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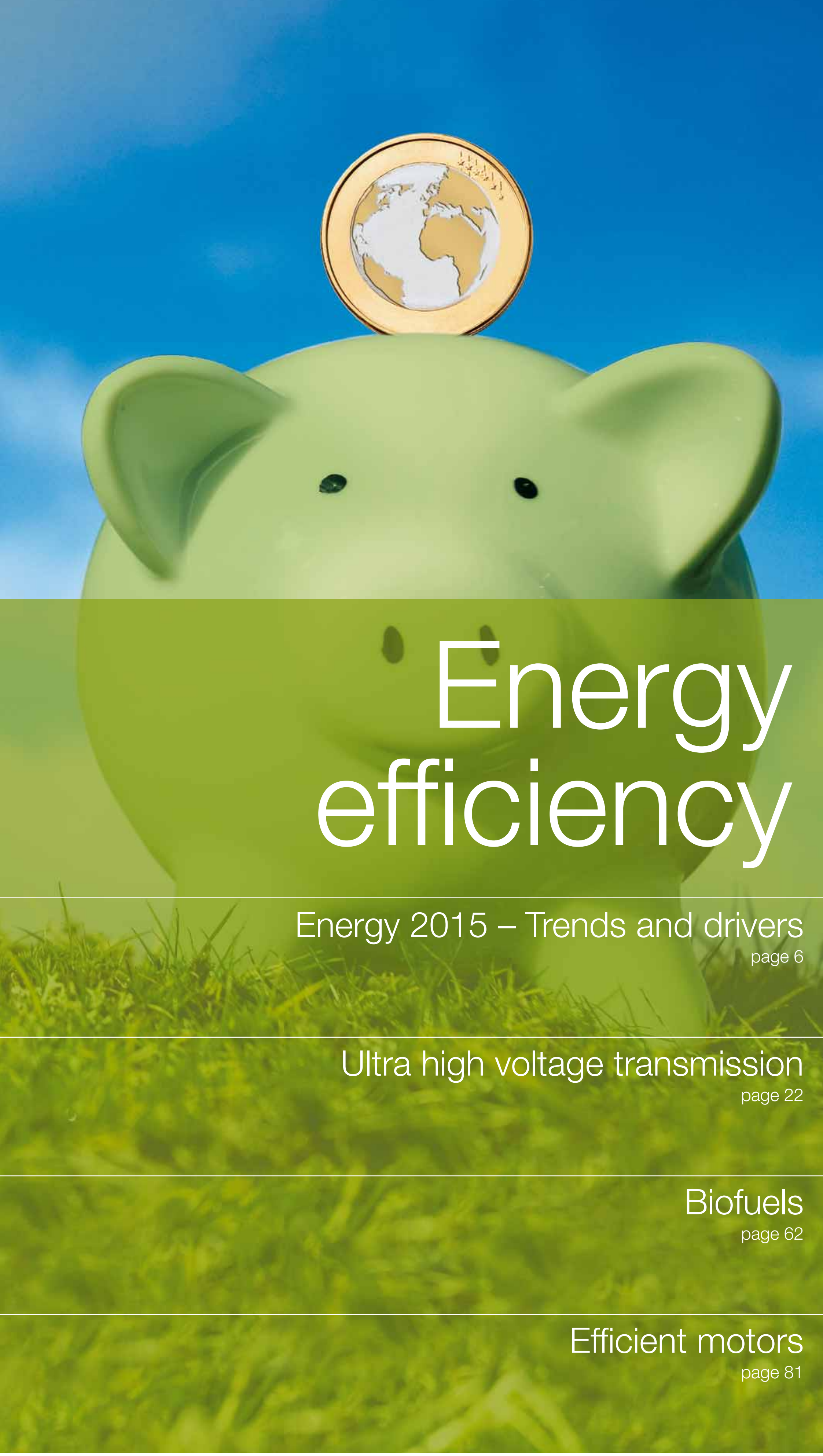

Energy efficiency

ABB

Two of the most important objectives confronting industry (and indeed society as a whole) are financial success and environmental responsibility – goals that are often perceived to be in contradiction. When it comes to energy however, whether electric or fuel, and whether in exploration, generation, distribution or usage, saved resources really do translate into saved money! This issue of ABB Review is dedicated to presenting how ABB technology can help customers improve their competitiveness through greater *energy efficiency*.

Energy efficiency – the other alternative fuel

Energy is the lifeblood of today's economy. From the extraction of raw materials, through manufacturing and transport to final usage, society relies on the continuous and predictable nature of its supply. Any threat to the availability of this resource can endanger local or even global prosperity. Furthermore, the world's thirst for energy is growing. Especially the highly dynamic emerging economies are set to account for a significant share of this global increase.

Facing this scenario, it is legitimate that all stakeholders are taking part in the debate over where this energy is going to come from. Relying on the traditional sources alone cannot be the solution: On the one hand, the indications for man-made climate change seem to be increasing, as is being reflected in ongoing events in global energy policy. On the other hand, access to these primary energy sources is increasingly developing into a political "tug-of-war", with different players struggling to secure favorable access. Furthermore, the implications of diminishing oil reserves cannot be ignored.

The obvious and most frequently fielded response lies in tapping new sources – whether variants of traditional sources or regenerative energies. Visionary future technology scenarios such as the hydrogen economy or nuclear fusion may be on the horizon, but the time scales required to realize these options are long, and tend to shift with time. Discussions over energy sources for the more immediate future are moving between nuclear, fossil and renewable sources.

Governments as well as non-governmental organizations, industry, research institutions and energy consumers have clearly accepted the challenge. New primary energy sources are being explored; coal is used in different ways; CO_2 sequestration is being evaluated; nuclear power is on the brink of a global revival; bio-fuels are being developed; wind and ocean energy is exploited; taxation or certificates are introduced as incentives for change and more.

Most stakeholders would agree that none of these answers can suffice in isolation. The answer lies in adopting a mix of most of the proposed solutions. However, the time-scale that the realization of any of these requires mean that immediate change is not around the corner. Is there an alternative that can deliver a fast solution while at the same time being economically viable?

Fortunately, this question can be answered in the affirmative: This "other alternative fuel" is energy efficiency.

Using less energy for the same tasks has the same overall effect on the global energy balance as the introduction of other alternative energies. While both roads have to be taken, an increase of the efficiency of existing infrastructure can now be realized – and rather than leading to higher overall costs, the necessary investments are recoverable through operational economies. The savings start with the extraction of primary energy – in oil fields for example. A better control of the exploration process saves energy and increases recovery. The more efficient transport of energy from the primary source to the point of conversion offers further saving opportunities – for example through greater efficiency in pipelines and ships. The untapped saving potential is huge and addresses ecological as well as economic issues – a key incentive for its fast introduction.

The Carnot cycle in which thermal energy is converted to mechanical energy has a theoretical efficiency limit; research on turbine technology and combined cycles as well as better control processes can never surpass this limit but can push equipment closer to it. Transmission and distribution of electrical energy is not possible without losses in the lines, but high voltage DC and FACTS (Flexible AC Transmission Systems) offer excellent ways to reduce these losses. A major part of the world's electrical energy is consumed in electric motors. Depending on the application, the use of variable speed drives to run motors reduces energy consumption by up to 70 percent. Considering that the life cycle cost of a motor is up to two orders of magnitude higher than the initial cost for the drive, the energy saving argument gets a strong back-up from economic considerations.

The need for energy efficiency is huge and immediate, and ABB is dedicated to doing its part. Through almost all its products and services in the automation and power areas, ABB contributes to the more efficient management of energy.

In this issue of ABB Review, we present a broad spectrum of applications of ABB technology boosting energy efficiency. You will discover energy efficiency as the one "low hanging fruit" in the energy orchard where proven technology can be introduced immediately with very short payback periods.

We hope that reading this ABB Review issue gives you many ideas on saving energy: for your own benefit and for a better world.

Enjoy your reading.

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

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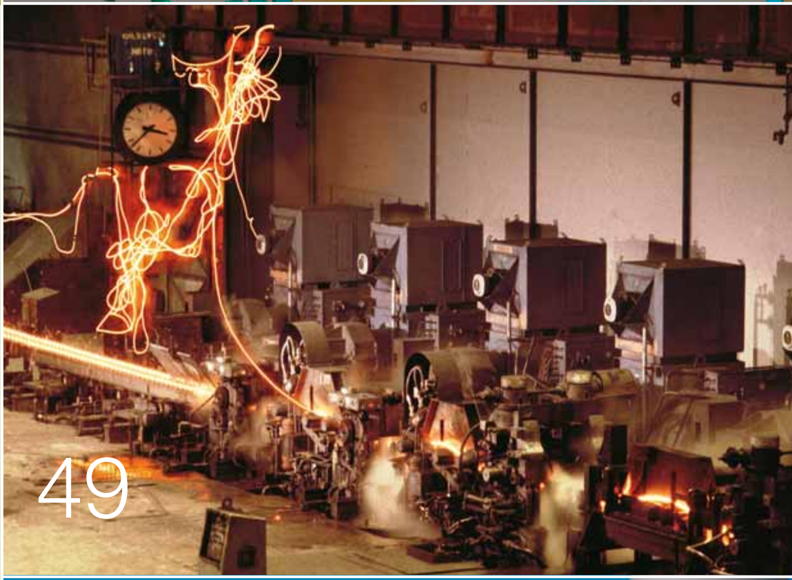


Alternative energies

Energy efficient products

Perpetual pioneering

The world in 2015 – trends and drivers

Friedrich Pinnekamp

In the globally networked world of today even slight changes of influencing parameters can have a huge effect on the development of society. With the fast changing political scenery, the soaring economic development and ongoing leaps in technology, a forecast into the future is a risky undertaking. Nevertheless, as the future development of the world's energy is one of the backbones of the global society, the need for reasonable planning is obvious. Utilities need to make long term investment decisions for their power generation portfolio as well as the transmission and distribution infrastructure, providers of alternative energy solutions seek a sound decision platform and, last but not least, industrial groups and their suppliers want to know where market and technological development will lead.

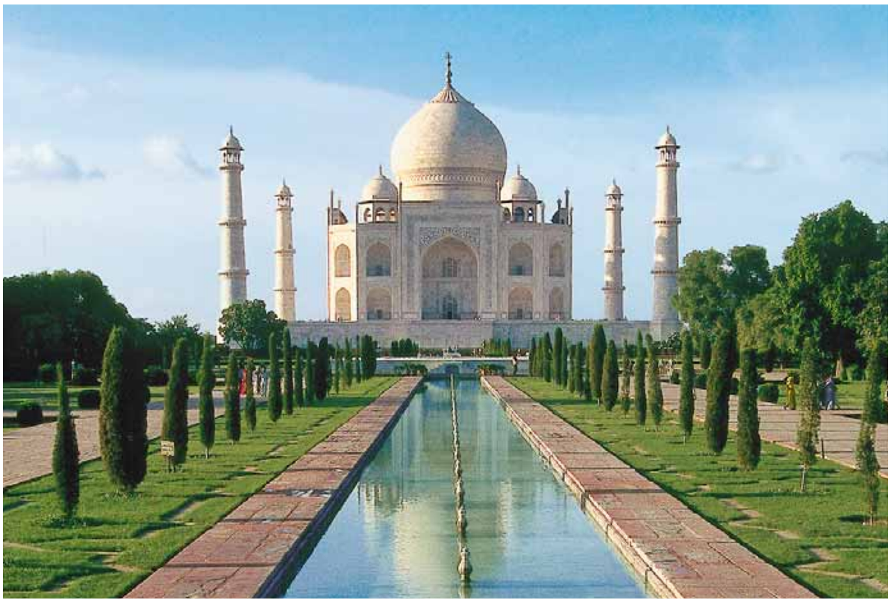
A look into the future is obscured by the fact that disruptive events like pandemics, terrorist attacks and technological breakthroughs may have a significant influence on the development of the world, but they are by nature unpredictable.

Forecasts based on the extrapolation of developed or emerging trends seem to be more reliable within a reasonable time span. As those trends are driven by a few major forces, there is a chance of a meaningful prediction by analyzing these drivers.

ABB has looked at six prominent trends with strong influence on the upcoming needs of people and requirements of the industry. These trends address

- Changes in the global society
- Globalization
- Energy industry restructuring
- Primary energy concerns
- Electrical energy needs
- Environmental issues

Within the next ten years an additional 200 million people will be living in mega-cities, this urban migration being the traditional way for poor people to gain access to better economic conditions.



A rapidly changing global society

Exponential population growth, falling mortality and fertility rates, a shift in the demographic balance between young and old, chronic poverty in much of the southern hemisphere, urbanization and the growth of mega-cities, mass migration within and between countries, the rising influence of religion in some cultures and growing secularism in others, and the worldwide impact of the digital and IT revolutions – these are all factors that are driving societies and individuals towards increasingly rapid change.

With world population currently at 6.5 billion and rising by 75 million a year, changes in the structure, values and relations within and between societies are the driving force behind all other movements that shape the world we live in.

The population problem is exacerbated in the mature economies by the combination of falling birth rates and longer life expectancy. This is creating ageing populations which could, in time, lead to tension between the younger and older generations 1.

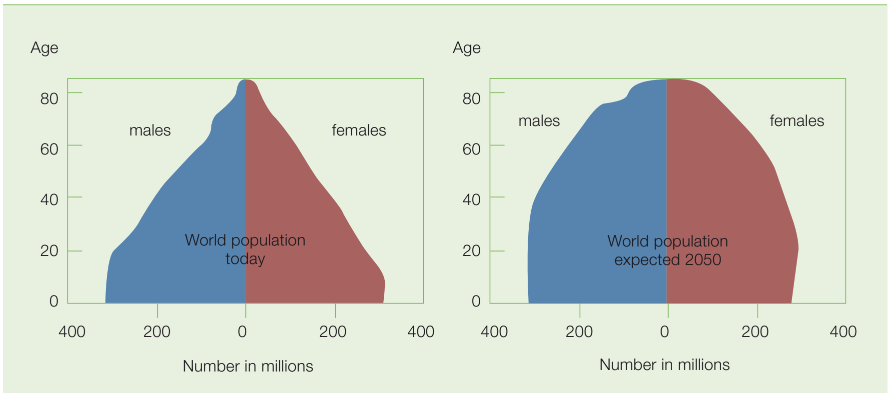
Severe poverty in the least developed countries will remain at a high level, even if the ambitious anti-poverty goals of the United Nations are achieved. The number of conflicts sparked by poverty and injustice is likely to grow, leading to increased social and political instability.

Within the next ten years an additional 200 million people will be living in mega-cities (bringing the total to 600 million by 2015), this urban migration being the traditional way for poor people to gain access to better economic conditions.

People living in urban areas or migrating to developed countries have greater access to global communications platforms like the Internet, TV, and mobile and fixed line phones.

These same technologies are aiding the dissemination of knowledge and taking education into a new dimension. While growth levels of higher education in the mature economies are flattening out, those in the rapidly developing economies are rising steeply. The number of well-trained

1 Projected development of world population



engineers in these countries is impressive. In the West, on the other hand, traditional disciplines like electrical engineering have declined resulting in severe shortage of skilled engineers.

With the gradual integration of China, India, and other developing countries into the world economy, hundreds of millions of working-age adults will join a more globally integrated labor market.

Globalization

Globalization is driven by new technologies, new economic relationships and the national and international policies of a wide range of actors, including governments, international organizations, business, the media, labor and civil society.

The impact of globalization on individual societies is multi-faceted. The mechanisms by which the flow of trade, capital, ideas and people cause economies and societies to change are highly complex.

The world economy is projected to grow by about 40 percent between 2005 and 2015, and average per capita income by 25 percent. Large parts of the world will enjoy unprecedented prosperity, and a middleclass population could be created for the first time in some formerly poor countries.

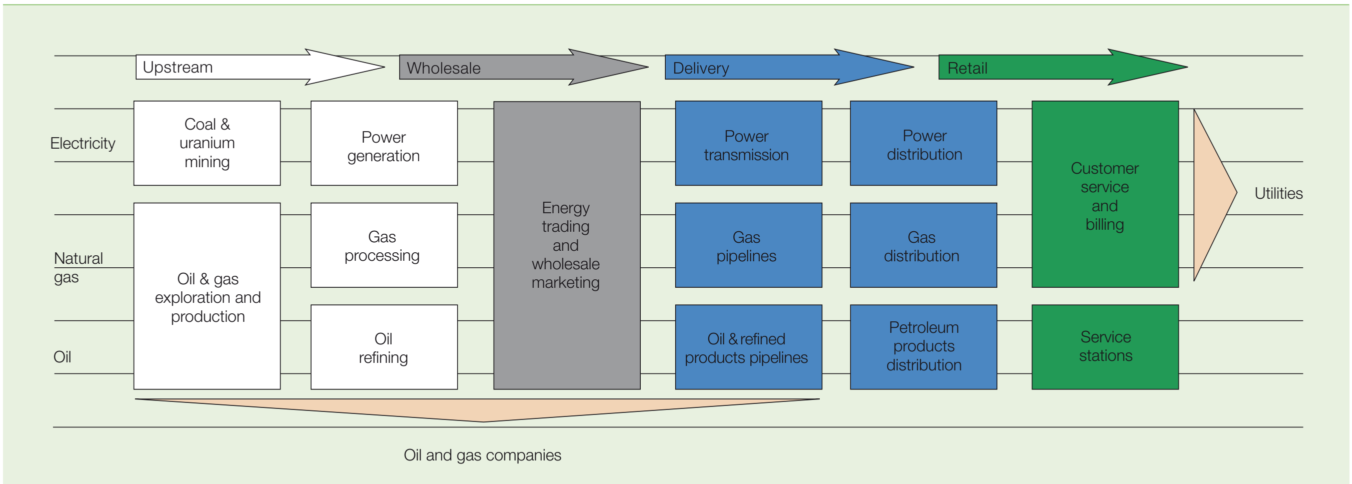
With the gradual integration of China, India, and other developing countries into the world economy, hundreds of millions of working-age adults will join a more globally integrated labor market. Existing patterns of production, trade, employment and wages will be transformed.

The greatest benefits of globalization will accrue to those countries and groups that can access and adopt new technologies. The growing two-way flow of high-tech brain power between the developing world and the West, the increasing size of the computer-literate workforce in developing countries, and efforts by global companies to diversify their high-tech operations will foster the spread of new technologies. Information and communication technology (ICT) is an important driver of globalization, facilitating the borderless exchange of ideas, opinions, and data at high speed. It enables multinational companies to work across time zones and obtain an advantage over companies based in only one location.

Continuous restructuring of the energy industry

The global energy industry is undergoing continuous restructuring. Processes like liberalization and deregulation, market consolidation, the spread of wholesale energy trading and the commoditization of electricity and gas

2 Energy industry value chain



are changing the very nature of energy trading. Large-scale investment in renewable forms of energy by oil and gas majors, the development of enabling technologies for ultra high voltage transmission and the storage of electric power, combined with political intervention by governments to stimulate or discourage trends and technologies are all influencing the energy industry across the entire value chain 2.

A key factor affecting the structure of the world energy industry is the liberalization and privatization of electricity and gas markets. However even after almost 25 years there is still no clear picture of the effects of these actions. Market liberalization is opening up a new era in wholesale electricity trading. European countries are not liberalizing at the same tempo, which means there is considerable variation in power trading arrangements, ranging from central dispatch to exchange-based models. The ultimate objective is a market in which gas and electricity are traded as commodities with flexible and innovative products and services.

Another factor that drives the restructuring of the energy industry is the need for additional investment in energy infrastructure to meet the growing demand for energy services worldwide. Investment is required to replace capacity that is being retired, expand supply where needed, and cover the cost of cleaner energy systems.

Politicians drive restructuring by using subsidies and taxes, supported by corresponding laws and regulations, to develop and encourage the use of renewable energy, increase environmental awareness and promote energy savings.

However, small-scale renewable power generation is unlikely to have a major influence on the structure of the energy industry in the medium term.

Another driving force is the lack of supply reliability that the various blackouts of 2003 revealed. The fact that energy security has many dimensions such as safe energy supply based on market economics; technological, environmental, social and cultural aspects, as well as being of military strategic importance, adds to the complexity of the restructuring process.

The future of primary energy resources

Most forecasts on future patterns of energy see a continuously rising demand for primary energy in the first two decades of this century. This can best be described as an extrapolation of past development, even though consumption is shifting significantly to emerging economies, in particular China and India.

The primary energy resources of oil, coal, natural gas, and uranium will all still be available in 2020 and beyond. The International Energy Agency (IEA) estimates that a total investment of $16 trillion will be necessary over the next three decades to meet the expected surge in demand for energy, of which 60 percent will be required for power plants and transmission and distribution networks.[1)]

The correlation between primary energy and gross domestic product has been strong in the past but is expected to lessen over time with the increasing use of energy-efficient technologies in some regions. Nevertheless, global economic growth as a whole will still proceed hand in hand with a rising demand for energy over the next 20 years.

Covering almost 38 percent of world energy consumption oil is expected to remain the dominant energy source in the next two decades, even though more than 30 percent of the resources required have yet to be discovered. Natural gas remains an important source of energy for power generation (about 30 percent). Because it produces lower CO_2 emissions, natural gas is an attractive choice for greenhouse gas mitigation.

Consumption of coal will increase in almost all countries except Western Europe. The largest increase is projected for China and India, both of which have huge deposits. These two countries will account for 72 percent of the worldwide increase in coal consumption.

Nuclear power may again become popular in the mature economies after a period of stagnation. Other primary energy resources like wind, wave, geothermal or solar energy will become part of the energy mix but are not expected to contribute significantly to global energy supply in the next 15 to 20 years. Many of the alternative technologies to fill the potential gap in energy supply are still at the development stage and might not become economically viable for some time. Energy savings, especially in the transportation sector,

Footnote

1) See also ABB Review 4/2004.

The world in 2015

could significantly extend the availability of oil. Biofuels of different types will also reduce this sector's dependence on oil.

> The growth in new business opportunities is compounded by uncertainty about the future of primary energy resources.

In summary, uncertainty about primary energy resources is driven by:
- Limited accessibility to energy resources for political reasons
- Limited availability of economically viable technologies for exploiting future resources
- Limited availability of alternative energy resources to replace traditional sources to a sufficient extent and at an affordable cost
- Limited use of fossil fuels to prevent impacting the environment and at affordable cost.

Changing electrical energy needs

With demand growing at a constant rate and with most of that growth taking place in developing countries, the regional differences in the way electricity is generated, distributed and used are likely to be accentuated. In the mature economies the ageing infrastructure poses a challenge. In emerging economies new installations have to be constructed and the need for technologies that protect the environment and reduce energy intensity is high on a global scale 3.

Although the energy mix for power generation is not expected to change significantly, those countries that increase the amount of renewable energy in their mix will need to address grid reliability. Transmission and distribution grids in many parts of the world are operating close to their capacity limits and although new grids are being built in the rapidly growing Asian economies, they are not being built fast enough to meet escalating demand.

The top priority for all countries will be to ensure a reliable supply of electric power with the cost of refurbishing existing grids or building new ones being a major challenge.

In China and India, this is leading to the construction of new power plants in remote locations close to primary energy sources. New transmission lines with the capacity to deliver large volumes of power are therefore required.

Many utilities see reliability as one of their most pressing concerns as the impact of poor reliability on society as a whole can be crippling. The blackouts in the United States are estimated to have incurred costs and lost revenues of more than 10 billion dollars, and are attributed to underinvestment in transmission and distribution capacity and the use of outdated technology and incorrect operating procedures.

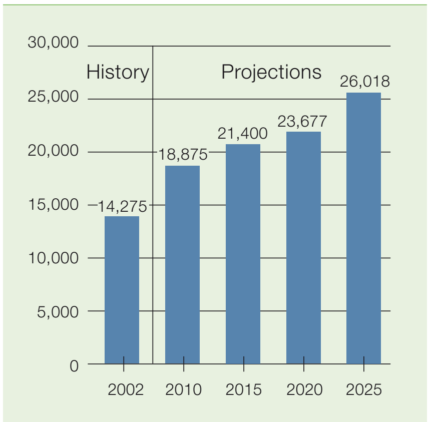
Attempts to reduce system losses are driven by environmental factors as well as the requirement for supply security. Modern transmission and distribution systems tend to lose 6–7 percent of the electricity they transport. Approximately 70 percent of those losses occur in the distribution system, which is more extensive than the transmission system and operates at a lower voltage level.

Not only utilities are keen to reduce losses. Electrical energy savings have a direct impact on the bottom line of industrial plants, commercial businesses and households. This drives the demand for energy-efficient electrical equipment like motors, drives and consumer appliances.

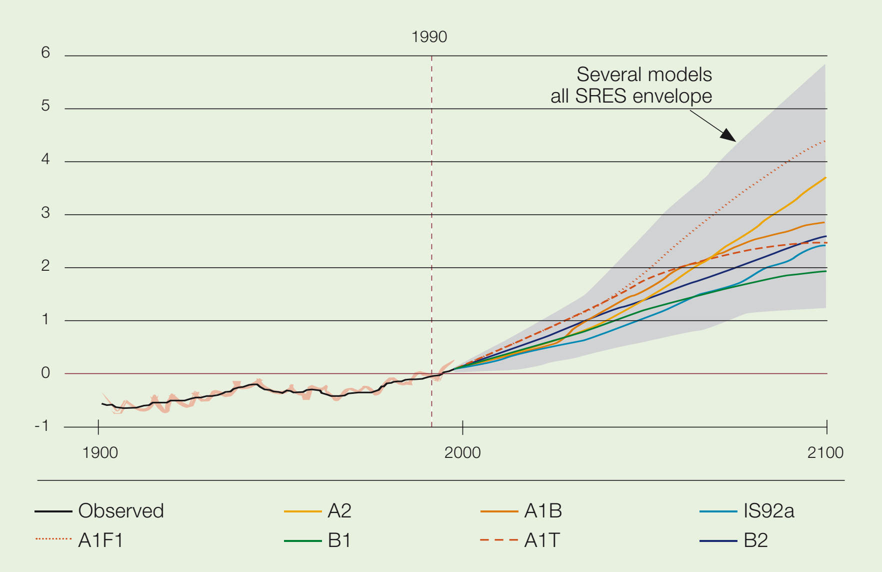
Technology development has opened new ways of managing grids. Progress in static reactive power compensation and power storage technologies enables new sources of electrical energy to be connected to existing grids. Power electronics have made it possible to control grids and new FACTS (flexible AC transmission systems) devices are improving controllability.

Technologies that save energy or improve efficiency are becoming more widespread. Low-loss and energy efficient power semiconductors are reducing losses in the grid. Continuous reductions in energy loss are being achieved by advanced motors and power-electronics-based variable speed drives.

3 World net electricity consumption in billion kilowatthours, 2002-2025. Source: IEA



4 Projected global temperature change from various models.
Source: Cambridge University Press, 2006



R&D initiatives on "smart" or "self-healing" grids that improve supply reliability are also driven by advances in information and communication technology.

The environment as a business factor
Even though the debate on the scale and impact of environmental change is ongoing, there is a consensus that the world has a set of compelling problems to solve like greenhouse gas emissions, climate change, and the depletion of natural resources 4.

The concern, perceived as most pressing in the world today, largely because of the global reach of its potential impact, is the growth in concentrations of greenhouse gases. The increasing importance of emission reducing technologies is a catalyst for new business opportunities. These opportunities lie in zero- and low emission technologies for the power generation and manufacturing industries, and in improving the energy efficiency of industrial processes and equipment by using efficient motors and applying variable speed drives.

The growth in new business opportunities is compounded by uncertainty about the future of primary energy resources. This is likely to intensify research into technologies for generating renewable energy and the use of alternative bio-fuels in the transportation industry. In recent years, the technologies used to burn fossil fuels of all kinds have improved tremendously. This applies to oil, gas and coal as well as to combustion engines in cars.

