mode. This implies that a non-negligible amount of emitter current goes into the transistor base.

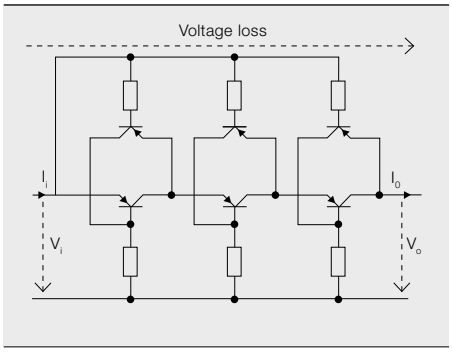
In reverse mode ($V_o > V_i$ and $V_o > 0.6V$), the upper transistors are forward-biased and thus conducting. Their purpose is to render the lower transistor group non-conducting by reverse-biasing them. This is needed because bipolar transistors are relatively symmetrical. Indeed, the collector and emitter can be inverted

The electronics were designed using an iterative approach to optimally distribute the power budget according to the different operation modes and device structure.

7 Leakage measurements for six 470µF capacitors. Data courtesy of Kemet



8 ABB's proposed novel reverse current blocking barrier



A team of engineers and corporate research scientists developed the wirelessHART adapter with the lowest voltage drop on the market.

and the transistor still works as a transistor, albeit with worse characteristics. This implies that a protection circuit composed of only of the lower transistors would not fully block the current.

For V_i = 1.5 V and I_i = 4 mA, the forward mode voltage loss at −40 °C is approximately 0.78 V for three series Schottky diodes with a power efficiency of about 48 percent. For the proposed transistor solution under the same conditions, the forward-mode voltage loss is about 193 mV and current loss is 69 µA with a power efficiency of around 85 percent. A more detailed discussion and analysis of the transistor-based blocking barrier can be found in [6].

The electronic circuit was designed using an iterative approach to optimally distribute the power budget according to the different operation modes (stand-by, demodulation, and modulation) and device structure (analogue, digital). By using the techniques described in this article, a team of engineers and corporate research scientists developed the wirelessHART adapter with the lowest voltage drop on the market.

For further information, refer to www.abb.com/fieldbus

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Water

Water is an essential element of life. Yet access to it is not equally distributed. In fact one sixth of humanity has no access to safe drinking water, and contaminated water supplies remain a major cause of disease.

It is not just the developing world that is seeking to address its water supply. Many cities in industrialized nations are faced with legacy infrastructures that need to be modernized to meet rising demands, reduce leakage losses and address energy and environmental issues.

Issue 4/2011 of *ABB Review* will be dedicated to water technology and ABB's contribution towards it. Productivity-related articles will discuss measurement technologies, drives and pumping as well as the overlying network management and control systems. Ways of raising the energy efficiency of the water supply will also be examined. In terms of unconventional sources of water, the journal will look at desalination plants. These and other topics will be discussed in issue 4/2011 of *ABB Review*.

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