Nevertheless, the development of new technologies will most likely be driven by the tradeoff between the cost of these technologies and the various benefits they offer – tax breaks, lower emissions, reduced fuel consumption, and longer service life.

The renewed interest in building nuclear power plants may inhibit the spread of alternative forms of power generation. The tradeoff between clean energy restrictions and economic growth is, however, complicating the implementation of measures especially in the rapidly emerging countries.

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Looking back from 2015

An ABB analysis

Friedrich Pinnekamp

This study was conducted based on interviews, written statements and personal discussions with a large number of external experts, opinion leaders, politicians and members of the scientific community.

The majority of these authorities considered that a closing up of national economies is more likely than a move towards a global society. They further believed that the gap between the emerging and mature economies will continue to close, with both groups seeing some growth.

ABB is taking these indications seriously and is preparing for the various possible scenarios. Even though the uncertainty of the future direction is high, there is one overriding concern in all the scenarios – energy efficiency.

In the global and open society with virtually free access to energy for all, it is the general shortage of primary energy and shared environmental concerns that dictate the careful use of energy. If the world turns towards more protectionism, it is the lack of security in its supply that forbids excessive use of energy.

When the development of the emerging economies gathers speed again, it is once more the shortage of resources that hampers their growth. For a stagnating mature society it is simple economic reality that forces a reduction of energy consumption.

So, in the next decade, energy efficiency is the name of the game.

Assumption of growth rate measured at purchased power parity varies from five percent in the first scenario to three percent in the last.

	Open global society	Mature economies become more competitive
Economic growth	Prosperity has been taking hold of most regions over the last decade. Strong trading blocks (for example the European Union) exist, but their purpose is not protectionist – they are well integrated into a global economy.	Growth in the mature industrialized part of the world has been strong for a decade. It has been possible to maintain a balance between high standard of living and international competitiveness. Worldwide growth has not met earlier expectations, hence prosperity has not spread globally.
World characteristics	The world economy is globalized with free flow of goods, labor, technology and finance. The WTO has produced treaties to secure cross-border trade. Multinational companies prosper in this climate.	Governments of the mature countries have benefited from their export strength and secured markets beyond their own economies. Emerging economies have been more protectionist against foreign influence.
Attributes of societies	Societies have become well-integrated into the global market with their flexible labor forces. Most of the world's population has access to knowledge and electricity – both of these are foundations for prosperity.	Strong economic growth has enabled the mature economies to ease the burden of an aging population by attracting young and educated migration workers.
Energy market	Steady price rises for oil and gas have made energy efficiency a global priority. More and more alternative energy sources are becoming economical and the exploitation of previously uneconomical oil and gas finds is gradually being realised.	High energy prices underline conservation and alternative generation is having an impact. Liberalization of the energy market is ongoing. To secure energy in a world of dwindling primary resources, many bilateral agreements have been made between increasingly powerful suppliers.
Power grid	The electricity grid is being expanded all over the world to reach most of the global village. There are no signs of consolidation and power sales remain in the hands of suppliers.	The replacement of outdated infrastructure has had a positive influence on the competitiveness of mature economies. The volume of new grid installations in the developing countries has been lower than expected.
Environment	Climate change, biodiversity and the health of the environment are concerns of more people than ever. Political leaders and large companies in all economies of the world are tackling the issue of energy efficiency and global warming, a concern that has now gathered momentum.	Trading schemes for CO_2 reduction have been established in most mature economies. Fuel for transportation is increasingly being derived from oil-independent sources (which are mainly promoted in mature economies).
Technologies	The opportunity to develop modern grids has provided impetus for the introduction of new technologies such as ultra-HVDC and ultra-HVAC, current limiters, high power circuit breakers and super conductive systems. New methods for energy storage have promoted renewable generation.	The positive economic climate in the mature economies has spurred R&D investments in both the public and industrial sectors beyond expectation.

Emerging economies get stronger	Retreat into protectionism
Having failed to reform early in the new century, the mature economies struggle to keep up with the exceedingly exuberant developing nations, primarily in Asia: China, India, South Korea and to some degree the Middle East have capitalized on their increasingly educated but still cheap labor force.	Stagnation in the global economy, including recession in some parts of the world, has lasted for a decade. Global trade has slowed significantly and domestic markets have grown in importance. Western economies have been affected by the slowdown in Asia, an area that could not maintain its past growth rate. International cooperation is limited. Nations are becoming introverted and are seeking self-sufficiency.
Globalization has facilitated the full participation of emerging economies on the global market. WTO treaties were sufficiently effective to promote international trade between most regions. Multinational companies have adapted their global footprint to better make use of the strengths of the various regions.	Asia is affected by social unrest, environmental challenges and over-heated economies. The WTO has failed to provide a foundation for sustained international trade. Disappointed governments have turned to protectionism, resulting in decreasing standards of living even in the mature economies. Movement of people and labor, knowledge and technology is restricted.
As conditions in the developing nations have improved, migration of skilled labor has slowed considerably. Living standards are improving and these nations are driving global consumerism.	A large number of people in the world are still without electricity, a situation unlikely to change due to financial difficulties in these countries and the tough investment climate. Access to information remains restricted in countries with closed societies.
Energy demand has increased beyond what was planned for a decade ago. To meet this great need for primary energy, the development of energy efficiency and alternative energies including nuclear are high on the agenda everywhere. Bilateral energy agreements are sought wherever possible in an attempt to secure access to limited resources.	Global stagnation has reduced the expected energy demand compared to forecasts of 10 years ago. The need for primary energy is still acute, but with protectionism and the desire for self-sufficiency in ascendance, energy efficiency measures, alternative energy and nuclear power are prioritized. Difficulties in securing access to primary energy through long-term bilateral agreements have grown as supplying countries are closing ranks to drive up prices. The risk of war over energy is escalating.
The mature economies have only partially been able to replace their outdated electrical equipment and networks. Large investments in new infrastructure has, however, gone into the emerging economies in an attempt to redress the imbalance between supply and demand in those areas.	In response to the black-outs of ten years ago, the mature economies have squeezed existing infrastructure to its limits without major investments in the electrical grid. Many grid interconnections were planned but only a few implemented. The emerging countries have been installing new grids but not at the pace intended.
Due to environmental awareness in the emerging economies, these have succeeded in implementing the necessary regulations to control their pollution. The latest technologies are playing an important part in making this possible. The global expansion of nuclear power, promotion of renewable energy and energy efficiency measures have reduced the threat of energy shortage.	As global cooperation has crumbled, so has the worldwide initiative related to climate change issues and CO_2 trading. National initiatives driven more by local priorities for clean air than any global concerns have taken their place. Alternative fuels are slowly entering the markets of the mature economies.
The insatiable energy demand of the emerging economies has led to the installation of cutting-edge technologies for high productivity generation and transmission of electricity. Combined with the latest energy efficiency applications in new factories, this has resulted in these young economies gaining further advantages over their more mature competitors.	Only few new technologies for generation, transmission and energy savings have been introduced in the energy sector.

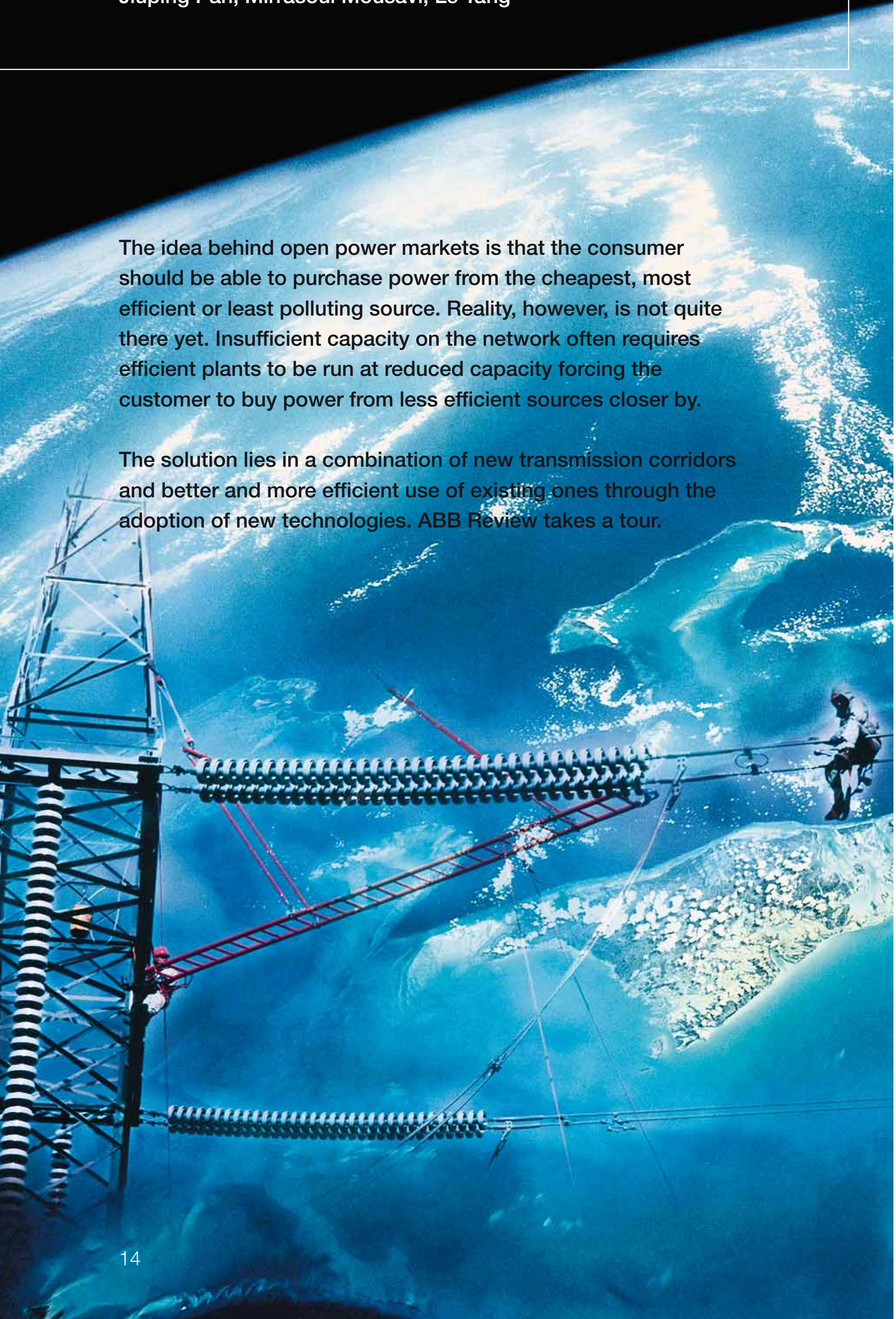
Power to be efficient

Transmission and distribution technologies are the key to increased energy efficiency

Enrique Santacana, Tammy Zucco, Xiaoming Feng, Jiuping Pan, Mirrasoul Mousavi, Le Tang

The idea behind open power markets is that the consumer should be able to purchase power from the cheapest, most efficient or least polluting source. Reality, however, is not quite there yet. Insufficient capacity on the network often requires efficient plants to be run at reduced capacity forcing the customer to buy power from less efficient sources closer by.

The solution lies in a combination of new transmission corridors and better and more efficient use of existing ones through the adoption of new technologies. ABB Review takes a tour.



The electrical energy generated by power plants is delivered to the end users hundreds to thousands of miles away via a network of interconnected transmission and distribution wires 1 2 3. Key components on this network include transmission towers, conductors/cables, transformers, circuit breakers, capacitors/reactors, HVDC/FACTS devices, and monitoring, protection, and control devices. In general, the network that delivers energy over long distances from power plants to substations near population centers and operates at high voltages is called the bulk power transmission network. The distribution system delivers energy from the substation to end users over shorter distances, is less interconnected and operates at lower voltages. The transmission and distribution (T&D) system is designed to ensure reliable, secure, and economic operation of energy delivery, subject to load demand and system constraints.

The blackouts of recent years provide testimony to the lack of sufficient reliability and optimization capability in T&D systems on all continents.

A T&D system can be designed to provide three levels of services 4:

The first level of service provides the minimum level of connectivity and energy transfer capability under normal operation conditions. This is the most basic service. If this service fails to live up to its requirements, economic development of the areas served is compromised.

The second level of service allows for secure and reliable service to consumers in the event of plausible component failures. It requires redundant paths between power plants and consumers and thus a higher level of redundance in T&D capability.

The third level of services enables the optimization of geographically distributed and diverse energy resources to achieve maximum social and economic welfare. This can include optimizing the utilization of the various power plants to reduce the greenhouse gases that may contribute to global warming, and maximizing the overall economic efficiency of meeting the energy demand through market-based energy transactions. Such optimizations are simply not possible without sufficient T&D capabilities beyond the level required by the second level of service.

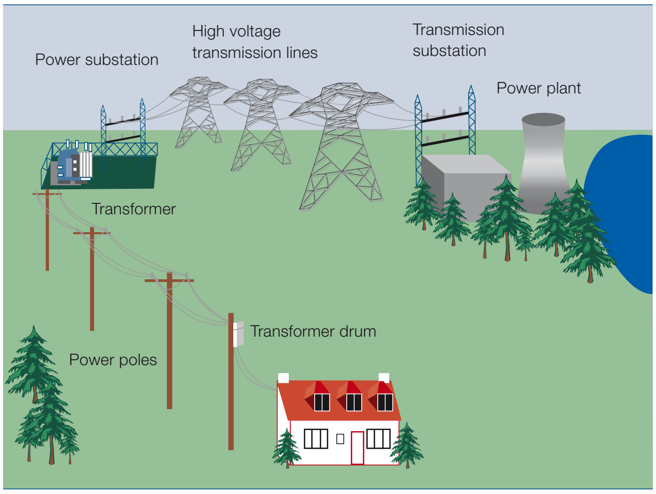
Unfortunately, most T&D systems in the world today achieve only the second level and partially the third level service. The blackouts of recent years Factbox provide ample testimony to the lack of sufficient reliability and optimization capability in T&D systems on all continents.

As is illustrated in the following section, a well built T&D system also affects the level of energy efficiency in power delivery.

Inadequate T&D hinders energy efficiency: An example from North America

Sufficient transmission and distribution capacities are an essential prerequisite for the efficient operation of electric power systems through the optimization of generation resources and loss minimization in the energy delivery system. Due to significant under-investment in network expansion and modernization, current T&D infrastructure in the United States often forestalls such measures 5.

1 Transmission and Distribution systems connect the power plants to the end users (source: www.howstuffworks.com)



Factbox Significant power outages in recent years

North America	14-Aug-03
London	28-Aug-03
Denmark/Sweden	23-Sep-03
Italy	28-Sep-03
Greece	12-Jul-04
Australia	14-Mar-05
Moscow	25-May-05
European blackout	4-Nov-06
Victoria, Australia	17-Jan-07
South Africa	18-Jan-07
Colombia	26-Apr-07

Transmission congestion issues in the United States

Transmission congestion occurs when flows of electricity across a line or piece of equipment must be curtailed to keep the flow levels under the limits required, either by physical capacity or by system operational security restrictions. Power purchasers always look for the least expensive source of energy available to transmit across the grid to the load centers. When a transmission constraint limits the amount of energy that can be transferred safely to a load center from the most desirable source, the grid operator must find an alternative and more expensive (or less efficient) source of generation to meet the system demand. An industry survey in 2003 examined the six operating ISOs[1] in the United States including New England, New York, PJM[2], Midwest, Texas, and California [1]. This survey found that the total congestion costs experienced by the six ISOs for the four-year period from 1999 to 2002 totaled approximately $4.8 billion. Public data available from the RTO-administered[3] energy markets have

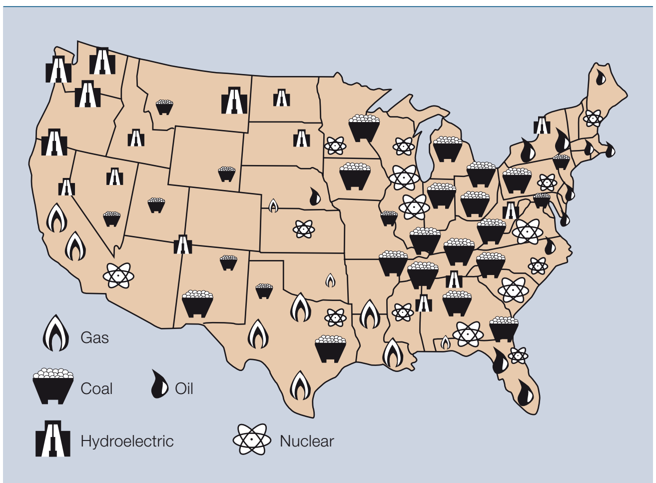
Footnotes

1) ISO: Independent System Operator

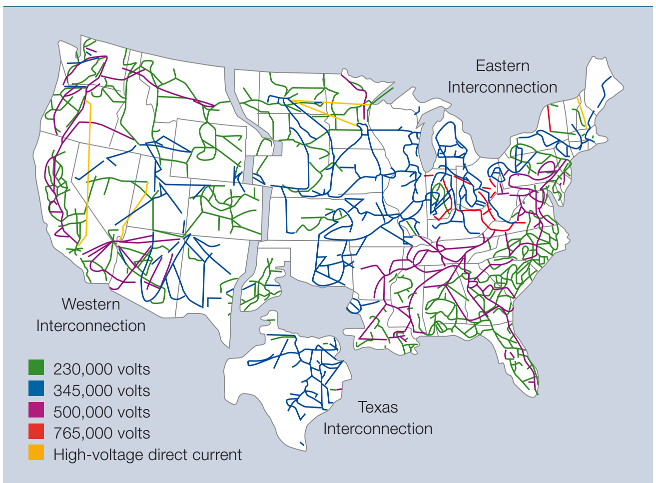
2) PJM: Pennsylvania New Jersey Maryland Interconnection

3) RTO: Regional Transmission Organization

2 Power plant locations in the United States (source: US Department of Energy)



3 Transmission grid in the United States (source: US Department of Energy)



Energy efficient grids

shown increased congestion costs over time. A more recent study has indicated that, based on the reported congestion costs for New York ISO and PJM from 2001 to 2005, the total congestion costs are nearly $ 1 billion per year in New York and more than $ 2 billion per year in PJM [2]. Transmission congestion also calls for frequent transmission load relief actions 6. When demands are very high and local generation is limited, grid operators may have to curtail service to consumers in some areas to protect the reliability of the grid.

HVDC transmission is more efficient for long distance bulk power transfer when using overhead lines. HVDC systems can carry 2–5 times the capacity of an AC line of similar voltage.

Electricity losses in T&D systems

Transporting power from the generation source to the load always involves some losses. These losses add to the total electrical load and so require additional generation, hence wasted resources. Overall, the losses in transmission and distribution systems account for 6 to 7.5 percent of the total electric energy produced [3]. Typical losses are about 3.5 percent in the transmission system and about 4.5 percent in the distribution system. Losses vary greatly in terms of network configuration, generator locations and outputs, and customer locations and demands. In particular, losses during heavy loading periods or on heavily loaded lines are often much higher than under average or light loading conditions. This is because a quadratic relationship between losses and line flows can be assumed for most devices of power delivery systems. The annual monetary impact of T&D losses is estimated at over $ 21 billion (based on the average national retail price of electricity and the total T&D losses in 2005 [3]).

In recent years, T&D losses in the United States have been marked by an increasing trend, mainly due to increased power transactions and inefficient T&D system operations 8.

Technologies to improve efficiency in transmission and distribution systems

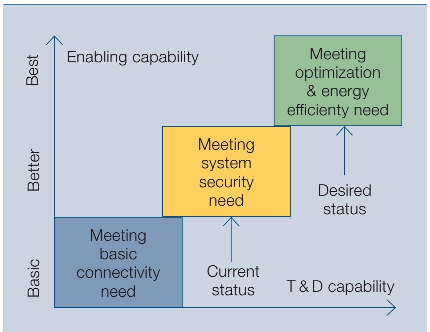
Technology options for improving efficiency of transmission and distribution systems may be classified into the following three categories:

- technologies for expanding transmission capacity to enable optimal deployment and use of generation resources
- technologies for optimizing transmission and distribution system design and operations to reduce overall energy losses
- new industry standards for energy efficiency power apparatus

Expanding transmission capacity to enable optimal deployment and use of generation resources

There are three major technology options that permit transmission capacity to be augmented: building new lines – AC or DC, upgrading existing lines, and utilizing existing lines closer to the thermal limits.

4 The three levels of services provided by transmission and distribution systems



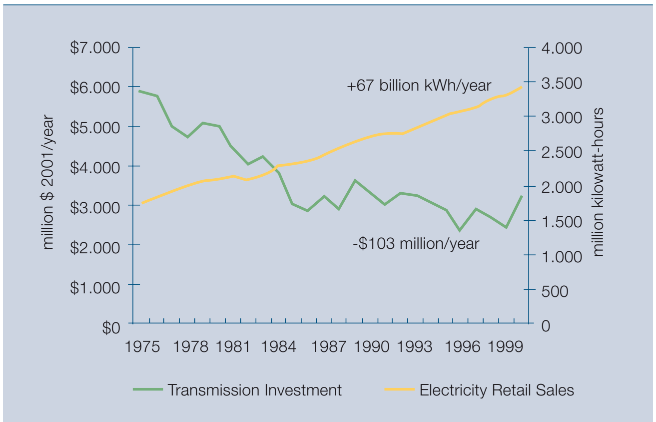
Constructing new lines

There are two technological options for new lines: high voltage AC (HVAC) and high voltage DC (HVDC). Thermal constraints typically limit transmission capacities of HVAC lines to 400 MW for 230 kV, 1100 MW for 345 kV, 2300 MW for 500 kV and about 7000 MW for 765 kV. However, in addition to these thermal constraints, the capability of AC transmission systems is also limited by voltage constraints, stability constraints and system operating constraints. As such, the power handing capability of long HVAC transmission lines is usually lower than these values.

HVDC

HVDC transmission is more efficient for long distance bulk power transfer (eg over 600–1000 km) when using overhead lines 9. HVDC systems can carry 2–5 times the capacity of an AC line of similar voltage 7. The environmental impact of HVDC is more favorable than AC lines because less land is needed for the right-of-way[4]. HVDC transmission has been widely used to interconnect AC systems in situations where AC ties would not be feasible on account of system stability problems or different nominal frequencies of the two systems. In addition, HVDC transmission is also used for underwater cables longer than 50 km where HVAC transmission is impractical because of the high capacitances of the cable (otherwise intermediate compensation stations would be required). A recent development in HVDC transmission utilizes a compact voltage source converter with IGBT[5] technology permitting an improved quality of supply in AC power networks. The technology uses small and

5 Transmission investment is falling behind electricity demand growth (source: EEI)



Footnotes

4) See also "Light and invisible, Underground transmission with HVDC Light", Dag Ravemark, Bo Normark, ABB Review 4/2005 pp 25–29.

5) IGBT: Integrated Gate Bipolar Transistor (a power electronic switching device).

low profile converter stations and underground cable transmission – reducing environmental impact. This technology, which is called HVDC Light™, opens up new possibilities for improving the quality of supply in AC power networks with rapid and independent control of active and reactive power, emergency power support and black start possibility.

Efficiency of HVDC

Losses in an HVDC system include line losses and losses in the AC to DC converters. The losses in the converter terminals are approximately 1.0 to 1.5 percent of the transmitted power. This is low compared to the line losses, which are a function of conductor resistance and current. Since no reactive power is transmitted in DC lines, line losses are lower for DC than for AC. In practically all cases, the total HVDC transmission losses are lower than the AC losses for the same power transfer 7.

Obstacles to new lines

One significant barrier to line construction, whether AC or DC, is the cost allocation controversy. Lines frequently cross regions in which the local benefits are questionable. Should these costs be socialized or should they be allocated directly to the benefactors only? This remains an area of disagreement in politics and society.

Even if a line has financial support, the issue of permitting and siting can become a long, arduous process that many utilities struggle with for years. By the time permission is finally granted, the requirements may have changed and additional studies be needed.

Upgrading existing lines

There are three ways to upgrade the capacity of existing lines: raise the voltage, increase the size and/or number of conductors per phase, or use high-temperature conductor materials. Increasing a line's voltage reduces the current required to move the same power. An upgrade from, 230 kV to the next voltage level of 345 kV for example, increases a line's capacity from about 400 MW to 1100 MW.

A high-temperature conductor is capable of transmitting two to three times more current than conventional power lines of the same diameter without increasing structure loads.

Reconductoring

Since a conductors' resistance is approximately inversely proportional to its cross-section, increasing this cross section or adding parallel conductors increases the line's current-carrying capacity. For instance, A 230 kV line can be increased from 400 MW to 1100 MW by adding new, larger and bundled conductors.

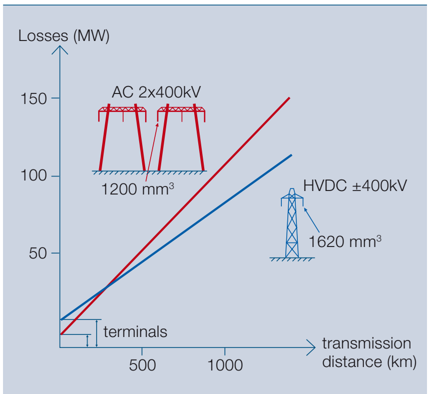
Recent technological development in the area of high-temperature conductors provides an effective way of mitigating thermally constrained bottlenecks for short- and medium-length lines. A high-temperature conductor is capable of transmitting two to three times more current than conventional power lines (ie, aluminum-steel reinforced conductors – ACSR) of the same diameter without increasing structure loads.

For both of the above options (raising voltage or reconductoring), the same right-of-way is used and new land use is normally not required. However, because of the increased weight of the new conductors or increased insulation requirements, the towers may need to be strengthened or rebuilt. The major substation equipment, such as transformers and circuit breakers may also need to be changed.

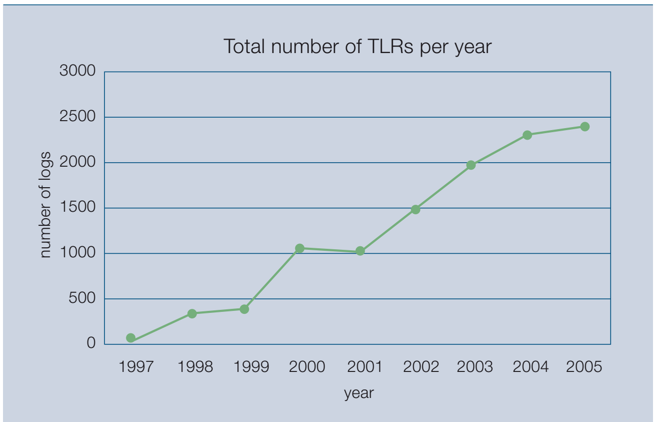
New lines or upgrades?

The issue of constructing new lines versus upgrading existing corridors is

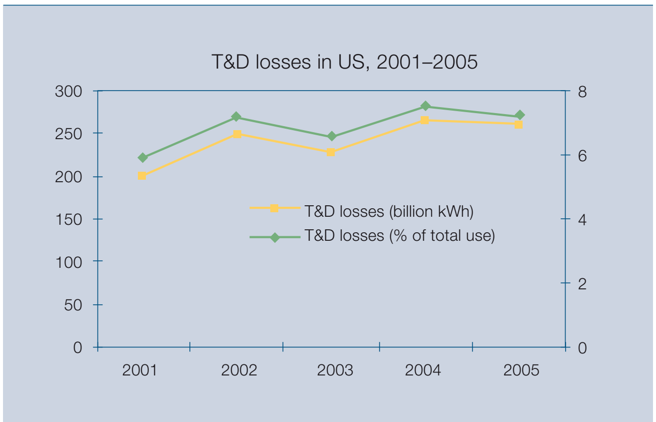
7 HVDC lines have lower transmission losses over long distances than HVAC lines



6 Transmission loading relief (TLR) incidents are on the increase (source: NERC)



8 Transmission and distribution losses in the USA, 2001–2005 (source: EIA)



9 An HVDC station: HVDC is seeing increasing use in bulk transmission over long distances and other applications

10 FACTS equipment increases the capacity and stability of AC lines

certainly not determined by technical questions alone. As mentioned earlier, the process of obtaining permission to build a line takes many years in the U.S., and there is no guarantee of success. However, the DOE[6] recently issued two draft designations for national interest electricity transmission corridors as part of the implementation of the EPACT 2005[7]. This is intended to simplify the permit-granting process in order to speed up the construction of large lines in the most critically congested areas.

Make full use of transmission capacity

In many cases, transmission lines are operated well below their thermal loading capacity due to voltage constraints, stability constraints, or system operating constraints. Several technologies are available and are being applied to improve the utilization of the transmission capacity. The phase-angle regulator (PAR) is the device most often used to remove thermal constraints associated with "parallel path flow" or "loop flow" problems. Series capacitor compensation is another commonly used technology for increasing transfer capability of long-distance HVAC transmission lines. A family of devices based on power electronics technology, often referred to as FACTS devices (Flexible AC Transmission System)[8] can be used to enable better utilization of lines and cables and other associated equipment such as transformers 10. The simplest of these devices are the thyristor controlled capacitor and reactor banks (SVC) that have been widely used to provide quick reactive power compensation at critical locations in the transmission grid. Another commonly used device is thyristor-controlled series capacitors (TCSC) that can provide reactive compensation as well as damping of power system oscillations. More sophisticated use of power electronics is employed in what is called static synchronous compensators (STATCOM). This device can absorb and deliver reactive power to the system based on the variations of the system voltage fluctuations. The most sophisticated of these devices is the Unified Power Flow Controller (UPFC). The UPFC can regulate both real and reactive power in a line, allowing for rapid voltage support and power flow control. It is estimated that FACTS devices can boost the transmission capacity of lines now limited by voltage or stability considerations by as much as 20 to 40 percent.

11 Distribution transformers account for a considerable part of total transmission and distribution losses. New materials help reduce these losses

Potential benefits of building and operating unconstrained transmission grids

Reduce the prices for electricity

The operation of unconstrained transmission grids provides cost effective generators access to the load and so increases the efficiency of the electric power market. The operation of an unconstrained transmission grid has the potential advantage that it may permit full use of the regional load shape diversity that may result from weather condition differences and time zone differences. As a result, efficient generation resources can be dispatched at full capacity for more hours, permitting the usage of less economic resources to be reduced.

> Losses vary greatly in terms of network configuration, generator locations and outputs, and customer locations and demands.

Improve system reliability

Unconstrained transmission grids will potentially improve overall system reliability. At the given level of capacity

Footnotes

6) DOE: Department of Energy (USA)

7) EPACT: Energy Policy Act

8) See also "Grid flexibility, FACTS: novel means for enhancing power flow", Rolf Grünbaum, Johan Ulleryd, ABB Review 4/2005 pp. 21–24.

reserve, an unconstrained transmission grid can provide adequate emergency power from adjacent (interconnected) regions to the region that is experiencing catastrophic multiple outages, such as the simultaneous losses of several generation units and transmission lines.

Promote emission reduction and fuel diversity

Unconstrained transmission grids provide opportunities to use generation sources with lower pollution, and to use more renewable energy sources located remotely from major population centers. The opportunity for greater fuel diversity will also contribute to national security goals to increase reliance on domestic fuel sources. It will also be helpful to keep a balanced regional generation resource mix such that a temporary shortfall of one type of resource will not cause significant problems.

> The use of superconducting conductors to replace copper in transformer windings can reduce the load losses significantly.

Reducing T&D energy losses through optimized system design and operation practices

The following are some of the most widely recognized loss reduction techniques in T&D system design and operation resulting in higher efficiency.

- Reconducting – replace a conductor with a larger conductor or add additional conductors in parallel.
- Voltage upgrades – upgrade a portion of the transmission or distribution network to a higher voltage level.
- Voltage optimization through reactive power compensation – install reactive power resources at chosen locations to minimize reactive power transfer on the T&D grids.
- Direct delivery of power to mega load centers through HVDC.
- Equalizing phase loading – improve the balance of phase currents of distribution systems.
- Superconducting materials at or near liquid nitrogen temperatures have the ability to conduct electricity with zero resistance. High temperature superconducting (HTS) cables now under development can carry three to five times the power of conventional cables with copper conductors. These cables can be used instead of overhead transmission lines or cables in places where environmental and space constraints prohibit the use of overhead lines. The load losses of HTS cables will be significantly lower than those of overhead lines or conventional cables, even when the power required for refrigeration is included. A major vendor of superconductors claims that HTS cable losses are only 0.5 percent of the transmitted power compared to 5 to 8 percent for traditional power cables. Furthermore, the use of superconductors to replace copper in transformer windings can reduce the load losses significantly. For the case of a 100 MVA transformer, the total losses (load losses, core losses and refrigeration power) can be 65 to 70 percent of that of a conventional transformer.

Other notable technologies and design practices that can increase the efficiency of the grid include:

- more underground distribution lines – these could save up to 80 percent of distribution losses
- DC distribution networks
- microgrids to eliminate long distance transmission
- intelligent automated grid design
- real-time online control systems
- load management through smart metering
- energy storage devices

The estimated potential for improving energy efficiency directly through transmission and distribution loss reduction is higher than 1 percent of total delivered energy. This will result in an annual savings value of $3 billion dollars[9].

Footnotes

[9] Assuming the 2005 U.S. national average retail electricity price.

[10] 1 Quad = 10^{15} BTU = $2.931 \cdot 10^{11}$ kWh = $1.055 \cdot 10^{18}$ J

Improvements of energy efficiency of power apparatur

Another key to upgrading the efficiency of T&D systems lies in the improvement of the energy performance of power apparatus. This could be implemented as part of a program to better manage energy demand, contribute to the security of energy supply, and mitigate climate change.

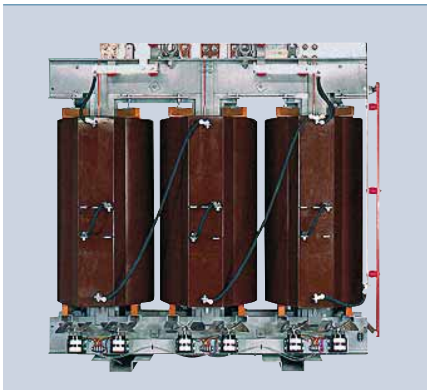
Transformers

Distribution transformer losses in particular make up a considerable fraction of the total loss incurred in transmission and distribution systems 11 12. Based on a study of the Pacific Northwest transmission and distribution systems, it was found that distribution transformers accounted for over 30 percent of losses while substation transformers contributed only 2 percent [4]. With their widespread application and long life span, distribution transformers represent a great energy saving potential. From the energy savings point of view, even a minor increase of one-tenth of one percent in transformer efficiency leads to significant energy savings as most transformers are energized around the clock.

Using currently available technologies, transformer losses can be reduced by at least 15 percent in a cost-effective manner.

Two types of losses are commonly evaluated for loss reduction: core losses and coil losses. Core losses are often referred to as no-load losses

12 Transformer load losses can be reduced through appropriate choices in the materials and geometry of windings



because they occur in the core of an energized transformer regardless of its loading conditions. When a transformer is energized 24 hours a day, every day, this loss amounts to substantial energy consumption over the transformer's life (typically 20–30 years). Coil losses, on the other hand, occur in the transformer windings and vary with loading conditions 13. Hence they are referred to as load losses.

Transformer no-load losses can be reduced by using magnetic core steel materials or optimizing their geometries. Increasing the core cross-section or decreasing volts per turn reduces the core losses by decreasing the core flux density. Decreasing the conductor cross-section also reduces the no-load losses by decreasing the path length of the magnetic flux. The caveat involved in these steps is that they typically result in increased load losses. Load losses can be reduced in a number of ways including the application of higher conductivity materials such as larger cross-section conductors or adopting copper conductors instead of aluminum conductors. Utilizing lower loss winding methods reduces the length of the winding conductors. Smaller magnetic core cross-sections and fewer turns also reduce the winding losses. Superconducting transformers, in particular, have minimum winding losses.

These explanations show that steps to reduce no-load losses often result in increased load losses and vice-versa. Hence, the transformer loss reduction is an optimization process involving physical, technological, and economical factors tempered by some form of life-cycle economic analysis. Most often, a trade-off has to be considered with respect to the core/winding material, design, and how the buyer evaluates the Total Cost of Ownership (TCO) of the transformer. Such an evaluation takes into account the initial cost of the transformer as well as the life cycle cost including losses.

The TCO is most often evaluated by electric utilities during the procurement process. Although industrial and commercial consumers directly pay for their energy losses, they are ironically less enthusiastic about TCO evaluations, due in part to their procurement practices and the relatively short transformer life cycles.

In many cases, transmission lines are operated well below their thermal loading capacity due to voltage constraints, stability constraints, or system operating constraints.

The energy efficiency of transformers is improving in many markets due in part to government policies and initiatives and market forces. The US Energy Act of 1992 required the DOE to provide a cost-benefit analysis of increasing energy efficiency for distribution transformers. The study performed by the Oak Ridge National Laboratory (ORNL) found that energy efficiency gains are technically feasible and may lead to substantial energy savings of 3.6 to 13.7 quads[10)] of energy over the period from 2000-2030 [5]. In 1995, the Environmental Protection Agency (EPA) launched the Energy Star Transformer program in partnership with electric utilities to promote and support the use of high-efficiency, cost-effective distribution transformers. This program is raising public awareness of energy efficiency as a means to reduce greenhouse gas emissions.

Energy efficient distribution transformers have recently been put in the spotlight worldwide 14. Canada, Mexico, and states of California, Massachusetts, New York, Minnesota, Vermont, Wisconsin, and Oregon have already adopted energy efficiency programs. Such programs are further supported and promoted by the Consortium for Energy Efficiency (CEE), a North American, nonprofit organization that promotes energy-efficient products and services.

Although no mandatory efficiency standards have been implemented to date, there are various industry standards for energy efficiency evaluation of distribution transformers. The National Electrical Manufacturers Association (NEMA) standards eg, TP-1, 2, 3 may be voluntarily adopted by transformer vendors for determining energy efficiency and measuring energy consumption of distribution transformers. NEMA TP-3 provides labeling guides for energy efficient transformers. The IEEE standard PC57.12.33 provides guidance for distribution transformer loss evaluation. This standard is in draft status and more detailed than NEMA TP-1.

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy recently issued a Notice of Proposed Rule Making (NOPR) that sets minimum energy-efficiency standards for liquid-immersed and medium voltage dry-type distribution transformers. The new efficiency requirements are expected to impact around 50 to 60 percent of the distribution transformers produced today. These transformers normally use the least costly and most readily available steel grades known in the industry as M4, M5, and M6. The proposed energy efficiency improvement requires the use of more efficient M2 and M3 steel grades for the grain-oriented silicon core steel. Furthermore, this requirement places additional demand on highly efficient core material as dry-type transformers are typically produced with non-grain-oriented core steel. As a result, the final cost of the transformer and availability of supply commodities for energy efficient transformers will be evident challenges in the implementation phase. The DOE will eventually mandate energy efficient transformers, but the implementation is unclear at present. Following the DOE mandate, NEMA documents will be adopted in some form in line with a worldwide energy efficient effort that is taking place in North American as well in IEC markets.

The way forward

The foregoing sections introduce technologies that can be applied individually or in combination to increase the efficiency of the power system. The world wide potential for energy saving is enormous. In the US alone, the potential for energy saving through transmission and distribution loss reduction is higher than 1 percent of total delivered energy, which has a market value of around $3 billion dollars. In addition, the savings in congestion costs amounting to billions of dollars annually can be achieved with enhanced T&D systems.

In addition, electric transmission and distribution is also the main enabler for optimizing the generation portfolio and reducing fossil fuel consumption through access to clean and renewable energy sources.

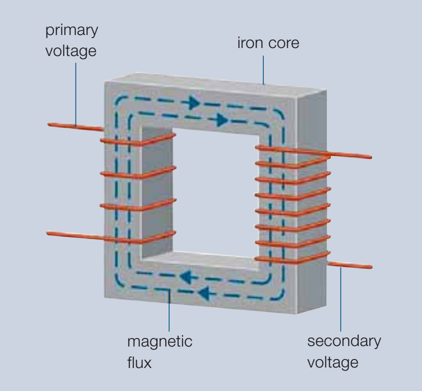
The following roadmap has been developed by the Business Roundtable Energy Task Force T&D working group that included leading U.S. utilities and T&D vendors.

> The operation of unconstrained transmission grids provides cost effective generators access to the load and so increases the efficiency of the electric power market.

- Adequate investment is needed to expand the network capacity and controllability to enable optimal deployment and use of power generation resources.
- Optimal network design and operation with advanced technologies and practices are essential to save energy.
- The establishment of new industry standards for energy efficient power apparatus is needed to reduce consumption.

Technologies to significantly improve the world's T&D system efficiencies are available today. Deployment of these technologies is not only an issue of balancing long-term benefits with costs but also an issue of conventional utility practices, supportive regulatory environments and societal support. ABB's advanced technologies and best design and operations practices will play a major role in improving the efficiency of the energy systems of the world.

13 Transformer principle (source: Precision Graphics)



14 An NA pole-top three phase transformer

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Ultra high voltage transmission

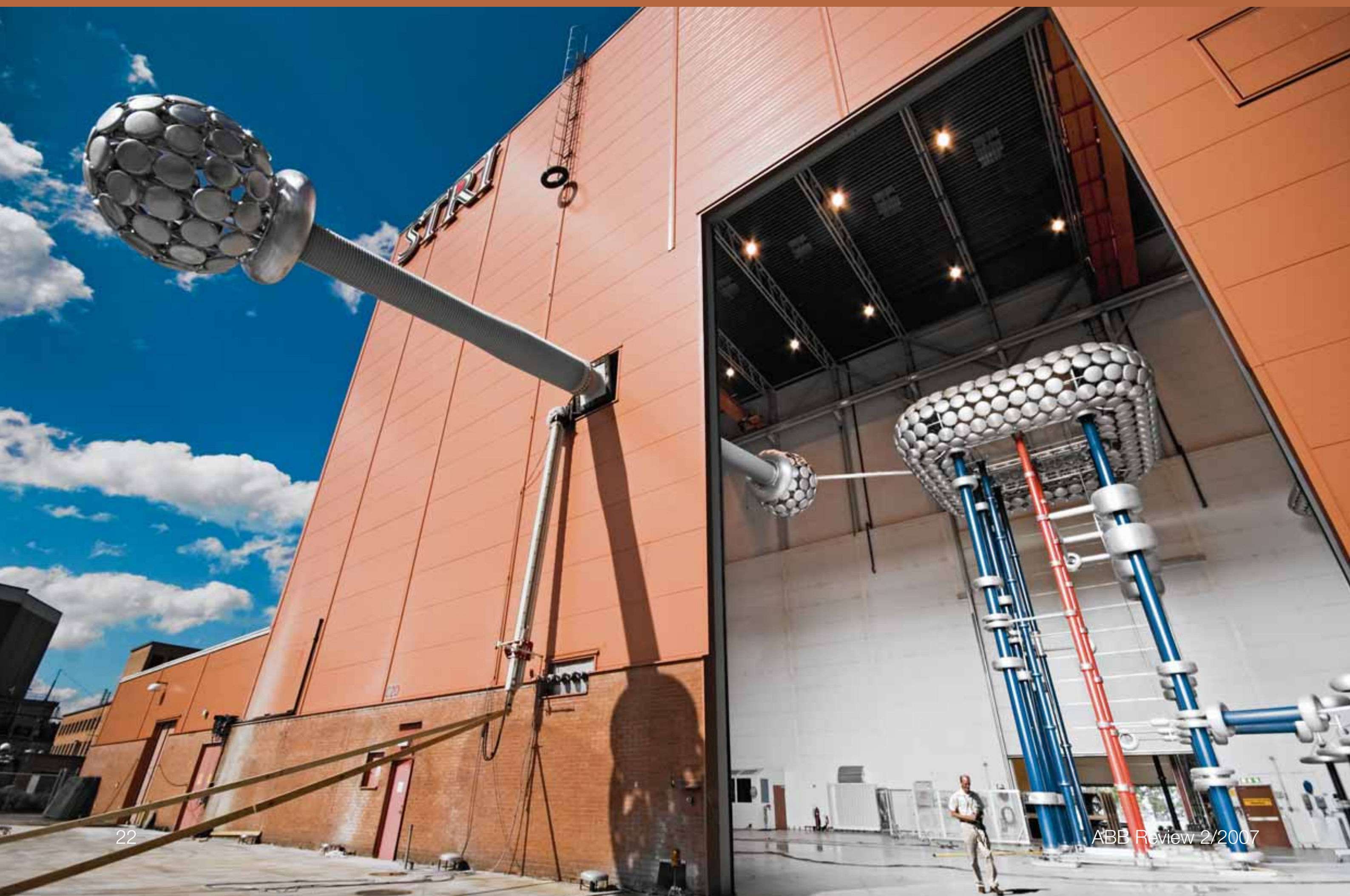
Alternative scenarios for long distance bulk power transmission – 800 kV HVDC and 1000 kV HVAC

Gunnar Asplund

Not only is global energy consumption steadily growing, but energy is increasingly being drawn from resources located far from the place of usage. The topic of transporting energy over long distances is growing in importance.

Oil is often shipped in super-tankers and gas in pipelines. Coal for electricity production uses rail transportation, a solution that can require the costly reinforcement of tracks. It may be more economical to generate the electricity close to the source of the coal and transmit it to the consumers. As many renewable energy sources such as hydropower, wind and sun, are location-dependent in their production, there is often no alternative to long-distance transmission.

The transmission of electrical energy is thus set to play an important and growing role. In this article, ABB Review looks at a recent development in the area of bulk power transmission.



From the advent of electrical transmission, AC has established itself as leading technology in electrical networks. Its advantage lay in the possibility of using transformers to raise it to higher voltage levels, facilitating economical transmission. Both AC and DC generators produce electricity at a relatively low voltage level. If this voltage were used for transmission over long distances, high and prohibitively expensive losses would ensue.

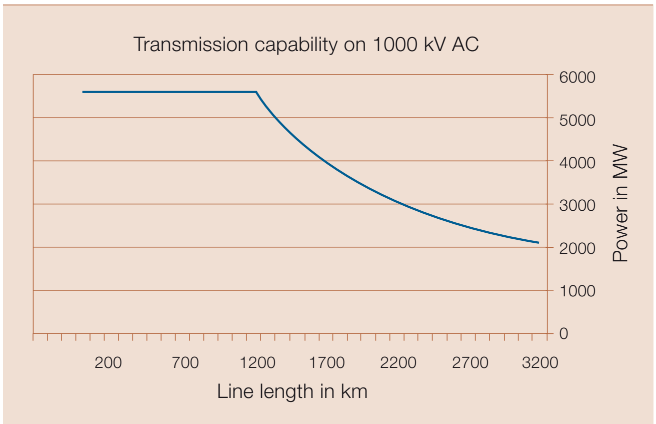
AC technology is also very flexible when connecting different locations to form an electric grid, permitting a very robust and reliable electric supply to the consumers.
In its early days, the question of reliability of supply was predominant: As generation took place relatively close to consumption, priority was not focused on transmitting large power quantities over large distances.

To render AC more suitable for such bulk transmission, a typical measure was the adoption of series compensation for lines. This works quite well when power is transmitted from one point to another, but is normally not used inside a meshed grid as the flow of power is more unpredictable.

The development of AC systems has seen continuing increases in transmission voltage. When power consumption is low, voltage can also be low. Typically, doubling the voltage quadruples the power transfer capability. Consequently, the evolution of grids in most countries is characterized by the addition of network layers of higher and higher voltages.

In OECD countries there was an almost exponential increase of electric power consumption until the oil crisis at the beginning of the 1970s. The impact of this crisis halted plans to go for higher voltages such as 800, 1000 and even 1200 kV.

1 The capability of an AC line degrades with increasing length: This graph is for a 1000 kV line with max. 70 percent compensation and 30 degree angle between terminals



Thirty years ago, the capacity of grids was largely in balance with demand. With the growth in consumption, this situation changed. Generation has increased in new places: For example, wind power parks are normally constructed in locations where the grid is weak. Deregulation of power generation has also lead to increased trade with more electric power transmitted over longer distances. This poses more stringent requirements on the transmission system.

The evolution of grids in most countries is characterized by the addition of network layers of higher and higher voltages.

In developing countries the situation is very different. It is more akin to the situation in OECD countries in the 1950s and 1960s. However, the rate of development is much higher, especially in China and India. Technology has advanced in the last thirty years, and solutions adopted do not necessarily have to follow the example set by OECD countries.

In developing countries, AC is being adopted for new grids, as indeed it was in other countries. It is, however, also used to some extent for transmission of power from distant generation sources.

AC transmission over long distances

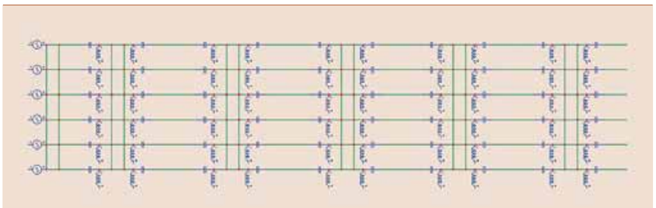
Prerequisites for a line built to transfer power over long distances are stability and the ability to survive faults such as lightning strikes. The design criterion that must be fulfilled is defined as N-i with i=1[1]. This means that the maximum power that can be lost without the stability of the AC system as such being compromised is equal to the power of the largest generating unit or the line with the highest capacity. If all power from a distant generating plant is transmitted on a single line, the AC system has to withstand the loss of all this power. If larger amounts of power are to be transmitted, several parallel lines must be used that are interconnected every 300 to 400 km to increase reliability.

AC lines have quite high power handling capability if short. The capability is dependent on the voltage and the thermal rating of the conductors. Longer lines have higher impedance and this reduces the power transfer capability. The equation for transfer of active power is:

$$P = \frac{U_1 \cdot U_2 \cdot \sin(\delta)}{X}$$

Where P is the active power, U_1 and U_2 the voltage at each end of the line,

2 Six parallel AC lines in six sections with series and shunt compensation. The line can continue to function despite the failure of individual components



Footnote

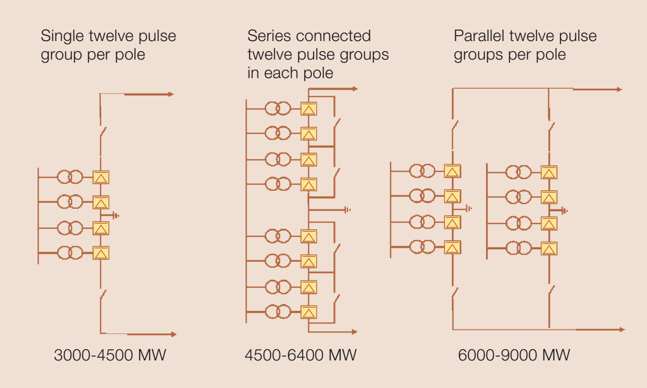
[1] The design criterion N-i defines the number of elements whose failure can be tolerated before the overall system loses functionality. Applying this to electricity networks, N represents the number of major components in the network (ie, generators, substations, lines etc), and i the number of these components that can fail at the same time without leading to instability in the network.

δ the phase angle between the two ends and *X* the line impedance.

As the length of the line increases, the impedance of the line increases with it. For the transfer power to be maintained, the angle δ must be increased. This is possible up to an angle of around 30 degrees, after which problems with dynamic stability can be encountered. The best way to overcome this problem is to reduce the impedance by series compensation. This can be done without significant problems up to a compensation of around 70 percent. At higher levels of compensation the system will be less robust 1.

When a line is loaded below SIL (surge impedance loading) it will produce reactive power; if shunt compensation is not added the voltage can rise excessively. If the line is loaded above SIL, it will consume reactive power and the voltage can drop too far. From a reliability point of view, it is necessary to build an AC transmission in sections with both series and shunt compensation as well as interconnection between the sections 2 in order to assure that full power transmission is possible at all times.

3 Alternative converter configurations for 800 kV HVDC line



Technical challenges

1000 kV and 1200 kV AC has been tested in several test-installations and even short-time commercial applications but is not currently used in any commercial application[2]. There are several challenges involved in building such lines and new equipment needing to be developed includes transformers, breakers, arresters, shunt reactors, series capacitors, current and voltage transformers, and connecting and ground switches.

There are also special requirements in the domain of control and protection. At single phase earth faults, the challenge is to clear the fault without opening the breakers of all three phases. The problem lies with the high capacitive current generated by the operating phases that flows into the fault. This can be achieved with the help of tuned reactors that minimize the induced current.

800 kV AC is fully commercial and all equipment are available. Development is ongoing for all equipment of 1000 kV AC.

800 kV DC transmission

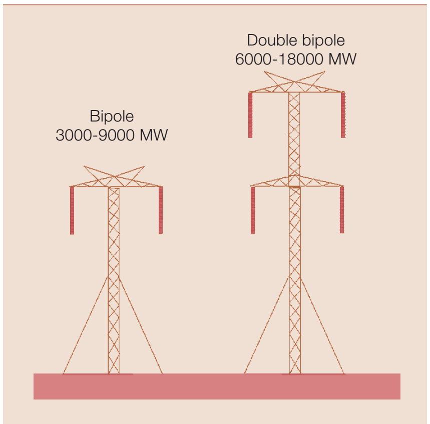
System aspects

The principle of DC transmission lies in converting AC to DC in a rectifier station, transmitting the power in a DC bipolar line and converting the power back to AC in an inverter station.

> Thirty years ago, the capacity of grids was largely in balance with demand. With the growth in consumption, this situation changed.

From a system point of view, DC is a simpler technology for transmission over long distances. The rectifier and inverter stations can control current and voltage very quickly and are therefore suitable for the control of power flow. The phase angle differ-

4 Using 800 kV HVDC, power transfer of up to 18000 MW is possible on a single right of way.



5 Extensive equipment testing is required before commercial 800kV HVDC can be offered commercially. These pictures show the transformer a, the transformer bushing b and the valve hall bushing (title photo, page 22) being tested in Ludvika, Sweden.

Footnote

[2] 1200kV AC was commercially operated on a line connecting Russia and Kazakhstan from 1989 to 1996. The line was taken out of operation due to the collapse of the Soviet Union.

ence between the sending and receiving end is of no importance if the only connection is DC. In fact, the connected networks can even be asynchronous as DC has no phase angles and does not depend on the frequency.

Faults on DC lines or in converters will give rise to increased frequency at the generating end and decreasing frequency at the receiving end – unless there is sufficient overload capability in the remaining pole, and parallel DC lines are available to handle the power difference. If the fault is permanent, a scheme to trip the generators should be implemented in order to maintain frequency stability in the sending network. This is normally only a problem if parallel synchronous AC lines exist; especially if their power rating is much lower than that of the DC lines – such lines can trip when the phase angles increase too much.

Configurations

For 800 kV HVDC, several converter configurations are possible 3. Possible line configurations are shown in 4.

Technical challenges

The highest voltage of HVDC today is 600 kV. The Itaipu project was commissioned more than 20 years ago and is operating two bipoles of ± 600 kV and transmitting 6300 MW over a distance of 800 km. 800 kV HVDC requires development of transformers, transformer bushings, valve hall wall bushings, thyristor valves, arresters, voltage dividers, DC filter capacitors and support insulators.

Technical achievements

Development has been going on at ABB for several years and all equipment that must be exposed to 800 kV has been designed, manufactured and tested. Some examples are discussed below:

Transformer prototype

A simplified transformer prototype has been manufactured, including all the insulation details for an 800 kV converter transformer 5a. The initial testing of the transformer prototype included:

- DC withstand 1250 kV
- AC withstand 900 kV

The tests were successfully passed.

Transformer bushing

A prototype of the transformer bushing for the highest 6-pulse group has been produced 5b. The bushing has passed all type and routine tests, including:

- DC withstand 1450 kV
- AC withstand 1050 kV

Wall bushings

The wall bushing is based on the well-proven design for the recent installations at 500 kV. Besides the electrical requirements, the 18 m length of the wall bushing (title picture page 22) has been a mechanical challenge. However, all electrical and mechanical type and routine tests have been passed successfully. Also the seismic withstand has been verified by calculations. The design and manufacture of the 800 kV wall bushing is completed, and the bushing is installed in the 800 kV test circuit, including:

- DC withstand 1250 kV
- AC withstand 910 kV

Deregulation of power generation has lead to increased trade with more electric power transmitted over longer distances. This poses more stringent requirements on the transmission system.

Long term test circuit

As a final demonstration of its feasibility, a long term test station has been built and put into operation. Here, all equipment is tested at 855 kV for at least half a year 6.

Station design

When designing 800 kV HVDC with a power of 6000 MW, it is important to design the station so that a failure of a single critical component results in a loss of only a fraction of the power. 7 8 shows a station with four power blocks. This can be configured in one of the following manners:

- Two poles each consisting of two series connected groups
- Two poles each consisting of two parallel groups.

6 Voltage withstand endurance testing on the 800 kV test circuit at STRI, Ludvika

Factbox 1 The ability of a combined AC and DC transmission to maintain stability despite the loss of DC links: scenario 1 11a with strong AC link

Number of lost DC groups	Number of parallel 500 kV lines									
	1	2	3	4	5	6	7	8	9	10
1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
2	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
3	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
4	no	no	no	no	yes	yes	yes	yes	yes	yes
5	no	no	no	no	no	no	no	yes	yes	yes
6	no	no	no	no	no	no	no	no	no	no
7	no	no	no	no	no	no	no	no	no	no
8	no	no	no	no	no	no	no	no	no	no

Successful testing

Based on all development work made the conclusion is that 800 kV is now available for commercial transmissions.

Comparison of AC and DC

Cost

10 provides a cost comparison between transmitting 12,000 MW over a distance of 2,000 km with AC and DC. 800 kV HVDC gives the lowest overall cost and the optimum is at the lowest losses in the line.

Advantages and disadvantages of AC

The major advantage of AC is the flexibility with which loads and generation along the route can be connected. This is especially important if the transmission route passes through a highly populated area and if generation facilities are located at many places along the route.

One disadvantage of AC is its cost. The system described above is quite expensive as, in reality, a full electric infrastructure has to be built along the route.

Another disadvantage is the requirement of land and right of way. As AC transmission cannot fully utilize the thermal capacity of each line when the line is very long, a line in parallel will have to be installed.

Advantages and disadvantages of DC

One major advantage of HVDC is its low cost for transmission of very high power over very long distances.

A second great advantage is that the losses are quite low. The total losses in the transmission of power over 2,000 km are in the order of five percent. The third major advantage is that fewer lines are needed with less right of way requirement. As mentioned above, transmission of 12,000 MW can be achieved with two lines using 800 kV HVDC. Transmitting the same power with 800 kV AC would require eight lines.

The main disadvantage of HVDC is that power is transmitted from one point to the other and that it is quite costly to build tapping stations (although it is possible and has been done).

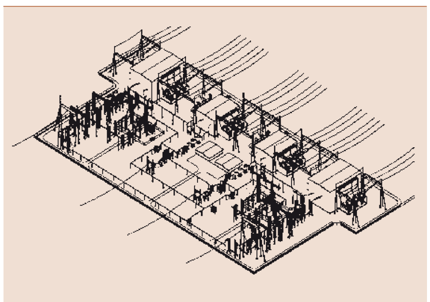
The major advantage of AC is the flexibility with which loads and generation along the route can be connected. This is especially important if the transmission route passes through a highly populated area and if generation facilities are located at many places along the route.

Combined AC and DC transmission

As mentioned above, the main disadvantage with HVDC is the high cost of the tapping of power along the line. However, a combination of low cost bulk power HVDC transmission in parallel with a lower voltage AC network could in many cases become the optimal solution in providing both low cost and high flexibility and the

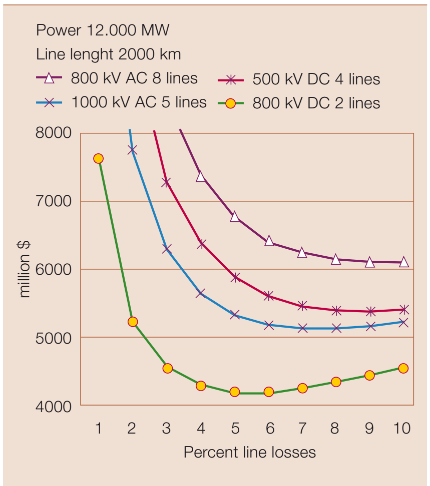
7 An HVDC converter station with four power blocks – the configuration is chosen to minimize the effects of individual component failures

8 An HVDC converter station with two poles each consisting of two series connected groups

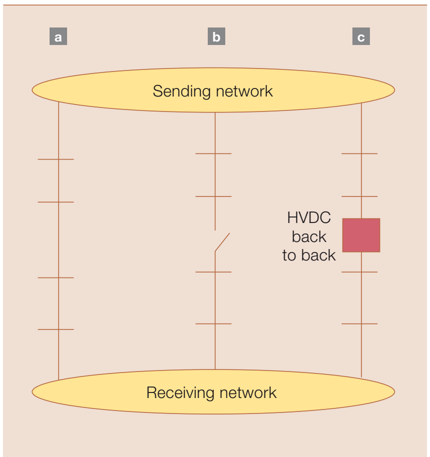


9 An artist's impression of the station of 8

10 The cost of stations, lines and losses as a function of the line losses



11 Three alternatives for combining AC and DC to connect two networks. In a, a strong AC link supports the DC, in b, the two AC networks are separated and in c the gap is bridged by an HVDC back to back link



ability to supply customer along the route.

There are however some technical problems with the combined AC and DC solution. Disturbances in the DC transmission will in many cases trip the AC connection as the phase angles becomes too large. This problem can be solved in various ways as is shown in 11.

Alternative 1

Option 11a uses a fairly strong AC connection that can withstand most disturbances in the DC connection without having to disconnect.

As an illustration, it is assumed that the HVDC transmits 12,000 MW over 2,000 km in two bipoles with each four converter groups. It is assumed that the HVDC can take a temporary overload of 50 percent if one or more groups should trip. Further, it is assumed that there is a parallel AC net of 500 kV lines that will have to pick up the power that the HVDC cannot transmit. The results in are shown in Factbox 1.

This table shows the system will remain dynamically stable after the loss of several DC groups. Each DC group has a power of 1500 MW. The outcome is dependent on the preloading of the AC-lines. Here it is assumed they are loaded up to 34 percent before the fault.

Alternative 2

Option 11b permits the two networks to operate asynchronously, each feeding half of the customers along the route. In this case there are no stability problems as the systems are asynchronous.

Alternative 3

Option 11c is the same as 11b but uses an HVDC back to back connection to increase the flexibility of power supply without needing to synchronize the two systems. Preferably this back to back is a Voltage Source Converter (HVDC Light), which will stabilize the voltages and increase the power transfer of the AC lines.

Conclusions

In order to transmit bulk power over long distances (more than 500–1000 km), 800 kV HVDC is normally the most cost efficient alternative. The biggest drawback of HVDC is the high cost of tapping power along the route.
A combination, where the bulk power is fed by HVDC and the power needed along the route is fed by AC seems to be the most cost effective and flexible solution. 1000 kV AC is more suitable as an overlay net to existing 400 or 500 kV AC nets in densely populated areas.

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Congestion relief

FACTS – the key to congestion relief

Rolf Grünbaum, Peter Lundberg, Göran Strömberg, Bertil Berggren

From the light that goes on when we flick a switch, to industry's ability to supply us with all the goods and services that we expect, the reliability and continuity of the power supply is something most people have come to take for granted. Not so ABB – the company has a collection of products and technologies, designed to maintain and improve the integrity and continuity of the power supply.

The requirements that are placed on today's grid are changing. Traditional power flows from power stations to the nearest big city are giving way to more complex patterns. Growing consumption and power trading mean that power must increasingly be transported over large distances. Growth in the use of renewable sources is placing a strain on the system because generation is often located in remote regions where the power grid is traditionally weak. The wholesale construction of new transmission corridors is not always the best option due to a combination of environmental, land-use, permit-granting and cost considerations. The alternative is to make more intensive use of existing infrastructure without compromising reliability. ABB has the technology that makes it possible!

The concept of transmission congestion implies, by definition, that there are limitations to how much power can be transferred across a transmission interface, and further that there is an incentive to actually desire to transfer more power. This incentive is often based on differences in power production costs on either side of the interface – a factor that has become more transparent through recent deregulation measures. In other words, there are consumers on at least one side of the interface who could benefit from being able to purchase power produced on the other side. But before such trading can become viable, the infrastructure must be able to support it.

The traditional approach to remedying congestion lies in reinforcing the system with additional transmission capacity (eg adding overhead lines). Although still feasible, this approach is becoming more and more complex and it is often challenged by the public. It is becoming increasingly difficult and time-consuming to obtain the permits to building new transmission corridors, or even expand existing ones.

An alternative that can postpone or altogether avoid the need for such investments lies in improving the utilization of existing infrastructure by permitting more flexibility and controllability. This can be done through the installation of controllable devices in the transmission system, such as FACTS (Flexible AC Transmission System) devices, possibly supplemented with advanced information gathering systems. Although, in general terms, the concept is commonly accepted, the application of these measures involves a number of challenges requiring attention.

FACTS solutions for congestion relief

Typically, different solutions can be envisaged – the solution selected depends on the nature of the physical constraint. However, the operational environment in which these solutions are applied is common to all, and the associated control strategies can to some extent be generalized.

In a general setting, the philosophy behind corrective control as applied to FACTS devices for mitigation is similar to that shown in 1.

The traditional approach to remedying congestion lies in reinforcing the system with additional transmission capacity (eg adding overhead lines). Although still feasible, this approach is becoming more and more complex and it is often challenged by the public.

Dissection of a fault handling scenario

During more than 99 percent of operating time, the focus of the control system is on loss minimization and on loop flow control relative to neighboring networks. Following a disturbance, the control objective instantly changes to handling the physical limitations of the network. Following the clearance of a network fault, transient phenomena must be attended to. These phenomena, which include first swing stability; power oscillation damping (POD); voltage stability/recovery and frequency control, require an adequate speed of control if mitigation is to be succesful.

After 10 to 20 seconds, when the transient period is over and the post-disturbance period starts, slower phenomena may require attention. The control objective switches to address these phenomena, which can include thermal limitations, voltage support (to avoid slow voltage collapse) and frequency support.

After 20-30 minutes the operator should have assessed the situation and taken proper actions to secure a system state that again allows equipment failures without risking such drastic consequences as blackouts.

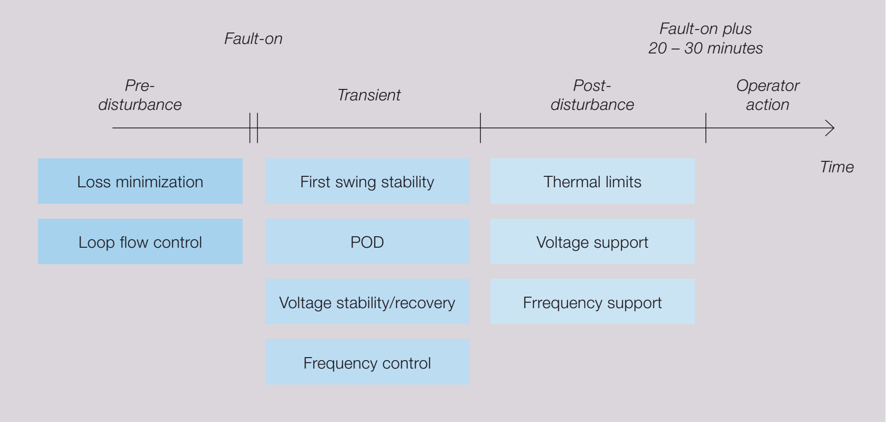
Corrective control applied to FACTS devices is thus a general control strategy that provides means for efficient operation in the pre-disturbance period while still maintaining security in a robust way. Or phrased differently, it is a way to provide the operator with as much time as possible in the event of severe disturbances.

The FACTS devices available provide different means of fulfilling the control objectives indicated in 1. FACTS solutions are usually subdivided into shunt compensation and series compensation.

SVC and STATCOM

Static VAr Compensators (SVC) and Static Compensators (STATCOM) are shunt-connected at critical locations in the transmission grid. Both device types use power electronics to dynamically control the generation or consumption of reactive power. This reactive power is exchanged with the grid to control the system voltage. In addition to providing dynamic voltage

1 Corrective control objectives – setting the right priorities is the key to mastering the disturbance and preventing blackouts.



support in both the short and long time perspective, these devices are capable of providing power oscillation damping in the transient period [1].

The main features of the SVC, the classical FACTS device, are described in [2].

STATCOM 2 is built on the power electronic concept of voltage source conversion. The ABB version, SVC Light®, uses IGBTs. This type of converter enables high performance features such as:

- Robust voltage support under severe disturbances
- Balancing of asymmetrical and rapidly fluctuating loads
- Power oscillation damping
- Active filtering of harmonic currents

SVC Light is described in [3] and [4] for a number of applications where high performance is needed.

During more than 99 percent of operating time, the focus of the control system is on loss minimization and on loop flow control relative to neighboring networks.

STATCOM with Energy Storage

An optional enhancement of SVC Light is an energy storage feature consisting of series-connected batteries 3 [5]. The size of the energy storage depends on the optimization of performance versus cost. The discharge time, ie operating time at full active power, is in the order of 15 to 30 minutes in the base case. Energy storage enables the STATCOM to also deliver and consume active power during a period of time.

The voltage source converter (VSC) uses series-connected IGBTs to deliver high performance and high power. The battery charge must be controlled throughout the complete load cycle. A typical application example is in conjunction with a renewable energy source such as a wind farm that has a strongly fluctuating production. The load balancing function with energy storage delivers active power at a scheduled power level and reactive consumption/production within operational limits, according to the set-point from the dispatch center.

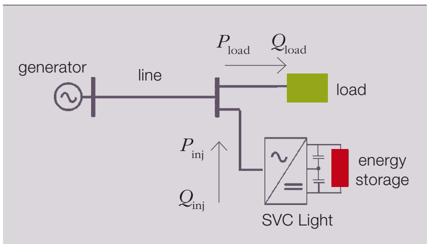
Thus, the combination of a renewable energy source and a STATCOM with energy storage can permit this otherwise intermittent source of energy to be used in the same way as a conventional production source[1].

Other benefits for the power system are the use of such devices in emergency operations for black starts or reconstruction of the network using the available frequency and voltage controls. With a STATCOM capable of modulating both active and reactive power output, power oscillation damping can be greatly improved. This permits higher power transfer levels and so relieves congestion.

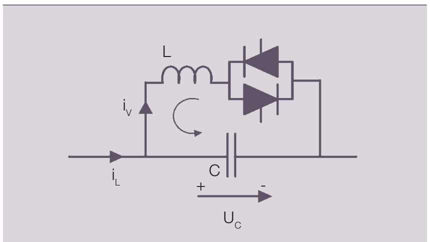
In principle, energy storage solutions are able to change the time at which a given power-flow across a congested interface occurs (if the storage solution is installed on the receiving side of the transmission corridor). Energy is stored in absence of congestion, and discharged when congestion re-

2 STATCOM (static compensator) equipment performs dynamic voltage control by producing or consuming reactive power.

3 Dynamic energy storage with SVC Light



4 Schematic configuration of TCSC (thyristor controlled series compensation) – TCSC permits variable series compensation



5 TCSC equipment used for power oscillation damping

Footnote

1) Intermittent sources of energy such as wind turbines normally require a spinning reserve of conventional power plants to back them up should availability drop. A measure such as this which permits energy to be buffered allows such reserves to be dispensed with or deployed otherwise.

turns. On the scale of a power grid, the energy storage capability that would be required would be too large to be feasible. However, for individual consumers, it may be an economically viable solution – in particular when there are power quality problems to be addressed.

A further application of STATCOM with energy storage would be as a frequency-controlled active disturbance reserve, in particular if it is installed on the receiving side of a frequently congested interface. Such an installation could additionally reduce the gap between transmission capacity and trading demands.

Thyristor Controlled Series Compensation (TCSC)

Other FACTS devices also have the ability to affect active power flows, even if they do not have energy storage capabilities. In particular, series devices can be used for this purpose.

TCSC 4 5 is often used at bottlenecks in which the power transfer limit is determined by poor damping of power oscillations. The technology has in particular been proven effective for situations where weaknesses in the transmission grid tend to split the system into two separate large groups of generators. The solution typically involves fixed series compensation combined with a smaller thyristor-controlled section. The latter is controlled to actively dampen the power oscillations. This more precise matching of damping to line conditions permits a larger power transfer [6].

The essential principle of TCSC is that the forward-biased thyristor is fired just before the zero voltage crossing at the capacitor. This injects additional current into the capacitor and increases the apparent reactance, typically up to a factor of three times the original reactance. This variation, which is referred to as boosting, helps mitigate the power oscillations. Contrary to the fixed series capacitor, the TCSC appears inductive in the frequency range below its fundamental frequency, thus effectively eliminating concerns for SSR (sub-synchronous resonance) for the TCSC part in relation to nearby turbine generators.

Lately, the ability to additionally perform active power flow control in the steady state has received increasing interest, in particular in the aftermath of recent blackouts. Even though a high boost TCSC has the capability to perform power flow control, it is often a better solution to subdivide the capacitor branch into a chain of series connected thyristor-switched capacitor steps. The outcome is a thyristor-switched series capacitor (TSSC). This can be seen in the right-hand part of 6.

For a power flow control application, it is natural to compare the TSSC with a PST (Phase Shifting Transformer). Whereas the PST is adequate for handling thermal limitations, it is too slow to mitigate phenomena occurring in the transient period. Furthermore, it has a deteriorating effect on the voltage profile, both in the short and long time perspective, and reduces angular stability in some cases.

The TSSC on the other hand is fast enough to act decisively to mitigate the transient phenomena, and can support voltages both in the perspective of short and long timeframes. However, whereas the PST can both increase and decrease the power flow on the path in which it is installed, the TSSC can only increase the flow. Furthermore, as a rule of thumb, the reactance of a TSSC should be limited to roughly 60 percent of the reactance between the two substations on each side of the TSSC. Thus, if the required power flow control capability is large (depending on the network topology) the TSSC solution may not be adequate.

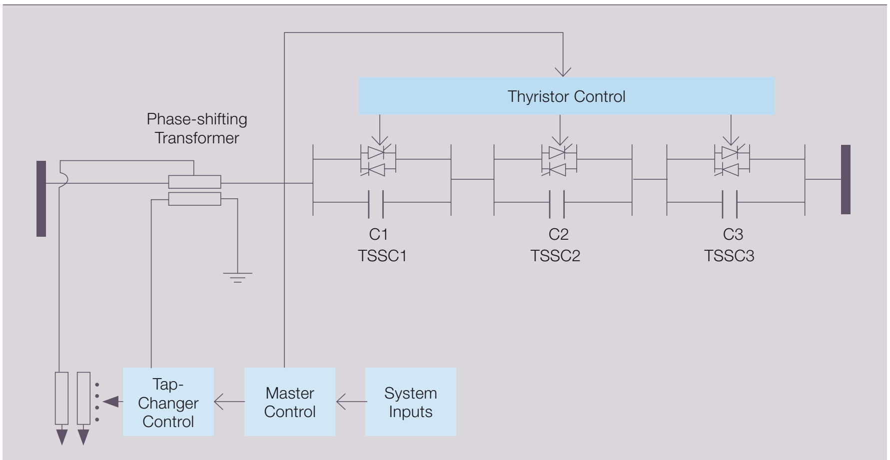
Dynaflow

For the purpose of relieving congestion in areas where combinations of control objectives are of concern, ABB is developing a power flow control concept called Dynaflow. It consists of a PST in series with a multi-step TSSC with coordinated control 6.

> Clear and transparent mechanisms for sharing responsibilities between system operators are advantageous for successful implementation of corrective control actions.

The total power flow control capability is divided between the PST and the TSSC, resulting in a smaller PST and TSSC. Dynaflow combines the positive qualities of both devices. It is thus capable of performing loss minimization and/or loop flow control in the pre-disturbance period, improving first swing stability, power oscillation damping and/or voltage performance in the transient period and supporting voltages and/or thermal limitations in the post-disturbance period. The control system and the necessary input signals for control are customized for the particular bottleneck to which it is

6 Schematic configuration of Dynaflow – Dynaflow consists of a phase shifting transformer in series with a multi-step TSSC with coordinated control.



applied. The introduction of high performance communication and measurement systems provides a basis for additional performance.

A typical application of Dynaflow would be in relation to city infeed. Highly populated cities are often characterized by having large consumption of active and reactive power while the generation sources are remotely located. This frequently has the consequence that the transmission lines feeding the city are heavily loaded and that dynamic reactive power resources are lacking.

A typical critical disturbance would be a line fault followed by a permanent disconnection of the faulted line. Assuming that the power flow would be unevenly distributed on the remaining transmission paths, and Dynaflow is installed on the path designed to pick up more load in order to avoid overloading the parallel paths, the sequence of control objectives could be as follows:

- In the pre-disturbance period, focus is on minimizing active system losses. A set-point would typically be obtained from a control center possibly based on an optimal power flow calculation.
- Immediately following the fault, all capacitive steps are switched in for the purpose of supporting a voltage recovery. This is particularly important for cities with a considerable proportion of electrical motor loads (eg in the form of air conditioning units). Without voltage support these units would have a tendency to stall and so become a significant drain on reactive power; this in turn can result in local voltage collapse and cascading outages.
- Once voltages have recovered, the control objective would shift to thermal limits. By combining the capability of the PST and the TSSC, power flow is controlled to avoid overload in the path in which the Dynaflow is installed or in parallel paths. Furthermore, if the initiating events are so severe that the overload cannot be completely removed, power flows can be distributed to give the operator as much time as possible to take remedial actions. This would typically imply that the overload is evenly distributed between the parallel paths.

WAMS and WACS

A corrective control scheme with the capability to perform dynamic power flow control taking also parallel paths into consideration generally requires that remote measurements are available. Recent advances in the fields of Wide Area Measurements Systems (WAMS) and communications, together with FACTS, open up new possibilities for such Wide Area Control Systems (WACS). Situations with several dynamic power flow control devices installed on parallel paths would in addition require a coordination of the control efforts.

> For the purpose of relieving congestion in areas where combinations of control objectives are of concern, ABB is developing a power flow control concept called Dynaflow.

Related issues

There are obviously limits to what can be accomplished with controllable devices. These limits will determine the new level of power transferred across a transmission interface. From an operational planning point of view it will become important to have efficient security assessment tools, permitting full advantage to be taken of the installed devices.

For historical reasons, bottlenecks are often found on the interface between different grids. Clear and transparent mechanisms for sharing responsibilities between system operators are typically advantageous for successful implementation of corrective control actions.

Conclusions

FACTS include a portfolio with controllable devices that can relieve congestions and improve the efficiency of the existing network. The exact type to be selected is determined by the nature of the bottleneck. There are often different options. This article presents STATCOM with Energy Storage, TCSC, as well as Dynaflow as three viable options for congestion relief.

The application of corrective control will in many cases benefit from the application of advanced information and control systems customized for the particular bottleneck.

It is important that operation planning is provided with efficient security assessment tools such that full advantage can be taken of the installations. This is in particular important when handling congestions on the interface between different systems.

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Harnessing the wind

How the wind is leading to a paradigm change in electrical power supply.

Jochen Kreusel

In the face of the anthropogenic greenhouse effect and concerns over future fuel shortages, the nature of the energy market is changing. Alternative sources such as wind energy have gained substantial and rapidly expanding market shares. To cite a much used cliché, the "wind of change" has truly come. Unfortunately, the expression is true in another sense also: Generation stops when the wind stops. As most consumers are not prepared to accept blackouts every time the weather changes, backup generating capacity is needed that can compensate the fluctuations at very short notice.

But this is not the only challenge. Thermal power plants were built where they were most convenient from the point of view of the transmission network – and this often meant close to major cities. Wind power, however, has to be generated where the wind blows. The transmission network is having to adapt to generation rather than vice-versa.

The electrical power supply system of the future must become a flexible mediator between unplannable generation and high expectations of the supply quality.

Energy efficient grids

One of the major advantages of the electrical power supply in industrial nations is the availability of electrical power in a standardized quality at any time and at practically any location. This has been achieved through systematic consumption-oriented structuring of the system since its beginnings at the start of the 20th century. Systems were frequently planned and constructed around consumption centers (the origins of electrical power supply were mainly decentralized and local), and thermal power stations, which predominate in most countries, follow the requirements of consumption in their operational patterns.

The energy storage required to compensate for fluctuations in consumption basically takes place on the primary energy side, where it can usually be implemented cost-effectively (for example, by stock-piling fuel). However, this basic principle has been increasingly called into question in the past 15 years. Essentially there are two reasons:

- The liberalization of electrical power supply which has been enforced in many parts of the world since the early 90s has led to the breakdown of the principle of local generation. Competition without the possibility of being able to supply from different power stations is not good policy.
- Climate change caused by anthropogenic greenhouse gas emissions, which is becoming more and more apparent, and the growing shortage of fossil primary energy carriers have led to a growing interest in renewable energy sources. After hydroelectric power, which has been used since the earliest days of electrical supplies, wind power has become the second most important renewable source in the world.

Wind power has been experiencing extremely strong growth around the world for the past 15 years.

The wind and the sun are almost ideal sources of sustainable energy supply: clean, available in the long-term and with high potential for growth in comparison to all other forms of renewable energy. However, their exploitation means a departure from a purely load-driven system operation. Since neither wind nor solar energy can be stored on the primary side, the electrical power supply systems of the future must be considerably more flexible than those of today. They must be able to balance between an unplannable and erratic generation side and the unchanged requirements for a high quality and reliable supply on the consumption side.

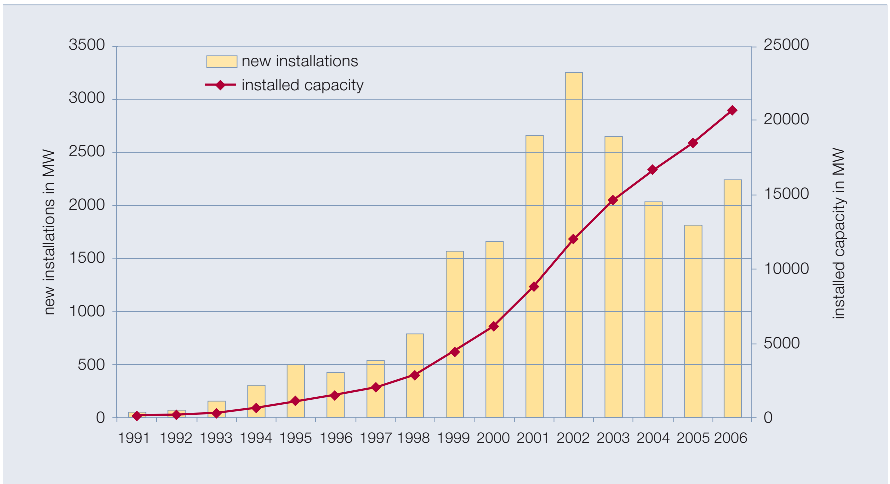
Basic structural changes in the electrical power supply sector

Two important trends have led to far-reaching change in the electrical power supply sector since the beginning of the 1990s. The first of these is the liberalization of the electricity supply, which can be observed throughout the world. This has led to the separation of generation, wholesale supply and energy marketing on the one hand and supply systems and system operation on the other. As a consequence, the planning of new power stations is no longer coordinated with the planning of grid expansion. In addition, system operators must react to the requirements of the power generators for unit commitment and load distribution. Only in the event of the system stability being endangered do system operators have the power of decision. Finally, system operators also have only very limited information about the power stations of independent power generators.

The second major trend is the effort to increase energy efficiency and to reduce the use of non-renewable primary energy carriers. In this respect, decentralized generating units with combined heat and power generation and renewable energy sources play a central role within the electrical energy supply sector. The latter are without doubt one of the most important fundamentals for a sustainable coverage of international energy requirements that is securable in the long-term. As a result, they have a firm place in the energy policy of many countries, and their development is often strongly promoted.

Wind power has been experiencing extremely strong growth around the world for the past 15 years.[1] Its advantages lie in the considerable amount of primary energy available (at least in coastal areas) and the fact that its generation costs are closer to competitive levels than is the case for other forms of renewable energy. It had previously remained largely unharnessed because its economic efficiency was as yet insufficient. The promotion of wind power in many countries has, however, resulted in a worldwide installed wind power output of more than 74,000 MW by the end of 2006. In Germany alone, the

1 Expansion of wind energy in Germany (source: Bundesverband Windenergie e. V.)



Footnote

[1] See also "Clean power from the sea" on page 69 of this edition of ABB Review.

country with the biggest expansion so far, more than 20,000 MW [1] has been installed to date (Germany's total peak load was 77,000 MW in the winter of 2005/2006). As a result, 30.5 TWh of electrical power was produced in Germany in 2006, corresponding to 5.1 percent of total production.

It is common to both these trends that, in addition to load fluctuations, further unplannable processes have to be increasingly considered by system operators in the electricity supply sector.

After hydroelectric power wind power has become the second most important renewable source in the world.

Consequences of a high proportion of unplannable generating capacity

The essential characteristic features of wind power are that it is location-bound – good wind conditions are frequently found outside the areas of concentration of power consumption – and it is volatile.

The selection of a suitable location for the generation of any type of renewable energy is guided by the availability of the primary energy supply – particularly if the costs for the use of the grid are independent of the infeed location. In Germany, wind energy converters are concentrated in the northern federal states [2]. These are areas in which grid infrastructure is typically least developed and consequently not well suited for handling high throughput. Such infrastructure must therefore be expanded. In addition to the around 20,000 MW installed on land in Germany, there are offshore windfarms with an overall output of around 30,000 MW. [3] shows the current estimate of the further expansion. The dena[2)] grid study on the effects of the expansion of wind power on the German transmission network has calculated an additional transmission route requirement of more than 800 km by the year 2015 [1].

However, a high proportion of wind energy in generation not only results in new requirements for the transmission network but also for the rest of the generating system. First of all, installed capacity should be considered: Wind energy converters located in land areas with typical wind conditions can only provide between 10 and 15 percent of their installed output at the availability that is usual for thermal power stations [3]. This figure improves to almost 50 percent for offshore turbines. The power shortfall must be sourced from so-called "shadow power stations": These are back-up (non-wind) power plants.

Because of this back-up, the installed generating capacity in networks in which wind power is incrementally built-up will not initially cause any problems in supply systems. However, the guarantee of short and medium-term reserve capacity must be adapted. Basically, just as in any other supply system, load and generation must be kept balanced at all times. In all generating systems, a certain part of the load, the so-called balancing band, is covered by power stations that are run in partial-load operation and can thus adjust their power output up as well as down at short notice [Factbox]. Since these balancing power plants require additional control engineering equipment and their installed capacity is not fully used, the balancing band should be kept as small as

Factbox Reserve to keep the power flowing

Seconds reserve is the generation reserve that can be accessed within seconds. It usually consists of generators running at partial load and whose output can be easily increased or decreased. Seconds reserve is used mainly for frequency control.

Minutes reserve (also known as warm or spinning reserve) is the next level of reserve. An unplanned generation or transmission outage or load fluctuation is initially absorbed by the seconds reserve control band. To free this reserve, generation is switched to other sources within minutes (UCTE rules, for example, demand that minutes reserve relieves seconds reserve in under 15 minutes). Minutes reserve usually takes the form of storage stations and gas turbines (started for the purpose) and thermal stations running at less than full power.

Hours reserve (also known as cold or stand-by reserve) is the next level of reserve and usually consists of power plants that have to be started for the purpose.

[2] Landscape in Mecklenburg-Vorpommern, Germany: Low density of population and industry in such regions mean that the power grid is traditionally weak

Footnote

2) dena: Deutsche Energie Agentur, the German agency for energy efficiency

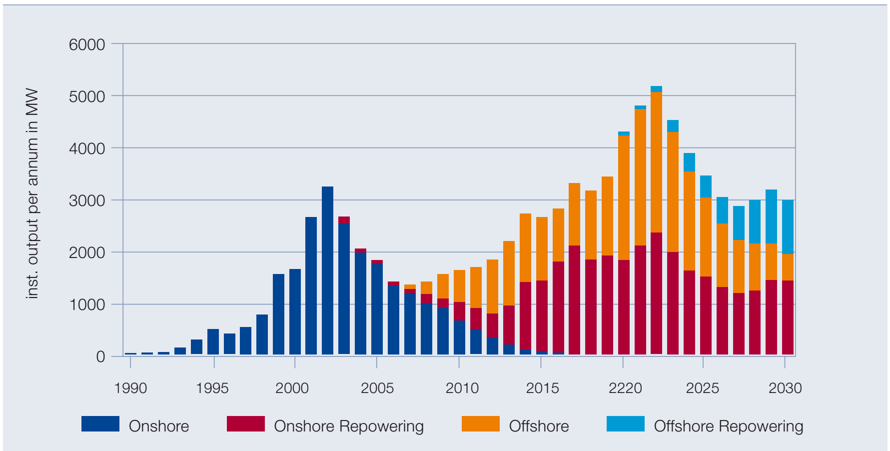
possible. The band's size depends on the amount of unplannable load fluctuations in the system; this is determined both by the load itself and by the size of the largest generating unit (whose failure the system must be able to compensate at any time). Within a network system, e.g. the European UCTE[3] system, there are binding requirements for the size of the balancing band and for the rate of output change that the balancing power plants must be able to deliver.

The spatial concentration of wind power generation off the coast will in many situations result in a permanent large-scale transport requirement.

A system in which wind power generation can fluctuate for a short time between zero and almost complete load coverage (as is the case in northern Germany or Denmark) will have substantially higher reserve requirements than a purely thermal system, in which the largest unit accounts for at most a few percent of the peak load and the load itself is quite well-known and predictable. The initial experience in northern Germany, using prediction methods for wind power generation that are doubtlessly capable of improvement, resulted in an average minutes reserve requirement of 25 percent of the installed wind power output [2]. Against such a background, the UCTE requirements for system balancing will doubtlessly have to be adapted. This is supported by investigations of the dena grid study [1]. According to this, a short circuit in the north German supergrid under strong winds conditions can lead to a generation failure that is an order of magnitude greater than the rotating reserve capacity prescribed in the UCTE.

The major failure in the UCTE of 4th November 2006 shows that the European network system already has a considerable unplannable generation capacity with influence on the system management. The report of the UCTE on this failure [4], in which the UCTE network was initially split into three asynchronous islands, firstly records that following the failure, wind energy converters in northern Germany automatically disconnected without any coordination with the system operators. Although in case of this particular major failure this behavior had a system-stabilizing effect (since the wind energy converters were located in a region with overfrequency, ie, excess generation) the opposite could also have been the case. Secondly, the report points out that the recovery of the synchronous network was impeded as a result of decentralized generation, of whose nature the system operator had inadequate knowledge and which he could not influence. This shows that the basic requirements of system management have changed significantly, but that the associated tools have yet to follow suit.

3 Expected further expansion of the wind power capacity in Germany (source: http://www.deutsche-windindustrie.de)



Technical solutions for the design of future supply systems

New options for transmission networks

A high proportion of renewable energy sources and changes in the electricity business give rise to different tasks for the transmission network than is the case in systems with local balancing of load and generation. Transport and reactive-power demand are above those of conventional systems. There are various alternatives for grid reinforcement:

First of all, the option of adding new supply lines should be mentioned. However, this is frequently time-consuming and can only be implemented with difficulty. The higher capacity utilization of existing lines and routes is therefore an interesting alternative. In addition, the operating voltage, cross-section of the line or operating temperature of existing three-phase lines can be increased[4].

The wind and the sun are almost ideal sources of sustainable energy supply: clean, available in the long-term and with high potential for growth in comparison to all other forms of renewable energy.

In particular, the spatial concentration of wind power generation off the coast will in many situations result in a permanent large-scale transport requirement. This situation is already foreseeable in Germany. The question arises as to whether a reinforcement of the 400 kV network, which was built for another purpose, ie, essentially reserve pooling, is really the right method – or would it be better to build an overlay network for this

Footnotes

[3] UCTE: Union for the Co-ordination of Transmission of Electricity, the association of transmission system operators in continental Europe

[4] See also "Power to be efficient" on page 14 of this issue of ABB Review

transport task. Such an overlay network is conceivable either at a higher voltage level using three-phase current technology, or using high-voltage DC transmission (HVDC). The latter permits the transfer of higher power outputs with identical space requirement and has the advantage that it has no reactive-power demand. If self-commutated IGBT-based HVDC converters are provided, these can, in addition to their transport functionality, provide fast and continuous reactive power support for the local network [4]. This option is particularly attractive in areas with high wind power generation – as explained above, the networks in these areas are often structurally weak. ABB has supplied installations using this technology under the name HVDC Light™ since 1997 and can now realize system power ratings up to 1,100 MW.

The capability of the self-commutated HVDC to instantaneously perform in any point of the PQ-diagram and, in particular, also the zero point [4b], combined with the fundamental advantage of transport without reactive power mean that this technology is ideally suited for the connection of the planned offshore wind farms. In this respect, it will often be appropriate not to establish the connection directly at the coast, but to extend the HVDC lines to suitable high-performance nodes of the transmission network. This could be easily reconciled with the concept of an overlay network for bulk transport.

More transparency for the system management

Power transmission and rapid changes in load flow during supply fluctuations from renewable sources place increased demands on the transmission networks. The more detailed and timely availability of information on the grid status, as can be provided by innovative wide-range monitoring systems [5], can support grid management in this respect. Decentralized vector measuring instruments can record current and voltage vectors in a high time-resolution. A highly accurate image of the dynamic system status is available to the grid management system through the system-wide time synchronization via GPS [5].

The fields of application of this new quality of information extend from the more exact observation of adjacent network areas – particularly when they contain elements that influence load flow such as phase-shifting transformers, FACTS or HVDC lines – to the continuous monitoring of the system for critical states and the identification of parts of the network that are no longer frequency synchronous. During the major failure on 4th November 2006, in which the UCTE network split into three sub-networks, this islanding was initially not detected in the control stations. Basically, it can be assumed that the probability of critical situations such as occurred on 4th November 2006, will increase in a transmission network that is more heavily loaded by transport. Better information availability for network control stations will be appropriate and necessary.

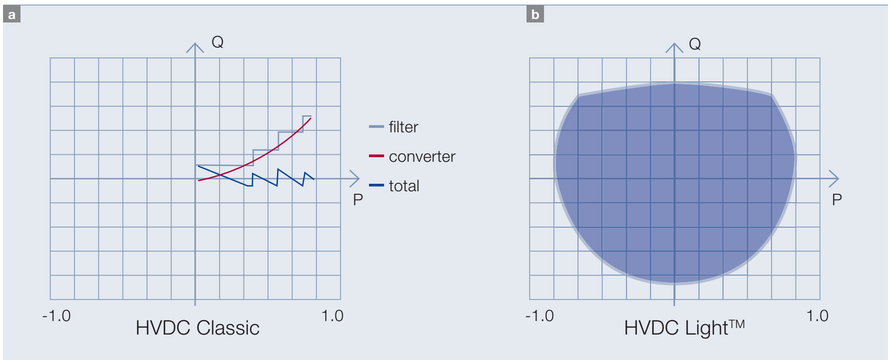
> The electrical power supply systems of the future will be characterized by a high proportion of renewable energy sources, by decentralized, externally determined generation and frequently by a strongly developed electricity business.

Challenge for thermal power stations

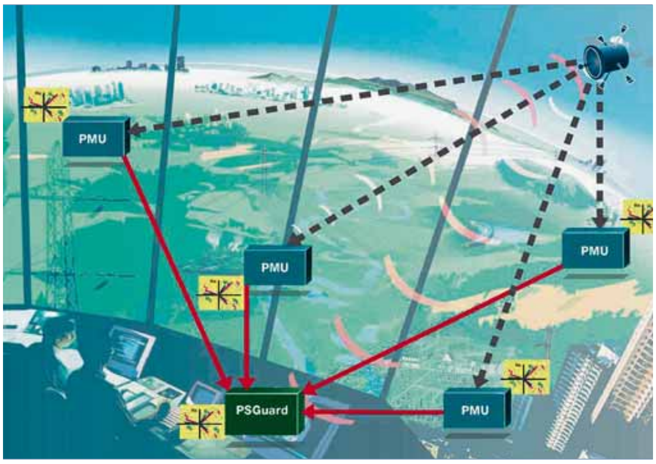
A high proportion of wind power generation leads to increased control engineering demands for the supply-independent generating subsystem. This concerns both primary and secondary reserve capacity such as minutes reserve [Factbox] and is especially relevant in systems in which coal-fired power stations are used for balancing. The use of modern instrumentation and control in the existing thermal power stations offers a considerable potential for improvement and can be realized with a low effort. The implementation of model-supported and comprehensively optimized operating characteristics for the turbine and boiler of steam power stations, as is provided in ABB's systems MODAN and MODAKOND, leads to a smoother, low-fatigue operation and a reduction in auxiliary demand in the percent range. During throttled operation, which is important for the provision of seconds reserve, efficiency increases of up to 0.48 percent could be verified. This increase is basically attributable to the fact that the output change rate required for balancing the system is obtained by minimum turbine throttling. Such improvements, which enable results significantly above the present UCTE requirements, become even more important in systems with a high proportion of renewable sources and a correspondingly unstable operation of the remaining generating system.

In view of the forecasting uncertainties in wind power, the provision of minutes reserve is of particular importance. The upgrading of existing power stations can be a technical necessity for reliable system operation but equally a commercial opportunity for the power plant operators – reserve capacity is a high-quality product in

[4] PQ-diagram of a traditional HVDC installation [a] and of self-commutated HVDC Light™ [b] – HVDC Light™ can continuously and quickly control each point of the four quadrants



5 Wide-area monitoring system with synchronized Phasor Measuring Units (PMU) [5]



The wind is a freely available but volatile source of energy

liberalized electricity markets. Systematic modernization of the instrumentation and control often offers considerable potential. In one case, an increase in the output change rate from 2 MW/min to 50 MW/min and an increase in the control accuracy of ± 5 to ± 0.5 percent could be achieved through the coordinated modernization of the turbine, boiler and unit control. In addition to this, the power station concerned is able to participate in primary and secondary balancing since the modernization.

A high proportion of wind power generation leads to increased control engineering demands for the supply-independent generating subsystem.

Outlook

The electrical power supply systems of the future will be characterized by a high proportion of renewable energy sources, by decentralized, externally determined generation and frequently by a strongly developed electricity business. This calls for new requirements for conventional generating subsystems and transmission networks, because the generating plants are location-bound, because the primary energy supply is often unstable and difficult to forecast, because there is a lack of information about the behavior of decentralized generating units and because of the influence of the electricity business. In this respect, the increase in the number of processes in the electrical energy supply system which cannot be planned or influenced by the system operator is of central importance. In the past, the load basically had this characteristic, and the system management took into account that the load was the guiding variable for the system operation. In the future, a significantly larger number of such processes must be considered and coordinated with each other, so that a safe, reliable and economic supply of electrical power, an important mainstay of industrial societies, continues to be available.

Solutions are already available for many of the consequential aspects. The increased control engineering requirements of the conventional power stations, the increase in the transport capacity of the transmission networks and improved information about the system status are examples of this. The main challenge in the coming years will therefore be to select the right solutions on the basis of a comprehensive understanding of the system and to integrate them in the supply systems in good time.

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Plant optimization

Online optimization of hybrid desalination plants

Goetz-D. Wolff, Stefan Lauxtermann, Ramesh Kumar

The rapid growth witnessed in the Middle East has brought with it the need for basic infrastructure like power and water services. Hybrid desalination plants are highly flexible and play a vital role in water and power production. However, increasing fuel prices and the need to conserve fuel resources are making it necessary to produce power and water in the most optimized way possible. The challenge of optimization lies in the large range of operational possibilities, which exist in short- and long term operation planning.

This article describes a new approach to the economical optimization of desalination and power plants based on different ABB online and offline optimization packages. The effectiveness of these packages is described through their successful implementation at the Fujairah Water and Power Plant (FWPP) in the United Arabic Emirates.

Desalination plants play an essential role in power and water production in the Middle East to meet the ever increasing and dynamic demands. In particular, the number of hybrid desalination plants being built is on the increase largely due to their flexibility in meeting different levels and combinations of production. However, these plants have a complex system structure; especially considering that at least two different desalination process types are used in one hybrid desalination plant. Nevertheless this structure is a hotbed of optimization possibilities.

One such hybrid desalination plant is located 20 km north of the city of Fujairah in the Gulf of Oman. Stringent cost pressure as a result of privatisation meant Fujairah's operators were looking for optimization initiatives to reduce production costs. In 2005 the Fujairah Water and Power Plant (FWPP) installed different ABB optimization packages (from its OPTIMAX® applications family)[1]. This performance monitoring and optimization system is the subject of the following paragraphs.

The Fujairah water and power plant

For power generation the plant consists of four General Electric 106 MW PG9171E gas turbines (GTs) with associated heat Recovery steam generators (HRSGs) and two Siemens NG90/90 119 MW steam turbines (STs) **1**. Water production is realized with five multi-stage flash (MSF) distillers, each with a capacity of 12.5 million

Footnote

[1] OPTIMAX® is described in greater detail on page 44 of this issue of ABB Review.

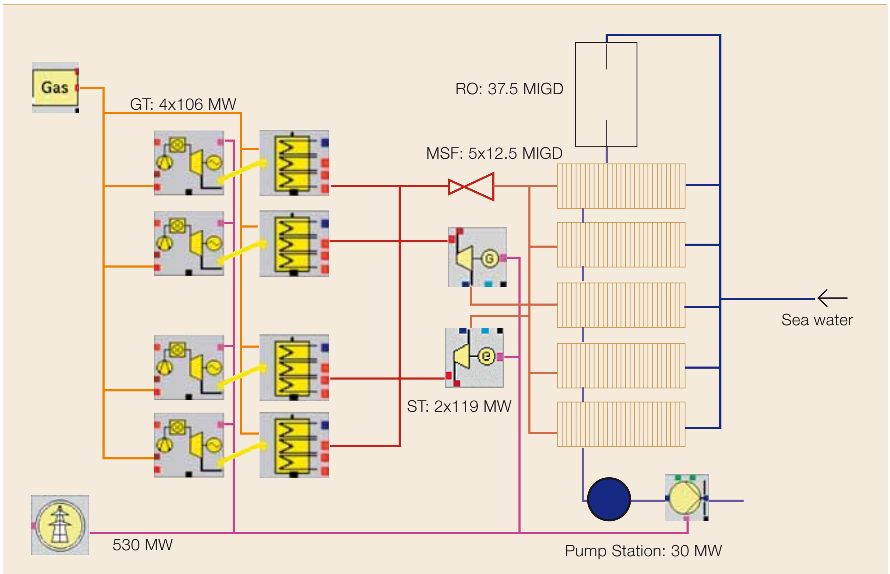
gallons per day (MIGD), and one two-stage reverse osmosis (RO) Plant with 37.5 MIGD capacity. In total the plant has a gross power capacity of about 660 MW and water production in the region of 100 MIGD at 46°C ambient temperature. The HRSGs feed high-pressure steam to a common header. The low-pressure steam used by the MSF units is taken from the steam turbine outlets, or is reduced from high-pressure steam by a reduction station.

Areas of optimization

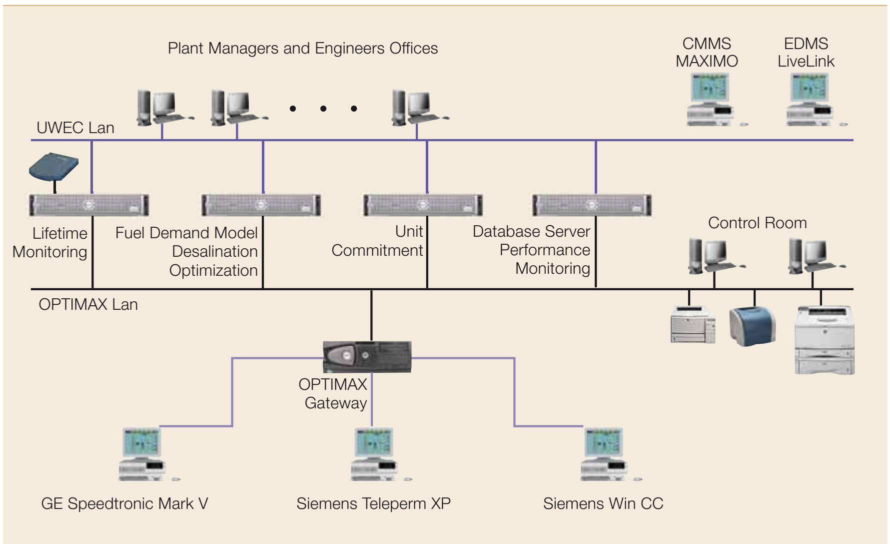
Fuel costs account for 90 percent of the total spent on fuel, chemicals, spares, and GT, ST, MSF and RO maintenance. With the exception of capital costs, fuel is by far the biggest expenditure in power and desalination plants. Therefore the key to increased savings lies in optimizing fuel consumption, and the following tools have been designed with just that purpose in mind:

- *Load Scheduling* which is used for day ahead planning and online optimization
- *Hybrid Optimization* makes online optimization and planning possible
- *Process Optimization* including
  - – MSF optimization
  - – RO optimization
  - – FD-Fan optimization (re-engineering of automation parameters)

1 Fujairah plant structure



2 System structure



Besides optimizing fuel consumption, these tools also allow for maintenance and workflow improvements in the overall work process.

With the exception of capital costs, fuel is by far the biggest expenditure in power and desalination plants, and therefore optimizing fuel consumption is the key to increased savings.

System structure

The modular system structure of the optimization system realized in Fujairah is detailed in 2. Real-time data is collected from a Siemens Teleperm XP via an OPC server, a Siemens Win CC and a GE Mark V system. The data is stored in the long term real-time database, Power Generation Information Manager, or PGIM (former *PlantConnect*) from ABB, which is then used as a common data source for all the optimization tools and other applications. PGIM is also a Plant Information Management System (PIMS) with a Human System Interface (HSI) enabling the user to view graphics, trends and reports. Performance indicators such as GT efficiency are calculated with the integrated software tool known as "Technical Calculation".

PowerCycle, also from ABB, is a model-based tool which is able to accurately simulate thermodynamic behavior of a plant under varying ambient conditions and different steady-state operating conditions. In Fujairah, the PowerCycle model is used for:

- *Data validation:* It reconciles online measurements to avoid measurement errors
- *MSF optimization:* It gives optimal internal MSF operation setpoints at a given load
- *Fuel Demand Model:* PowerCycle is used to calculate the expected fuel demand according to the plant design, and this is confirmed by performance measurements at plant take over

Other tools include:

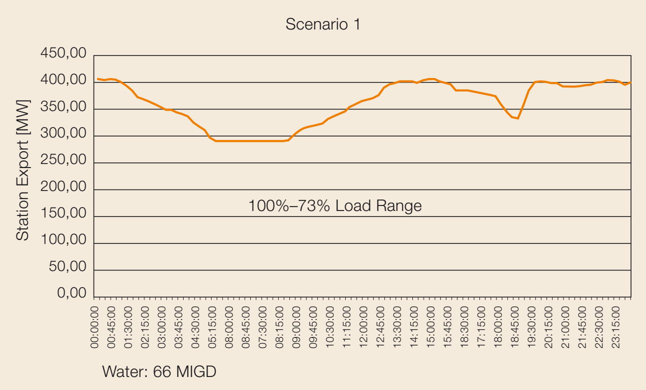
- *PowerFit* calculates optimal schedules. This software is mainly used as

a tool for day ahead planning
- *BoilerLife* determines the lifetime exhaustion of the main boiler components

Optimization solution

The optimization solution realized in Fujairah comprises:
- Load scheduling
- Hybrid optimization
- MSF optimization
- Process optimization
- Work process optimization

3 A daily electrical load curve for the Fujairah Water and Power Plant (FWPP)



Load scheduling

The loads, which have to be provided by the water and power plants, vary during the day. This is especially true in the regions where the humidity and the temperature vary, and it is this that affects the load. The example of a daily electrical load curve from the FWPP in 3 shows that the plant operates between 50 and 80 percent of its total net capacity. A 20 percent change, however, is considered normal. A load change of more than 150 MW is equivalent to about 1.5 times the maximum capacity of one GT.

The daily water demand is prescribed to the plant. Additional flexibility for plant production exists if the storage capacity of the potable water tanks is taken into account.

The aim of a load scheduling system is to find the optimum combination of plant components to satisfy particular electrical and water export requirements. In other words on the basis of the demands made by load dispatchers, the plant structure, fuel prices, variable maintenance costs, chemical costs, ambient conditions, and operation modes, entire plant and individual unit performance calculations are carried out. The end result is a proposed cost optimal plant operation based on a particular combination of GT, ST, RO and MSF units. In fact, the main benefits of optimization are realized by:
- Finding the best combination between GT and ST production
- Finding the best combination between ST production and bypass steam flow
- Finding the best combination between MSF and RO production
- Utilizing the water storage possibilities

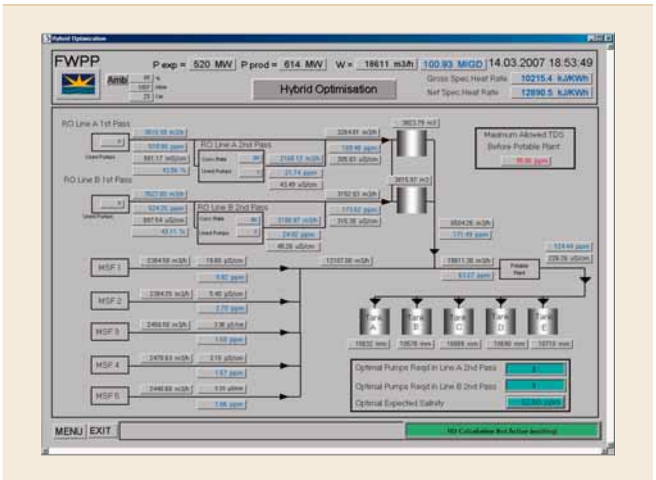
Suitable combinations enable plant optimization to remain valid from one to several days. The optimization software package comprises four sections:
- A Graphical User Interface (GUI)
- A kernel which coordinates the GUI, optimizer and database.
- An optimizer (CPLEX) whose task is to find the global minimum. It does this by using the Mixed Integer Linear Programming method.
- Orcale database to store all configurations and results. Schedules for all the major equipment are presented in either table form or as graphics.

In the Fujairah plant it has been proven – using specific test loads and conditions – that an average of 2.7 percent of the fuel costs can be saved by implementing this optimization software. The highest savings are realized in low load operation modes where a potential of 6 percent and more could be achieved.

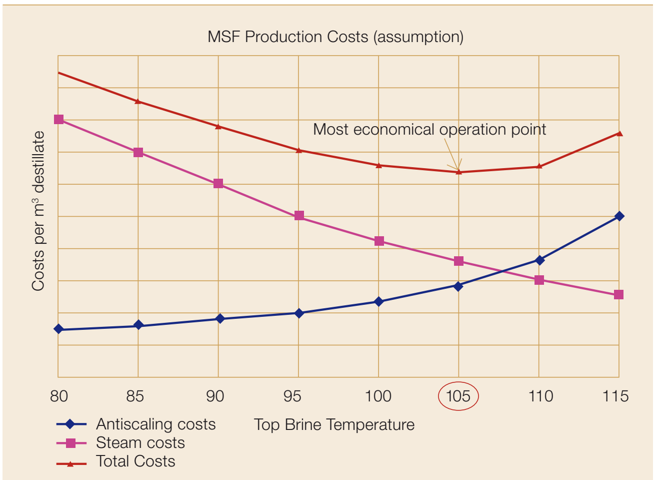
Hybrid optimzation

The Fujairah water plant is of a hybrid nature in that water is produced by MSF and RO units. Potable water has to be produced in a defined quality. However, the water qualities from both processes differ: that produced with the MSF units is almost demineralized and the water produced by the RO units is of a high quality. Therefore the mixed potable water from the two processes has still to be mineral-

4 Hybrid optimization



5 A Multi Stage Flash (MSF) cost minimum principle



Energy efficient grids

ized by the potable water plant to reach the optimum mineralization criteria stipulated by the health authorities.

The RO plant in Fujairah is a modern plant built by Degremont[2]. It consists of two lines, each with two passes. The salinity of the first-pass output is in the range of 500 ppm compared to 15 ppm for the second-pass output. Some water bypasses the second-pass and is instead mixed at its output. The water produced by the RO plant before optimization achieves a salinity value in the range of 80–100 ppm.

The aim of optimization is to find the minimum number of second path racks[3] needed to meet the guaranteed water quality of the total plant. This in turn reduces:

- Electrical consumption for second path rack pumps by 0.5 MW per pump
- Maintenance costs for second path racks
- Chemical costs in the potable water plant

In addition, reducing the number of running racks in the second pass increases water production by the RO plant since each second-pass rejects approximately 10 percent of the water.

The aim of optimization in an RO plant is to find the minimum number of second path racks needed to meet the guaranteed water quality of the total plant.

The picture/mimic in 4 is used for online hybrid optimization. In this production example two second-pass racks can be taken out of service compared to the standard approach of using one second-pass rack for every two first-pass racks in operation (1:2 ratio). Additionally an offline tool is also provided for modelling different scenarios. Hybrid optimization in the Fujairah plant saves the equivalent of 0.6 percent of the total fuel costs.

MSF optimzation

The main operational costs in an MSF plant are incurred by energy input by steam, chemical additives, and the electrical energy consumed by plant equipment. The job of the MSF optimizer is to minimize the sum of these costs by calculating other set point values that will keep water production constant. A typical cost curve with varying Top Brine Temperature (TBT) values is shown in 5.

The steam costs per m³ distillate decrease with higher TBT because the Performance Ratio (PR) increases if water production is to be kept constant. The chemical costs (eg antiscaling) per m³ distillate increase with higher TBT because of higher scaling at higher temperatures. The optimizer calculates optimized values for the following parameters because at a given load different combinations of these parameters can be used:

- Top brine temperature (TBT)
- Brine recycle flow
- Sea water to reject temperature (winter only)
- Sea water to reject flow
- Make up flow

Additionally, a process simulation package is used which is capable of modeling MSF units down to the stage level. A model of the MSF line 6 is configured by combining calculated optimized set points for the above mentioned parameters with other components such as a brine heater and pumps. The set points determined by the optimization package are used by the operators for MSF control.

An on- and offline optimization tool is available in the plant. The online tool calculates optimized settings every 10 minutes for a given distillated water production while the offline tool is used for planning purposes.

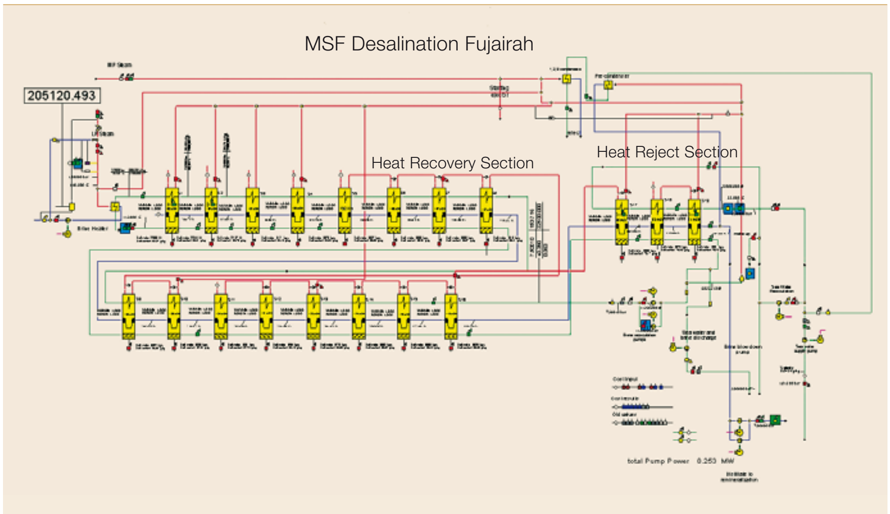
Using the MSF optimization tool under various operation conditions has saved up to 1.78 percent of the total MSF production costs.

Hybrid optimization in the Fujairah plant saves the equivalent of 0.6 percent of the total fuel costs.

Process optimization

It is essential to monitor the performance of the different plant areas to be able to detect any unusual drop in efficiency 7. The next sections describe the performance calculation in principle, and an example is given where out-of-design parameters were detected.

6 A Multi Stage Flash (MSF) model

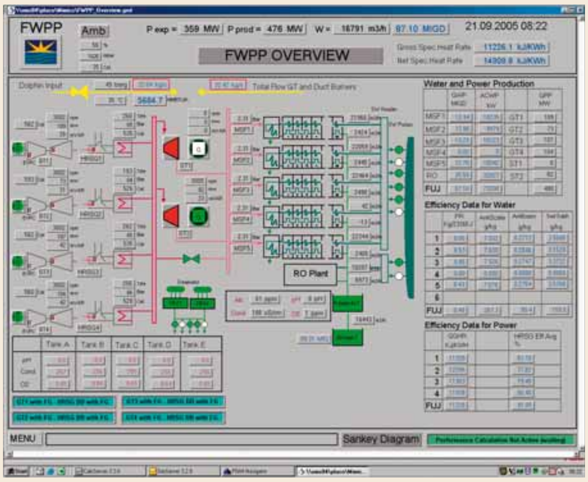


Footnotes

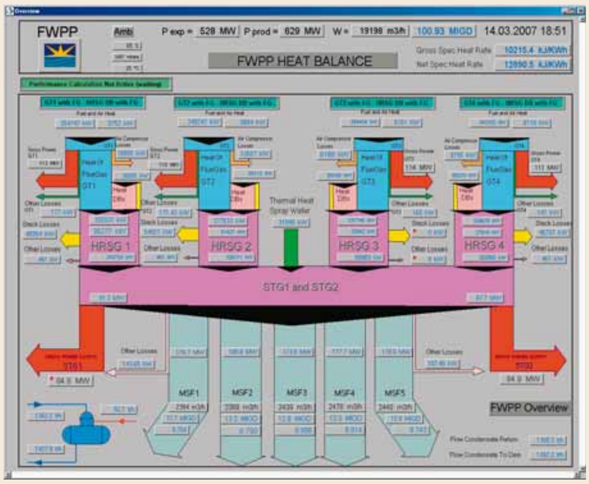
2) http://www.degremont.ca (March 2007)

3) A rack is a bundle of membranes for RO desalination (cubicle) which can be switched on and off separately.

7 FWPP process overview



8 Heat balance diagram with calculated heat flows



In the FWPP, performance calculations are performed for all major equipment, eg GTs, HRSGs, STs, feed water pumps,the MSF desalination plant, sea water intake pumps, the RO desalination plant and the HP pumps. The screenshot and respective trends 8 are used by operators and engineers to analyze the performance of the entire plant as well as individual areas. Comparisons between actual and expected performance in connection with supervisory identifiers make analyzing simple and effective. However in one particular case, a low HRSG performance was detected when the Performance Monitoring and Optimization system was used. An investigation disclosed that the problem lay with the FD-Fan. To be more precise the FD-Fan is started only when the average flue gas temperature behind the duct burners exceeds a specific control set point. In the FWPP, this value was set at 800°C. However, design criteria stated a value of 840 °C was required, and the 40 °C difference translated into a 1.7 percent drop in boiler efficiency during FD-Fan operation.

Additionally the fans never stopped once started because the lower set point temperature value of 700°C was deemed too low (the temperature rarely fell below this value). The operation practice was changed after the implementation of the software package, and the result since then has been increased efficiency.

Work process optimization

In addition to process and operation optimization, areas of the work process that can also be optimized and improved include:

- The *automatic creation of logs and reports* which saves working time and avoids manual entry errors
- The *automatic exchange of data with other systems*, for example computerized maintenance management system (CMMS)

In Fujairah more than 100 logs and reports have been automated, resulting in an estimated daily saving of about 18 hours work. Easy-to-use tools to configure different types of reports are developed by ABB using Microsoft Excel software in the system.

Altogether, more than four percent of the total fuel consumption is saved in Fujairah, with additional savings attributed to work process optimization.

Conclusions

The proven installation of a Performance Monitoring and Optimization System in the Fujairah water and power plant sums up the effectiveness of modern optimization techniques in power plants. In fact most of the optimization techniques described can also be used in power and desalination plants with a non-hybrid structure.

Altogether, more than four percent of the total fuel consumption is saved in Fujairah, with additional savings attributed to work process optimization. The benefits realized indicate the potential that exists for other hybrid and non-hybrid plants.

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Further reading

[1] **Ludwig Heinz, Stummeyer Karen,** FICHTNER, Potabilisation – Nachbehandlung von Destillat und Permeat aus Meerwasserentsalzungsanlagen, May 2004

[2] **Glade Heike, Meyer Jan-Helge, Will Stefan,** Strategies for optimization of the Reverse Osmosis Plant in Fujairah, June 2005

[3] Water Quality Regulation of UAE, Revision 2, January 2004

[4] On technical and market aspects of water desalination, Nils Huesgen, December 2002

OPTIMAX®

Improving operational and environmental performance

Marc Antoine

The primary key to energy efficient operation of a process lies in the reduction of the cost of fuel and consumables. Industrial plants are huge energy consumers, and therefore small percentage savings can have a significant impact on their bottom line. The answer lies in the use of powerful diagnostic and optimization tools.

The tool kit developed by ABB includes such features as monitoring and predicting plant performance, issuing early warnings for equipment diagnosis, sensor validation and preventive maintenance.

Maximize operational performance

ABB's OPTIMAX® operations solutions are designed to serve utilities with complex generation portfolios that are seeking to minimize energy generation costs, be it electrical or a combination of electrical and other forms of energy. In addition, questions as to whether or not it makes sense to buy or sell power or fuel, start or stop a unit, save life-time, or postpone a preventive maintenance outage can be easily answered.

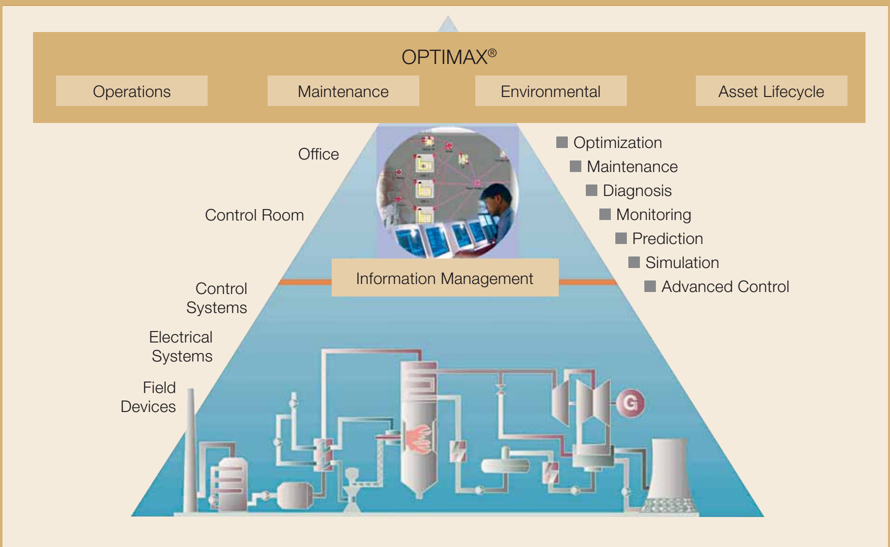
Minimize maintenance costs

In terms of variable costs, maintenance expenses are second only to fuel costs. The key to optimizing assets is often having information that is accurate, timely and actionable. The ability to act on reliable information is as essential as having access to the information in the first place. Decisions and actions taken have direct impact on operating performance, security of supply, equipment life time, power quality, and health and safety.

Work preparation and planned condition-based maintenance are increasingly important for reduction of downtime. The benefit of OPTIMAX® Computerized Maintenance Management Systems (CMMS) is to achieve and maintain a high level of availability, quality and safety of the plant. This applies to current plant operation but is particularly valid for inspection, overhaul and service activities. For industrial users this leads to a higher Return On Asset (ROA) which is a key driver of shareholder value.

Reduce emissions and waste

The measurement and reduction of hazardous emissions is increasing in importance and regulatory standards are getting stricter every day. Emission of greenhouse gases now has measurable economic value and operators have a real incentive to lower these emissions. The OPTIMAX® environmental solutions reduce emissions by monitoring flame quality, measuring coal flow and carbon in ash content, and providing Advanced Process Control (APC), which optimizes combustion, shortens boiler startup times and improves efficiency.



Extend the asset life cycle

From an economic perspective, plant managers seek to balance their investment in new assets against performance, risk and downtime. OPTIMAX® solutions for lifecycle optimization of assets are able to schedule the most economical operation of different generating units and trade-off income from sales against lifecycle costs. In addition, this approach is also capable of taking emission costs into account, ie more stringent CO_2 requirements may make plants that are still mechanically functional uneconomic to run. The advantage of these decision support tools is the ability to include plant ageing models to find the optimal operational strategy between maintenance outages, especially when operating under environmental constraints.

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In a league of its own

One of the world's most modern pulp mills uses ABB's 800xA Extended Automation System

Lena Sjödin

With an annual production of 500,000 tons of pulp – including 420,000 tons of kraft pulp and 80,000 tons of CTMP pulp – SCA's plant in Östrand, Sweden, is high on the list of Europe's largest pulp mills. Operating 24 hours a day all year round, wood from the forests in Northern Sweden is processed into chlorine-free bleached kraft pulp and semi-chemical pulp that is eventually used in everyday products such as magazine paper, tissue paper, hygiene products and packaging. Ensuring production stability and efficiency to the highest standards requires a flexible and reliable control system. These values are fundamental to ABB's Industrial^IT System 800xA mode of operation and that is why it was selected to help turn one of Europe's biggest pulp mills into one of the world's most modern.

Energy efficiency in industry

Following two years of construction work and expenditures totaling US $1.6 billion, another of SCA's[1] large-scale industrial investments in Sweden is complete. To be more precise, the Östrand mill (see photo below) is now perhaps one of the most modern in the world. Both the recovery boiler, which started operation in October 2006, and the water treatment system are controlled using ABB's Industrial^IT Extended Automation System 800xA[2] – an investment that has made an integrated system with graphical function design features and an advanced simulation interface possible.

A requirement of the new integrated control system was that it should unite electrical generation and instrument operations in the most advantageous way possible.

In search of integration

The decision to purchase an integrated control system was reached at the same time the company decided to buy a new recovery boiler. However, the search for possible control system suppliers had in fact started more than a year earlier. One of the most important criteria the new system had to meet was that it should unite electrical generation and instrument operations – which previously had separate control systems – in the most advantageous way possible. This was desirable partly to overcome the drawbacks in terms of production quality that come with having distinct departmental divisions, and partly because it takes both time and resources to maintain functioning communications between two separate systems.

The procurement process for the new control system started in 2003. An engineering group within the automation department undertook a four-month research period that included a number of research trips before a specification was established. According to Alf Eriksson, Östrand's head of automation systems, "We had a great deal of input and secured support from the organization throughout the procurement process. In order to really be able to compare what the different potential suppliers had to offer, we provided them with hypothetical flow charts to see what kind of technical solutions they could come up with. We then tested all of the proposals during a two-week testing phase." When the need to make a decision regarding investment in a new recovery boiler came up in August 2004, the organization was already prepared to choose ABB's Industrial^IT System 800xA. "Perfect timing," says Alf Eriksson. 1 shows a typical integrated solution based on System 800xA.

"Having everything governed by the same system definitely provides us with superior control," adds Alf Eriksson, who now oversees a comprehensively integrated department. "The advantages of the new arrangement will manifest themselves over time. But we are already seeing advantages in terms of simplified work routines for switching between maintenance and production modes, and the dialogue between the electrical-generation and instrument disciplines has become more natural."

"Green" power

The new soda recovery boiler is a combined recycling facility and steam boiler. Its raw materials are the used chemicals and wood waste from the kraft mill. The chemicals are recycled and reused while the wood scrap is burned to fuel the boiler. Steam is produced at a pressure of 105 bar and a temperature of 515 °C, higher than in any other comparable facility in the world. The new recovery boiler and the new turbine enable a doubling of present biomass-based electricity-production to 500 gigawatt hours per year. As a result external electricity requirements will be drastically reduced thus putting the Östrand pulp mill complex at the cutting edge of what is currently possible. Even at today's production level of 420,000 tons of pulp per year, the kraft mill will actually make a net contribution of "green" power to the electricity grid.

The system comprises nine operator stations and seven AC 800 M processing stations for control of the recovery boiler and the water treatment plant, as well as a control system simulator.

SCA's Östrand pulp mill, Sweden (Photo: Michael Berggren)

Footnotes

[1] http://www.scatissue.com/about/corphistory, (March 2007)

[2] More information can be found at www.abb.com/controlsystems, (March 2007)

This can be increased when, at some time in the future, the new boiler is expanded to its full capacity of about 800,000 tons.

Simulation is key to better understanding

A congenial work atmosphere reigns in the joint control room in Östrand 2 with a modern systems platform that can be modified to meet future functional requirements. System 800xA is open-ended and versatile with excellent modalities for aspect coupling, and involves clear advances from the standpoint of safety.

The system delivered by ABB comprises nine operator stations and seven AC 800 M processing stations for control of the recovery boiler and the water treatment plant 3. It also includes a control system simulator for the boiler with two operator stations and a smaller training system. The simulator is based on a mathematical model of the recovery boiler, which is a complex process involving both combustion and chemical reactions. There are pre-programmed scenarios such as basin leaks, electrical failure, dry-content problems and furnace leaks. These scenarios can be combined with a number of so-called ”snapshots”, each of which represents a different operational state of the recovery boiler.

The goal throughout has been to provide information in a way that is immediately accessible and easily comprehended even by occasional operators.

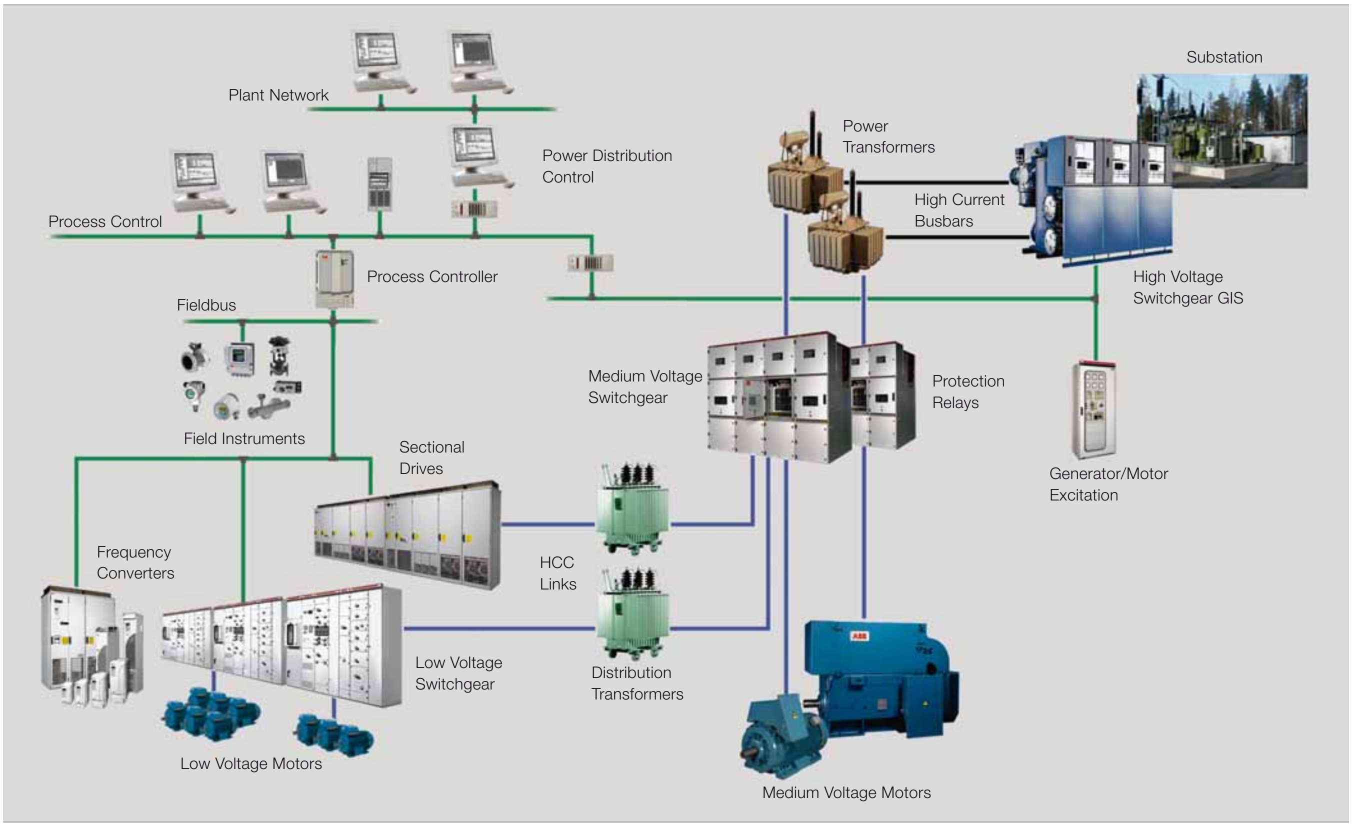
”ABB had the best simulator solution,” says Alf Eriksson. ”It enabled us to do a dry run with the recovery boiler before it was operational. Now we can conduct training using an exact mock-up of the control system. If we make adjustments to the programming of the operational system, it is easy to transfer them to the simulator, which means that it will remain useful over a longer term. ”

Old way of working translates into new way of thinking

The Östrand mill has a long tradition of proprietary programming, and this has also been extended to the new system. Östrand's standard protocols have been applied to the operation of ABB's System 800xA. The basic ideas and the thematic approach to the old way of working have been translated into a new way of thinking and related to a different process. The goal throughout has been to provide information in a way that is immediately accessible and easily comprehended even by occasional operators. To achieve this result the 800xA's graphical function design has been a useful tool and the Östrand mill is the first in Sweden to use it. Presenting information related to each function as a diagram rather than in text form facilitates a deeper understanding of the underlying process. The graphical function serves as an interpreter that translates the program language into something familiar.

”With graphical function design, you can easily access your application

1 A typical configuration of electrical integration



2 Control room at the Östrand pulp mill complex in Sweden (Photo: Michael Berggren)

3 Controllers at the Östrand mill (Photo: Michael Berggren)

translated to a universal language," explains Alf Eriksson. "This gives you a useful overview and facilitates troubleshooting, for example."

Östrand's standard protocols have been applied to the operation of ABB's System 800xA. The basic ideas and the thematic approach to the old way of working have been translated into a new way of thinking and related to a different process.

Fieldbus capability a must
Another important criterion for SCA was that the system should interface advantageously with data-bus technology and be able to handle an increased volume of information related to preventive maintenance.

The mill has a long practice of using Advanced Switching Interconnect (ASI) Profibuses, and great weight was attached to finding a new control system for water treatment that was compatible with existing field buses. With the new recovery boiler, all frequency converters and approximately 90 percent of switchboxes are controlled via Profibuses. Digital signals for everything from shut-off valves to alert systems are controlled by ASI. The analog signals are distributed to fieldboxes.

"We make extensive use of HART-I/O and have now begun to work towards managing the increased data provided by ABB's 800xA in developing routines that will make it possible for us to predict the need for maintenance more accurately than we can today," says Alf Eriksson.

Customer needs linked with system potential
A close relationship with ABB's service organization and a favorable service agreement were decisive factors behind the decision to invest in the 800xA. A resource person from ABB was present at the mill throughout the programming and installation period to assist in optimizing utilization by helping to unite the system's potential with Östrand's needs.

"The resource person has meant a lot to us and to the project," says Alf Eriksson. "We have learned a great deal in the process and I believe ABB has also gained some knowledge because of the critical scrutiny we bring to bear on functions and solutions."

Considering that the old solution with two different control systems had been in place for twenty years, the changeover was smooth, partly because the technical transition was carried out without a hitch and partly because operations and maintenance personnel took to the new control system in exemplary fashion.

"With graphical function design, you can easily access your application translated to a universal language" – Alf Eriksson.

"It goes without saying that the challenge was initially daunting but the longer we work with the new system, the more we see its advantages. We're not rushing around but are rather following a methodical course of improvement. All of our employees have worked impressively on this project. Many deserve praise for the support they have given to others. The result is that we have been able to meet our quality and productivity goals despite the enormity of the undertaking."

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Energy efficient rolling

On-line minimization of energy consumption in the hot rolling of long products

Anders Daneryd, Mats G. Olsson, Rickard Lindkvist

A typical working day for a rolling mill operator is not as straightforward as one would think. In fact a typical day can often mean a turbulent one where the operator has to battle process instability that interferes with production. Finding his way out of certain situations such as unstable rolling, which results in down time, less yield, and frequently the appearance of cobbles as a result of bar derailing, may be very time consuming.

Regaining stable rolling is often based on the individuals' experience. Judging what the best set of process parameter settings should be is a black art representing the very core of their professional pride. However, by the time production is back on track, valuable material and energy have been wasted in ensuring correct dimensional accuracy usually through trial and error. To aid operators in their task as well as to eliminate such waste, help is now available in the form of a software package for advanced rolling process optimization from ABB.

A product change (PrC) generally refers to the process of changing one stable rolling configuration for one material with specific finishing dimensions to another configuration with a different material and finishing dimensions, with minimal downtime and scrap production. Frequently, the number of rolling stands is also varied. An unsuccessful PrC may result in production delays of more than one hour, whereas a successful one is usually completed in a matter of minutes.

The difficulties of repetitively reproducing a product change with minimal disruption have challenged ABB's researchers, who now have responded with a unique online software tool for operators. This tool is based on state-of-the-art rolling models and optimization, simulation, and statistical methods, that guide the operator to optimal process parameter settings for stable and dimensionally accurate rolling.

Models for optimization, simulation and calibration

Mill availability and yield will certainly improve by being able to model, simulate, and optimize production speed and energy requirements, while controlling bar dimension, roll load sharing, groove utilization, and similar important process quantities. The *Adaptive Dimension Models (ADM™)* tool advises the mill floor worker – via an easy-to-use HMI – about the parameter settings that should be used to reach optimal conditions. With this tool complex calculations take less than a minute to complete, but in actual fact most are often completed in no more than ten seconds.

This tool can be accessed through an auxiliary PC located in the operators' booth 1 alongside the regular ABB Rolling Mill Control (RMC™) and Interstand Dimension Control (IDC™) displays.

Interstand Dimension Control for rolling stability

The IDC concept has been developed for rod and bar mills to achieve tighter tolerances head to tail, as well as improved product quality, yield, and availability. In addition it ensures fast product and dimension changes. It functions as an early indicator of abnormal mill conditions, which ensures a more consistent mill set-up and improved pass schedules.

The key IDC component is the U-gauge™ for online bar dimensional measurement 2.

Online information from the drive system and U-gauge is seamlessly communicated to the ADM tool 3. As well as this data, a few parameter settings (selected by the operator) required for various process simulation and optimization tasks make up the rest of the inputs. The output, in the form of adjustment lists, tables and charts, is usually given within a few seconds.

Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal interstand forces, and in particular compressive stresses.

This configuration in combination with high speed algorithms allow for a great number of interactive process optimization tasks in a short period of time. Having identified parameter settings that meet his demands, the operator can store these results as a new RMC rolling schedule for retrieval at some later date. In summary, the ADM tool requires only minimal configuration work before it starts delivering useful results.

Rolling maximization and minimization

Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal interstand forces, and in particular compressive stresses. Maintaining this together with the required dimensional accuracy of the finished product challenges the operator's skills. The ADM tool provides additional capabilities to assist the operator in fully understanding changes that occur in the state of the current rolling, and to plan for the optimization of an upcoming production run. With this tool stability and product dimensional quality are ensured and a vast number of related and important aspects previously beyond the reach of the operator can now be controlled. The core of the ADM optimization module permits the *maximization or minimization* of selected production aspects while keeping related and dependent aspects within permissible constraints 4.

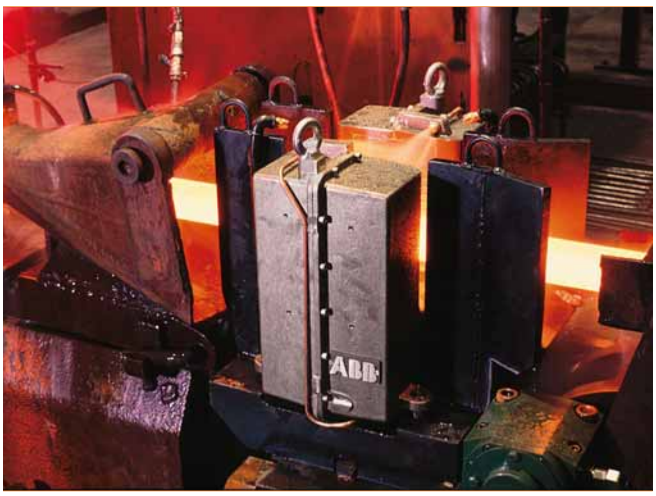
Factbox What causes derailment

Derailment happens because of a massflow mismatch, which occurs when an upstream pair of rolls "feeds" more material per unit of time than the neighbouring downstream pair of rolls is able to "swallow". The underlying cause of derailment is a lack of quantitative understanding as to how various process parameter settings (roll gap, motor speed, interstand tension etc.) affect bar deformation in the roll groove and hence the process massflow.

In mills with frequent Product Changes (PrC) and small batches there is a risk of several such events per day.

1 Operator's booth with control and monitoring equipment

2 U-gauge in operation for dimensional measurement



Energy consumption minimization

Minimizing energy consumption is one such optimization choice available to the operator, while at the same time allowable upper and lower limits are defined for bar width, area, speed, interpass tension, roll gap and motor speed. The finishing dimension and speed of the production to be analyzed is always prescribed without the need for user intervention. Using the selected aspect values the ADM optimizer then solves this nonlinear minimization problem and returns the optimal rolling energy consumption value, or power 5, as well as the influence of the determined optimal parameters (usually roll gaps and reduction factors) on width, area, tension, etc. The complex dependencies between process parameters are handled by consistent rolling models linking mass flow, spread, interpass tensions, torque and power. Controlling bar width and area, so called *groove utilization control*, is not only of importance when reducing roll wear, but it also plays an important part in preventing damage to the bar by ensuring it does not overfill the roll groove. Should the user by accident define inconsistent parameters leading to a solution exceeding one or more of the parameter bounds, a solution diagnostics procedure advises him how to obtain an admissible solution in an ADM rerun.

A real mill example

A real ten-stand example is solved in less than ten seconds on a regular PC. Potential energy savings have been shown to be as large as 10 percent for real rolling schedules. The starting point in 6 (iteration "0") corresponds to the actual mill process parameter settings, and the iteration history illustrates the convergence of the ADM optimization procedure towards a total rolling energy which is about 10 percent lower than at the outset. This implies significant cost savings for a continuously operated mill. Furthermore, ADM optimizes an imaginary process line with 20 stands within 30 seconds.

Other optimization objectives include:

- *The maximization of production speed*. Again system limits such as maximum available motor power, torque, and speed are set as well as limits defined at the operator's discretion based on his experience and knowledge.
- *The matching of individual stand powers to predefined targets*, so-called load levelling.
- *The matching of individual bar widths and cross section areas*, also with predefined targets.

The latter case is of concern when groove utilization control is the primary goal of optimization. Objectives, constraints, and process parameters controlling thermodynamics and microstructural properties will be included in ADM extensions.

The simulation functionality of the ADM tool allows quantities such as bar width, area and speed to be quickly calculated. It also allows sensitivity analyses to be performed.

Interpass tension modelling

In all optimization selections the interpass tension plays an important role and constraints ensuring stable rolling without compressive stresses may be specified, as well as tension setpoints. A unique modelling feature is the way in which tensions change bar dimensions, both in the deformation and interstand zones, while at the same time the overall model maintains a continuous mass flow. This is not only violated in other modelling approaches, but it also paves the way for a consistent analysis of the so called "endless rolling", in which bar dimensions may be controlled by relatively high interstand tensions.

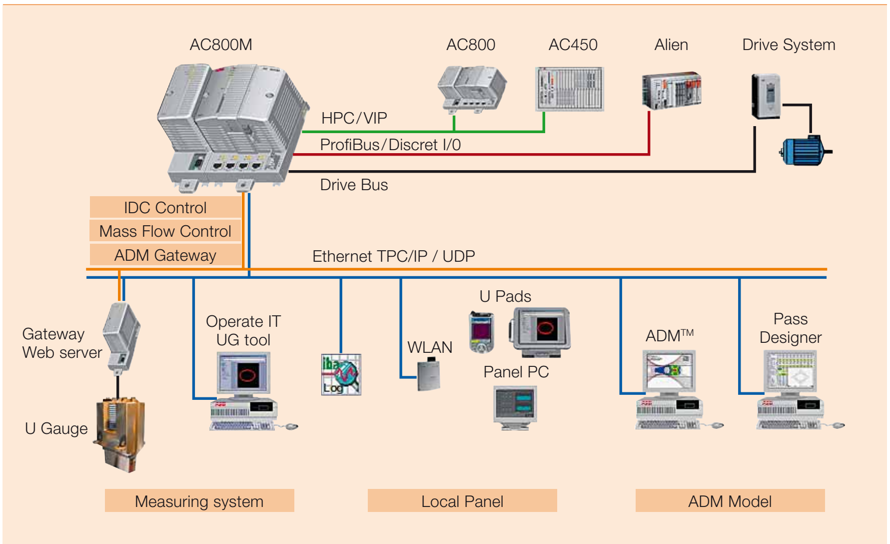
Model adaptation

Optimization may be carried out either for the current production run or for an upcoming one following a PrC procedure. For a current run, on-line drive system and U-gauge readings are used for model adaptation so that model accuracy is enhanced. Calibrated models from previous production runs may also be used in the PrC optimization provided their rolling conditions are similar. The logic of the ADM tool automatically decides the best model adaptation scheme. It is common knowledge that a rolling power model greatly benefits from adaptation and this in turn affects the accuracy with which energy consumption is determined.

Fast simulations for sensitivity analysis

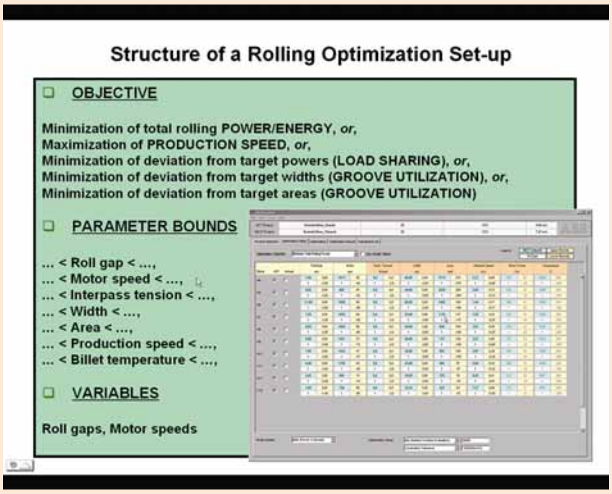
Another important feature of the ADM tool is the simulation functionality, which allows quantities such as bar width, area, speed, interpass tension, to be quickly calculated. Process pa-

3 Interstand Dimension Control (IDC) system components. The ADM tool runs on a dedicated PC connected to the system communication bus

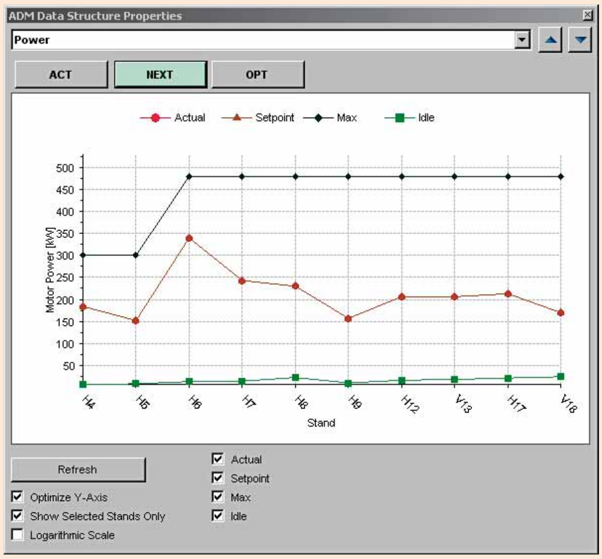


Energy efficiency in industry

4 The setup for a nonlinear optimization task with objective choices, parameter constraints and primary optimization variables is depicted. Also included is the corresponding ADM window for data entry.



5 Results chart for rolling power quantities

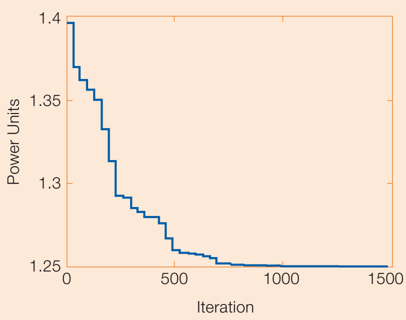


rameter inputs include roll gaps and motor speeds, along with information on billet and roll grooves. This feature is very useful when analyzing the effect of small changes or disturbances to the process parameters obtained in an optimization – so called *sensitivity analyses*. One simulation task requires a few tenths of a second for a 10-stand configuration whereas a 20-stand configuration requires slightly more than a second.

A statistical approach with uncertain materials and process conditions

Suppose a new material with uncertain materials properties (essentially its flow stress or resistance to deformation) is to be rolled the first time. To check for potential problems the operator may want to investigate for example the safety margins with respect to unstable rolling. He may then launch another simulation-based feature of the ADM tool, a *statistical evaluation* of the likelihood of interpass tensions exceeding allowable ranges. The core of this feature is based on the well known Monte Carlo approach, which has been adapted to the rolling models in a novel way. Results are presented as a probability of stable rolling for the configuration and process parameters at hand. In fact, all types of results pertaining to the bar, rolls and drives previously discussed may now be expressed as confidence intervals with lower and upper limits, rather than as one specific value obtained in a regular deterministic simulation. This also improves the accuracy of the energy requirement prediction as this is very sensitive to bar materials deformation properties.

6 Minimization of total rolling power (proportional to energy) for a Swedish 10-stand mill (intermediate and finishing part) configuration for the production of round 20 mm diameter bars.



ADM – a new standard in hot rolling

It is believed the ADM tool will set a new standard in a mill floor worker's daily strive for production perfection. HMI ease-of-use, robustness, and accuracy are corner stones of the ADM optimization, simulation, and model adaptation logic. It also provides an excellent educational platform to unite the many different "black art" PrC and process line fine tuning philosophies that usually exist among mill operators.

Towards on-line optimization

Further reduction of optimization times towards just one or two seconds is within reach using the latest numerical optimization developments. A fully automatic on-line optimization tool is envisioned thus alleviating the need for trial billets. To be more precise, optimization and adaptation is carried out during the time the bar head travels between the first two stands in a multistand rolling line.

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The energy optimizers

Energy management in cement manufacturing

Matthias Bolliger, Eduardo Gallestey, Gabriela Crosley, Michelle Kiener

Cement producers are large consumers of thermal and electrical energy, which on a global level are only available at steadily increasing costs. Efforts to reduce demands by using higher efficiency equipment and substituting fuels and raw materials to lower production costs have been addressed in recent years. These changes have introduced constraints that must now be managed to secure the required quality and productivity. Finding the optimal operating point within the boundaries of these dynamically variable constraints depends on the right price mix of fuels and timely purchases of electrical energy while constantly reducing demands for these resources. This article presents a set of solutions and tools to achieve these goals.

Energy efficiency in industry

To optimize the overall performance of a cement manufacturing unit requires a plant wide automation strategy. Reducing energy demand in all areas must be combined with the search for the optimal operating point that is consistent with productivity and quality targets, and in line with imposed environmental emission limits. Helping cement manufacturers achieve their operational objectives is ABB's Knowledge Manager (KM). KM is capable of gathering the information and data used by Expert Optimizer (EO) to model the process and to identify the best possible way of running the plant at all times.

> Reducing energy demand in all areas must be combined with the search for the optimal operating point that is consistent with productivity and quality targets.

Variable Speed Drives – an electrical energy saver

In the cement manufacturing process large fans draw air through the kiln, precalciner, mills and filters to an exhaust stack. Many smaller fans push the air into the grate cooler to reduce the temperature of the hot clinker leaving the kiln 1. All these airflows have to be adjusted and controlled as atmospheric conditions, process conditions and ventilation needs greatly effect the flow requirements. The control method employed has a major effect on the running costs. For example, a damper with a fixed speed motor is the least energy efficient solution and the application of variable speed drives (VSD) the most energy efficient. To be more precise, depending on the required flow rate, power savings of up to 70 percent can be achieved when the two are compared.

The difference in power demand for an air flow controlled fan is shown in 2. Fans are predestined for saving energy due to a quadratic load characteristic. Normal operation of large fans consumes about 90 percent of nominal air flow, which still represents a potential saving of 20 percent power. Nowadays VSD for large fans are usually installed in all new plants. However the potential for large energy savings still exists in fan replacements, especially in the cooler area.

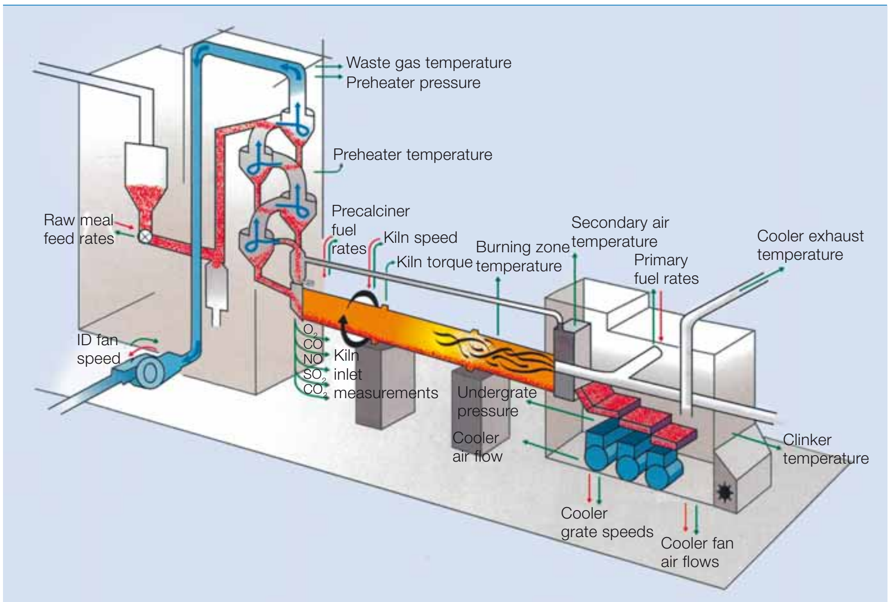
Optimized solution for Grate Coolers – Multidrive

Approximately 10 percent of the electrical energy required to produce one ton of clinker is needed to cool it. It therefore makes good sense to give careful thought to the choice of drive system for the cooler. One such choice is the Multidrive which is often referred to as an "optimized drive solution for the cooler area". It offers all of the benefits of VSD and eliminates – in an economical sense – many of the drawbacks of single drives. Unlike single drives (which have to have their own rectifier, DC link and inverter), the Multidrive system generates the required DC voltage in a "central" unit and feeds it onto a common DC bus to which the single, independently operated inverters are connected 3. In a Multidrive system all the desirable features of a single drive are still retained. In addition, the individual inverters do not all have to have the same power rating. On the contrary, a Multidrive package can consist of drives of very different sizes.

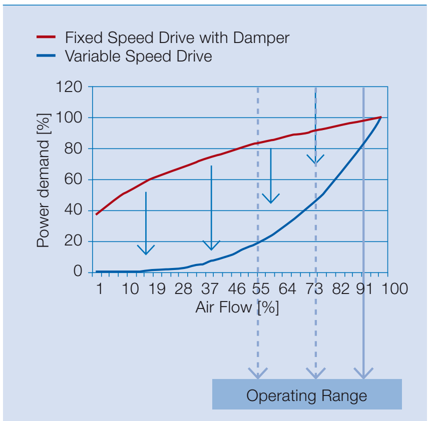
Some of the benefits of such a system include:

- *Reduced cabling* due to the single power entry for multiple drives.
- *Energy-saving motor-to-motor braking* which is required depending on the grate cooler type.
- *Reduced space requirement*
- *Elimination of the low voltage distribution* used for single drives or dampers and direct online motors in cases of replacement.
- *Cost effective reduction of harmonics* using an active front end supply unit or at least a 12-pulse line supply.

1 A kiln schematic showing the preheater for the raw material, kiln for the calcination process and grate coolers for the final clincker stage. This schematic also details the in- and output signals of an Expert Optimizer (EO) system



2 Power demand in percent of airflow using a damper and a variable speed drive



- All the benefits of a single VSD are retained.

Energy monitoring using Knowledge Manager (KM)

KM provides the solutions and advanced tools needed to facilitate the collection, organization and distribution of combined production, quality and energy information throughout a plant organization via web-based reports, trends, and graphs. On a single page all relevant key performance indicators (KPIs) for the process are calculated and displayed. Additionally, if an operator wants to maximize production and at the same time maximize the usage of alternative fuels, KM provides the information for proper analysis to establish what is and is not possible.

KM can be adapted and expanded to meet each company's specific requirements and is part of ABB's Inform[IT] application suite which deals with production information monitoring and reporting. It drastically simplifies cement production management by covering manufacturing related functions such as:
- Production tracking and reporting
- Process operations monitoring and reporting
- Material storage management
- Energy and emission reporting

With KM, identifying the influences that process parameters have on product quality, production capacity, energy consumption and emission levels is now easier than ever. It combines production related data, process variability, energy indexes and run-time quality parameters to produce comprehensive operation and production reports and trends. The quality of these reports and trends results in the better utilization of energy, equipment, inventories and capacities.

Based on the LINKman optimization system, Expert Optimizer (EO) combines rule based control with modern tools like Neural Networks, Fuzzy Control and Model Predictive Control (MPC).

Connectivity to Enterprise Resource Planning (ERP) systems (such as SAP) is essential to bring production data from the floor level to the enterprise management level. Here KM serves as the information broker between real-time control and its production environment, and the transactional based ERP systems.

The cost of production is directly influenced by the the energy usage. Different areas of production consume different amounts of energy, and KM tracks the amounts linked to the material being consumed or produced 4.

With specific information available at the right time and at the right place in the right format, decisions become more goal oriented, resulting in optimized processes and increased productivity.

Thermal energy savings using Expert Optimizer (EO)

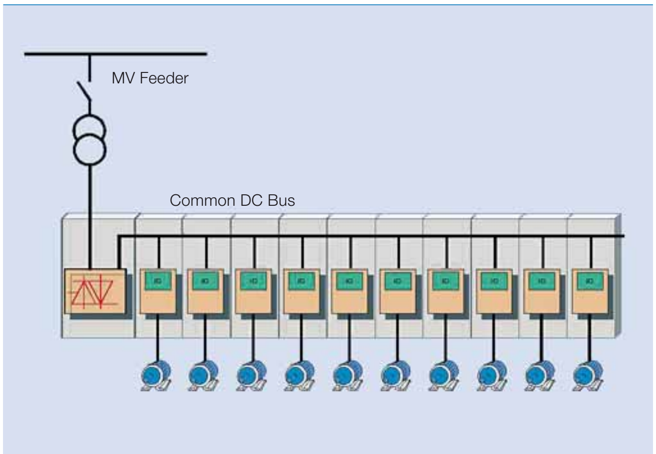
Cement manufacturing is a complex and energy-intensive process. A key stage in this process is the conversion of ground raw materials ($CaCO_3$, clay and/or shale) into clinker (synthetic cementitious minerals) in the kiln. A typical operation uses kiln exhaust gases to preheat the raw materials before they enter the kiln. Further heating, up to about 1,500 °C, takes place in the kiln's burning zone where the materials are partially melted and react to form clinker. Subsequent processing is required to convert the clinker to cement. Small amounts of gypsum ($CaSO_4$) are added and finally the mixture is ground to a fine powder.

Conventional control of a cement kiln requires the services of an experienced operator who must constantly interpret process conditions and make frequent adjustments to the set points established by the controller. This task is onerous enough, but it is made even more difficult by complex responses, time delays and interactions between individual process variables.

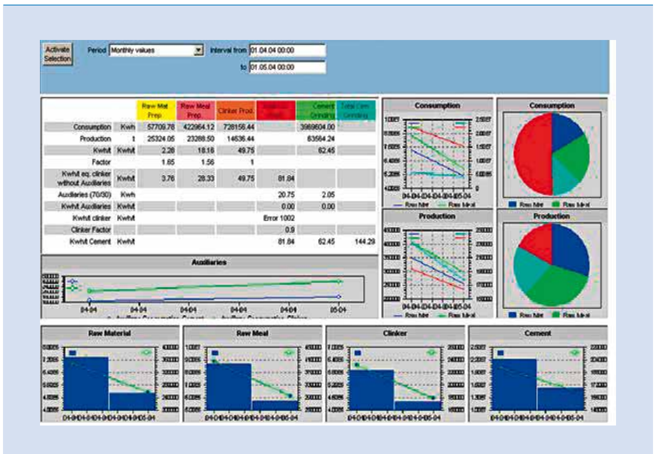
Footnote

[1] Burning zone temperature (BZT) is the predictor of product quality. If the BZT is low it is expected that the clinker will be insufficiently burnt and if the BZT is high it is expected the clinker will be over burnt.

3 A Multidrive system layout



4 Total energy report – thermal and electrical – with energy indicators



As a result, conventional kiln control normally forces a conservative approach to kiln operation, with associated temperatures that are higher than the optimum leading to unnecessarily high-energy usage.

EO is based upon the pedigree of proven successes from the well-known and highly regarded LINKman optimization system. It combines rule based control with modern tools like Neural Networks, Fuzzy Control and Model Predictive Control (MPC) Factbox. EO improves on conventional control by constantly interpreting kiln conditions and initiating appropriate actions. The various input and output signals are identified in 1.

Proper and stable kiln operation can reduce energy consumption and maintenance costs, increase kiln output, and improve overall product quality. However, while optimum operation involves maintaining Burning Zone Temperature (BZT)[1)] at minimum levels consistent with stability, this is difficult to sustain for three reasons:

- Variations in raw material feed composition
- Complexity of kiln operation
- Long time delays between kiln operational changes (ie, set-point changes and their effects)

The EO advanced kiln control system, however, operates the kiln in an optimum manner thereby ensuring a good quality product, lower BZT, and consequently, lower energy costs. The system achieves this by applying the appropriate level of expertise on a consistent and regular basis ie, by making frequent changes (every three or four minutes).

Today, reliable equipment and proven technical solutions are available to ensure the efficient use of energy without jeopardizing the quality and productivity of a plant.

EO is now typically in control of kilns for more than 80 percent of their run time. Calculations based on measured free lime and nitrogen oxide (NO_x) levels before and after EO installation estimate that in some cases savings in terms of fuel consumption approach eight percent per kiln.

Kiln fuel mix optimization

For some time there has been a need for tools that offer optimal management of the alternative and traditional fuels involved in the kiln process. In answer to this, EO has recently been enhanced with an *Alternative Fuels Optimization Module* that brings economic performance of kilns to new heights.

This module uses the data gathered by the information management systems (equipment, process, market, and laboratory) to calculate online the lowest cost fuel mix that satisfies the process and business constraints. The constraints to be satisfied are numerous but the most important ones are:

- Heat balance
- Excess oxygen level
- Clinker chemistry
- Volatiles concentration
- Emission limits (SO_2, NO_x, etc.)
- Maximum, minimum and speed of change constraints on actuators
- Operative constraints on fuel consumption
- Separate consideration of combustion process in precalciner and kiln
- Contracts (with customers or suppliers) to be satisfied at any cost

The basic element of this optimization algorithm is a dedicated kiln mathematical model developed in EO, which is used to implement the (model predictive) controller 5. This model can estimate cooler, flame, burning zone, backend and preheater temperatures, kiln energy requirements, emission and volatiles levels, etc. The optimization algorithms are able to cope with both hard and soft constraints, and this enhances robustness and reliability of the optimization process.

The input data is updated at sampling times of about 15-30 minutes, computations are executed and the new fuel setpoints are passed to the EO strategy module for implementation. Between sampling times, the “standard”

Factbox Model Predictive Control (MPC)

(Extract taken from ABB Review 2/2004, pages 13-19)
There are several ways in which optimal solutions can be approximated. One widely adopted approach to solving control problems involving systems which are subject to input and output constraints is Model Predictive Control (MPC). MPC is based on the so-called receding horizon philosophy, ie, a sequence of future optimal control actions is chosen according to a prediction of the short- to medium-term evolution of the system during a given time. When measurements or new information become available, a new sequence is computed which then replaces the previous one. The objectives of each new sequence run are the optimization of performance and protection of the system from constraint violations.

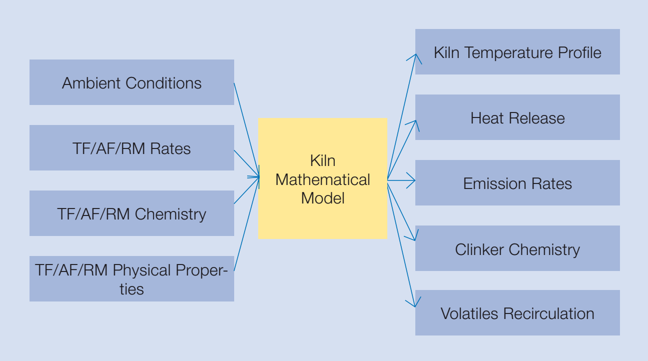
EO strategy guarantees process stability and the highest performance. In particular, this strategy enforces economically optimal reactions to changing conditions in fuel, waste, and raw meal quality as well as ensuring strict satisfaction of the environmental, contractual and technical constraints.

Electrical energy management

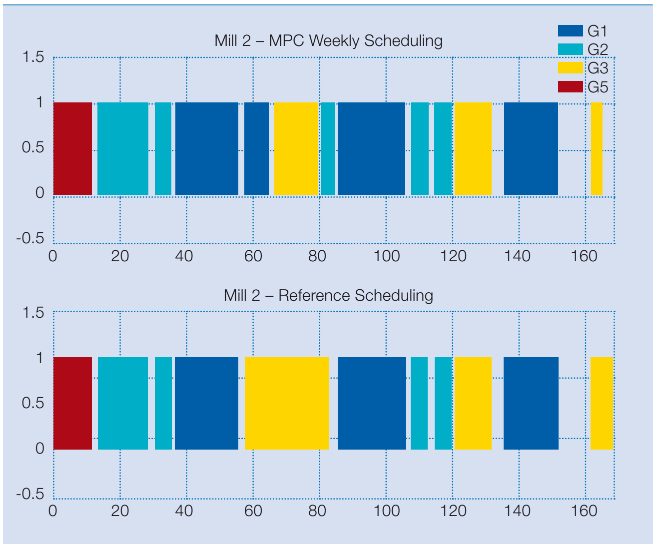
Cement production runs 24 hours a day with very limited spare capacity or redundancies installed. Thus, most of the equipment has to run around the clock, or if there are other constraints, during daytime like the quarry. The degrees of freedom available for electrical energy usage are therefore very limited and are mainly restricted to the cement grinding area. In this area scheduling, ie deciding when to produce a certain cement grade and in which mill, is performed manually using heuristic rules and relying on operator experience. However, the numerous mills, grades and silos, plus the various operating and contractual constraints, make the problem a complex one. Too often, the operator's choice is far from optimal. The solution described in the following text uses optimized scheduling based on MPC technology.

A typical mill on/off sequence and scheduled cement grades for effective electrical energy management is shown in 6. Using customer orders and energy price forecasts, the algorithm produces a reference schedule for the entire grinding plant operation defining what each mill will produce and when. Here the modeling functional represents costs associated with electricity consumption and the amount of low grade cement produced (cement produced during the switch from one grade to another). Electricity cost reduction is achieved by committing the production to time periods when the electricity tariffs are lower, and by making sure that contracted thresholds of maximum electrical power are not exceeded. Reductions in low grade cement are obtained by penalizing the number of production switches.

5 Typical cement Kiln model – inputs and outputs



6 Typical mill and cement grade schedule



In addition to the physical constraints imposed by the silo capacity and mill availability, other constraints must be considered:

- *Transition time:* A change of grade being produced by a mill might cause a time delay during which the mill throughput is conveyed to a special silo.
- *Order satisfaction:* As input, the optimization algorithm requires sales forecasts for every grade. If the sales forecast cannot be completely fulfilled, the algorithm will choose which grade to produce first according to a given ranking.
- *Transport system:* Whether it is by conveyor belts, bucket elevators or air based systems, there are constraints on the system for transporting the cement from the mills to the silos. For example, there might be three mills but just two independent transport routes. However, multiple mills can simultaneously discharge the same cement grade to the same transport route. On the other hand, one route can serve only one silo at a time and silos can be served by only one route at a time.

Summary

As shown in the above cases, energy management deals with different aspects of process optimization resulting in reduced thermal and electrical energy demand, and/or reduced costs using less expensive energy and fuel mix. Today, reliable equipment and proven technical solutions are available to ensure the efficient use of energy without jeopardizing the quality and productivity of a plant. The suite of available and integrated solutions discussed in this article – VSD, Expert Optimizer and Knowledge Manager – is a perfect example of how a plant wide automation strategy can achieve such goals. Since energy prices continue to fluctuate (tending towards an overall increase) the investment pay back time is generally good. In addition it has a positive ecological and environmental impact. All achieved while improving the bottom line.

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More productivity, less pollution

Power and productivity are fitting by-words for ABB's paint system activity

Hubert Labourdette

Paint application is a difficult industrial process but it is an area that ABB has much experience in. Over the years, the company's paint system activity, has developed a range of solutions for industrial paint shops that help improve overall productivity and quality. Automotive and general industry customers use these solutions for the surface finishing of cars, mobile phones, marine engines and cranes for example.

However, many paints contain organic solvents that are hazardous to human health and the environment. As companies are under pressure to reduce emissions and decrease their operating costs, optimized products, solutions and services are the order of the day. A crucial area of optimization is the paint booth and one that ABB has successfully tackled with the development of an air recirculation system combined with a state of the art energy saving process. This solution is described in the following article.

Paint application is a difficult industrial process, which has to face many demanding challenges simultaneously. For example:

- *Top-class paint finishing quality must be achieved* by spraying the object in a well controlled air environment, ie, in a paint booth with the correct temperature, air speed and hygrometry, and with the absence of dust.
- *There should be little or no waste.* Paint and solvent can be saved by using ABB paint robots and atomizers.
- *The exposure of operators to solvents should be avoided* to protect their health.
- *Energy should be saved.* The energy used represents between 25 and 30 percent of the paint application process cost.
- *It must be in line with environmental regulations.* This is now possible when using solvent paint thanks to Volatile Organic Component (VOC) treatment and to energy savings.

ABB has already addressed the paint material savings challenge with its cartridge bell system [1] and the majority of automotive carmakers are now equipped with it. A new paint robot generation 1, launched in 2006, dramatically reduces human activity in polluted areas by enabling a fully robotized process.

This type of process is very costly in terms of energy as large quantities of outside air (many hundreds of thousands of cubic meters per hour) need to be treated. Additionally, the mix of air and solvent which is rejected into the atmosphere no longer complies with environmental rules. These reasons alone are a compelling argument for paint booth optimization.

The ABB solution

To solve all these issues simultaneously, ABB has developed an air recirculation system combined with a state-of-the-art energy saving process in the paint booth. This solution combines air recirculation, solvent disposal and energy saving and is fully compliant with environmental regulations. It can only be applied in fully robotized areas. Since the launch of ABB's new paint robot generation this happens to be more and more common in paint shops.

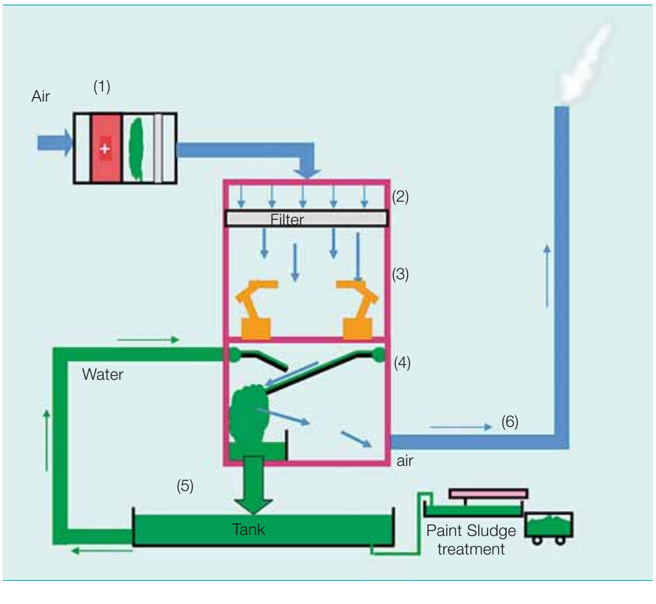
ABB has developed an air recirculation system combined with a state-of-the-art energy saving process in the paint booth. This solution combines air recirculation, solvent disposal and energy saving and is fully compliant with environmental regulations.

1 A new paint robot generation

Paint booth optimization

The paint booth process is illustrated in 2. An air make up unit (1) processes fresh air from the outside and controls its temperature, humidity and dust content. This fully controlled air is brought to the roof of the booth (2) at a constant vertical speed. It picks up solvent and paint during the spraying operation (3). A washing process is achieved through the venturi (4), where water mixed with paint material waste is sent to the waste treatment tank (5), and air mixed with solvent is blown through a chimney to the outside (6).

2 Paint booth process



Recirculation

The paint booth air recirculation process is shown in 3. After the washing stage (4), the polluted air is not vented outside. Instead, it is 90 percent recycled in the booth after it has been treated in (8). This recirculation system not only allows air reutilization, but the solvent concentration in the booth has a ratio that is in line with full optimization of the solvent burning process. Solvent concentration in the booth is monitored and maintained within safe limits. A specific air duct extracts 10 percent of the air flow and sends it to a Regenerative Thermal Oxidizer (RTO) (7). This extraction is counterbalanced by a small flow of air from the outside (1).

This process is very stable with very little influence from outside conditions. However, it requires a very efficient washing process (4) and a well specified dust filter.

Regenerative Thermal Oxidizer (RTO)

A regenerative process is used to treat the solvent in which burning is achieved at 800 °C. Thanks to the recirculation process, the air is solvent saturated. It goes through a high temperature ceramic chamber 4, where its temperature is raised to 780 °C after which it enters a combustion chamber. An auto-combustion phenomenon occurs at this temperature level, fully eliminating the solvents. This solvent-free air flow – with a temperature of 835 °C – is then sent through a second ceramic chamber where it is cooled to + 60 °C before being vented to the outside.

With the exception of the start-up phase, the amount of energy consumed by this system is close to zero, and thermal efficiency is close to 95 percent.

The air flow is periodically inverted to increase the ceramic temperature. With the exception of the start-up phase, the amount of energy consumed by this system is close to zero, and thermal efficiency is close to 95 percent. The process fully conforms to environmental laws in application in almost all countries.

Energy and water savings

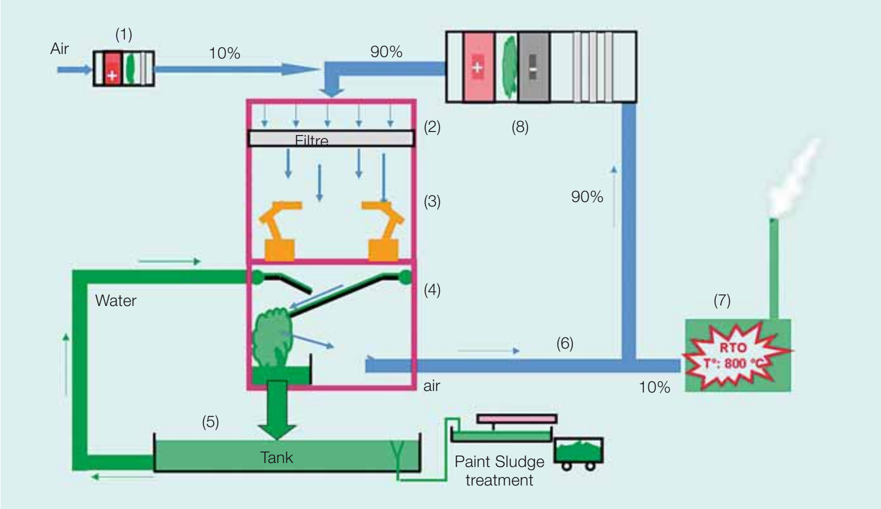
The paragraphs above have shown that solvents can be eliminated without additional energy. Another significant source of savings is in the outside air conditioning process 3 (1). Compared to a traditional scheme, ABB's process reduces the quantity of fresh air used – and hence the energy consumed – by a factor of 10! However, it requires the introduction of new equipment 3 (8). A more detailed illustration of the recirculation process is shown in 5. This entire concept has been optimized with energy savings in mind. After the washing step (A), the air humidity is too high and therefore cannot be reintroduced directly into the booth (C). Instead, it must be dried by condensation.

After a dust filtration stage, the air temperature is decreased to 14°C (B) to condense the water after which it is immediately increased to 19 °C. To reach an optimal level deemed necessary to achieve good paint application, the temperature of the air is increased by a further 2 °C by passing it through a fan. At the condensation stage, all water is collected and returned to the washing equipment. This approach creates a closed-loop system for the water, resulting in significant savings. Compare this to the traditional process, where a mixture of water and air is blown out, while fresh water is used in the washing equipment.

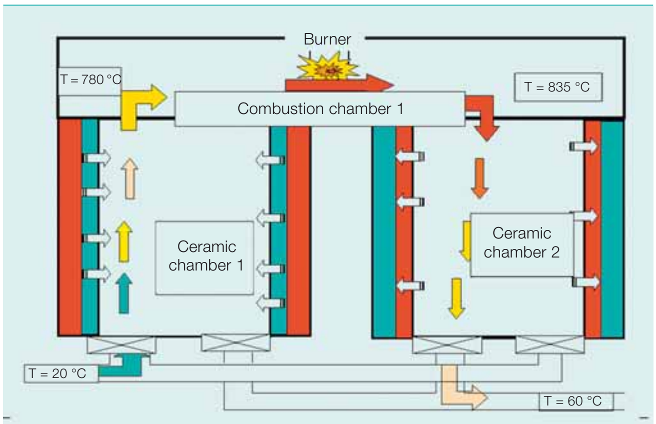
At the condensation stage, all water is collected and returned to the washing equipment, creating a closed-loop system for the water, and resulting in significant savings.

A cooling system is directly connected to the air treatment unit. It is used for the first step of air cooling, but as with all such systems, it generates a significant amount of heat. However, rather than creating a problem, this heat is utilized for

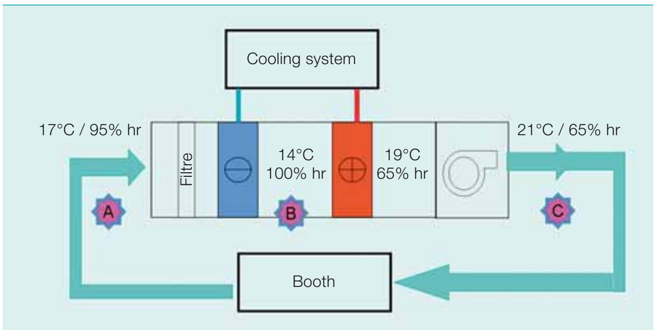
3 Paint process with air preheater and regenerative thermal oxidation (RTO) reduction equipment



4 Air circulation chamber

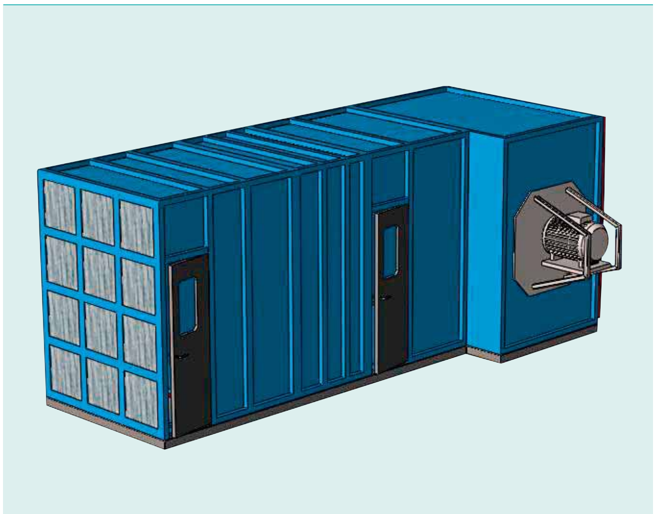


5 Air heating and cooling system



6 Compact and transportable air washing equipment

7 Compact and transportable air treatment unit and cooling equipment



the second step of air heating. The result is low energy consumption.

System implementation
ABB's air recirculation system can not only be implemented in new factories but it can also be used to improve the performance of existing ones. The latter case, however, creates an additional challenge in that all modifications, including start-up and commissioning, have to be successfully implemented during the two or three weeks of normal shutdown (ie, summer and Christmas holiday period). To achieve this, ABB has successfully developed a modular equipment range based on a plug and produce approach, 6 and 7.

Almost all elements of this range include products from other ABB divisions (PLC, drives, instrumentation etc.) and they provide a good overview of the ABB equipment portfolio. They are pre-assembled in a temporary structure close to the existing paint shop. As soon as production shuts down, the old equipment is partially disassembled and the new modules are then integrated into the paint line.

Customer benefits
The system offers very stable application conditions independent of outside weather variations, which results in a significant quality improvement. A new installation is very compact and requires a much smaller footprint than that of an older line, and it is fully compliant with environmental regulations. Substantial energy savings approaching 30 percent are realized when compared with existing lines. This represents a nine percent reduction in the total annual operating cost of the paint process.

Customers benefit from the very high level of engineering expertise acquired by ABB engineers in paint application from the many installations around the world. This experience is necessary to accurately define a complete system. Additional benefits are generated by using a fully robotized process without any manual paint application, an area in which ABB is the world leader.

Substantial energy savings approaching 30 percent are realized when compared with existing lines. This represents a 9 percent reduction in the total annual operating cost of the paint process.

Paint savings, the complementary challenge
The recirculation system requires a fully robotized process which produces further savings, ie, it reduces paint consumption (and thus cost) and hence environmental impact. Robots equipped with a state of art ABB paint atomizer increase transfer efficiency (defined as paint quantity used on a part divided by total quantity of paint used). In addition, the paint process is monitored by a sophisticated program, which accurately tracks all paint process related parameters as well as the paint pattern on the car.

The robot is now mandatory not only to achieve paint savings but also to avoid operator contact with very dangerous chemical substances Title.

This unique solution from ABB increases productivity and saves energy with less pollution.

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Reference
[1] **Yoshida, Osamu**, "More colors, less waste – ABB Cartridge Paint System: Cutting costs and reducing environmental impact", ABB Review Issue 1 2006, pages 43–46.

Shades of green

The dream of a sustainable and economically viable green biomass-based fuel for use in combustion engines is coming closer and closer to reality. This shift is guided by a mix of government directives and incentives. By 2020, so the EU stipulated on 15th February 2007, all cars must use a 10 percent blend of ethanol with petrol or methanol with diesel. The processes used to produce these two components differ in that ethanol uses fermentation to produce alcohol and methanol is produced using a gasification process to produce a raw but clean synthesis gas that is processed into biodiesel.

Today Brazil is already surpassing the EU 2020 goal of blending by using ethanol derived from sugar cane. As early as 1925, ethanol was produced and by 1975 a program was introduced that had by 1993 led to a 20 to 25 percent mix. This huge country has 313 ethanol plants in operation and, with export in mind, an additional 89 plants are planned. Biodiesel is also on the rise using palm oil or soybeans as raw materials. The existing 10 plants will soon be joined by 100 more.

The USA is using corn and wheat to produce ethanol on an increasing scale and in Europe experiments are ongoing with ethanol production from grain, sugar beet and vegetal cellulose from sources such as grass, tree branches, roots and stumps. Better economics are obtained with new combined plants. Waste products from ethanol production are used to produce methanol for bio diesel. The pulp and paper industry in Sweden is currently successfully testing gasification of black liquor to produce bio diesel. Another green source of vehicle fuel used in some countries is methane gas derived from mixed refuse which is used in cities to drive fleets of buses and small trucks.

Raw material for these different fuels will of course depend on the availability in the given area. However, will they all be sustainable, green and economically viable? The jury is still out and many shades of green show up when a strict analysis is made. For example some years ago the Dutch government decided to make biofuel from imported palm oil. On the surface, this looked very viable and truly green. A recent study revealed the consequences of the increased demand: Rain forests in South East Asia were burnt down producing massive amounts of CO_2, and replaced by palm oil trees needing fertilizers. Considering the global perspective, this Dutch initiative did not look so green any more. The greenness of a process can often only be judged when the entire production chain is taken into account.

Many biofuel technologies are being jump-started through governmental incentive programmes. In the long run, however, they must be able to stand on their own feet economically.

To be both truly green and financially viable, the process must be sustainable in all respects and a net contributor to the reduction of CO_2 emissions. Many processes currently in operation will not pass such rigorous test criteria, but some will, and it is these winners that will provide the green future we are dreaming of.

Biogas from waste

Two interesting biogas facilities were taken into production in Sweden in late 2006. The cities of Boras and Gothenburg are leading the battle against global warming by powering their fleets of trucks, buses and other vehicles with bio methane produced from the mixed refuse from domestic and industry's dustbins. The increasing interest in reducing carbon dioxide emissions in the transportation sector has created opportunities and incentives to convert to "green" cars using tax and duty reductions including free parking in the big cities of Sweden. Biogas production is rapidly being established as an alternative to fossil-based fuels.

The processes used in these two cases are supplied by Läckeby Water, a privately held company from southern Sweden. The equipment provided by this company consists of drum sieve modules, heat exchangers, filters, decanters and sand washers. These are combined into a process tailored to match the specific requirements defined by the available input mixture. The produced biogas is cleaned by the special Cooab technique, which emits as little as 0.1 percent of the methane into the atmosphere (other methods release two to four percent). Besides the reduction in greenhouse gas emissions, this means that more energy is converted into useful biogas.

The Boras and Gothenburg installations will, at full production, produce 25 GWh and 60 GWh per year respectively.

ABB's involvement with these two facilities consists of the supply of the automation system and electrical equipment such as motors, drives and switchgears. Through its participation in biogas projects of this type, ABB's engineers have developed know how that can be packaged into modular applications for reuse. Today, Sweden is the world leader in bio methane production for vehicles, hence application know how is at the forefront of development.

The Boras and Gothenburg installations will, at full production, produce 25 GWh and 60 GWh per year respectively, with that at Gothenburg representing the world's largest facility for biogas. Gas from the decomposition of biological refuse is washed and cleaned to provide bio-methane for the municipality's vehicle fleet. The corresponding reduction in CO_2 emissions is estimated to be more than 20,000 tons annually.

The process supplier, Läckeby Water, has supplied 4000 projects of different magnitudes to 68 countries around the globe. Encouraged by tax incentives, the sale of biogas-powered cars increased by 50 percent in 2005 growth that creates new opportunities for Läckeby Water and ABB. It is estimated that further installations in Sweden will, by 2020, create employment for 60,000 people, which equates to the manufacturing jobs lost during the last five years. This expansion is hence both environmentally and politically rewarding.

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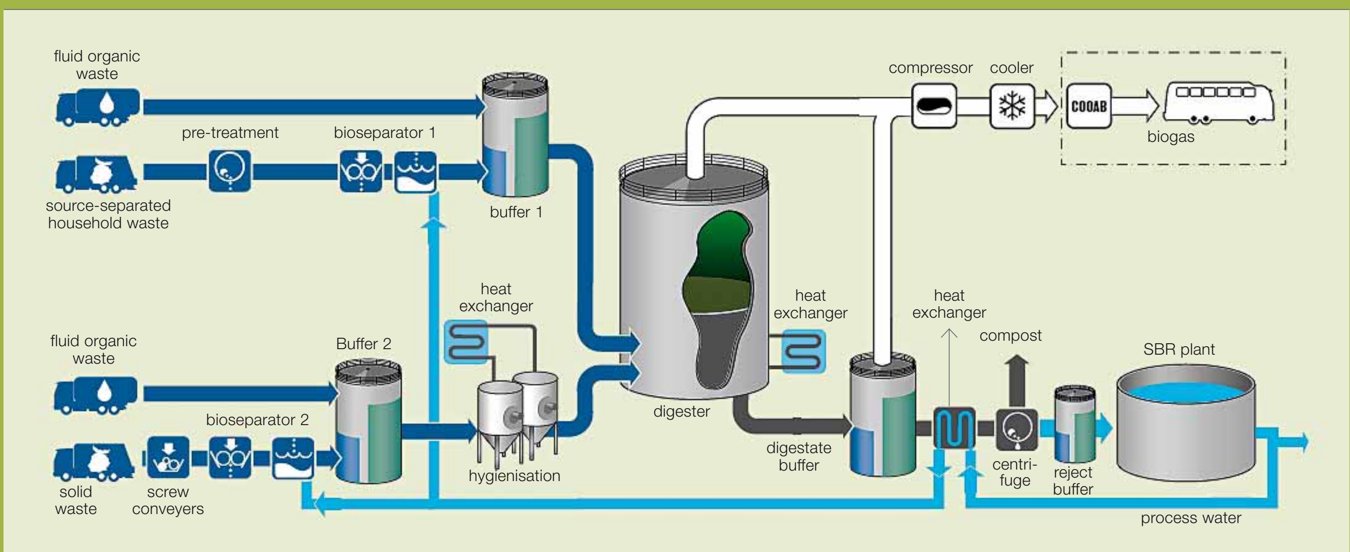
The Sobacken generation 2 biogas plant



Ethanol: Under royal guidance

The production of biofuels is being pursued in Thailand as a substitute for oil and natural gas. Developments are focusing on the active use of cheap organic matter. In fact, the production of gasohol (a blend of ethanol and premium petrol) in Thailand originated with the royal project of His Majesty King Bhumibol Adulyadej as early as 1985. This project produced ethanol from cane. Later, both the public and private sectors realized the business potential of ethanol production and participated in its development and testing.

In Thailand, there are currently eight major producers who have government approval for the manufacture of ethanol. One of them is an ABB customer, Thai Agro Energy Co., Ltd. The plant, located in Dan Chang, Suphan Buri Province, is designed to produce 150,000 liters of ethanol from molasses every day. The ethanol has a purity of 99.5 percent and is sold to make a blend consisting of 10 percent ethanol with premium petrol. The blend is called gasohol, and is positioned as an alternative fuel for automobiles.

Based on the success of its products with the Thai Agro Energy, ABB won another project to deliver similar equipment to Petro Green (also in Thailand).

When Thai Agro Energy started the project in 2004, ABB was asked by the French licensor and contractor, Maguin, to put forward proposals for the control and electrical systems. Following many rounds of presentation, discussions and evaluations with the customer, ABB was selected to supply the motor control center (MCC) for the 380 V motor, the automation system for controlling the ethanol production process, and field supervision and commissioning services. The products and services ABB provided included conceptual design, detail engineering, application software programming, MCC and control panel design and manufacture, FAT[1)], SAT[2)] and overall commissioning. The plant started producing ethanol in the first quarter of 2005.

The automation system consists of two ABB Process Portal operator consoles, an AC800M controller unit and an S800 for 450 I/O signals. The latest automation technology from ABB, IndustrialIT 800xA system, is a fully integrated system designed to improve plant productivity. By gathering all the key process data from field instruments, Process Portal will supply customized displays including alarm lists, process graphics, control faceplates and trend displays. The operators are at ease to perform their control functions efficiently while working in the familiar Window XP environment. For example, the operators can start or stop a motor through Process Portal and the feedback signal will indicate the motor status. Several control faceplates can be displayed at the same time. Operators can identify root causes of alarms: Trend displays are important tools to help them to analyze the process status. These tools are helpful for in-depth investigation and trouble-shooting using run-time data or historical data. Scheduled and on-demand reports are readily produced in Excel and can be distributed to management.

In addition to customized displays, other information such as drawings and diagrams are available. This comprehensive operational environment reduces the time between decision and action. With real time information available, the maintenance team can reduce maintenance costs through early detection of performance problems with the equipment such as field instruments, motors, or the control system itself.

Based on the success of its products with the Thai Agro Energy, ABB won another project to deliver similar equipment to Petro Green (also in Thailand). Again, ethanol is produced from molasses in a very similar process delivered by Maguin from France. This plant was successfully commissioned in November 2006.

With ABB's IndustrialIT 800xA and Motor Control Center, Thai Agro Energy Co. and Petro Green (among others) are now well equipped to proceed with an efficient mass production of ethanol. This will benefit Thailand economically by reducing oil imports and ecologically by supplying alternative energy for a clean environment. All in line with the wish by His Majesty the King to make Thailand better for it's citizens!

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Footnotes

1) FAT: factory acceptance test

2) SAT: site acceptance test

Green oil from ethanol by-products

Little Sioux Corn Processors, a corn ethanol processing plant in Marcus, Iowa (USA), is benefiting from adding an oil extraction unit to its process. This system extracts corn oil from the by-products of ethanol refining. These products are typically used in low priced animal feeds. Little Sioux can now sell this oil as higher grade animal feed or biofuel. The extraction cuts wastage of raw material and improves profitability.

GS–Cleantech Corporation manufactures the add-on extraction system, called Corn Oil Extraction System, or COES. COES is a completely automated system that integrates easily into an existing ethanol plant with no process interruption. COES utilizes a full complement of ABB products, including the Compact 800 HMI, a full PC-based control system with 800 series controllers and PLC units, ACS 800 Variable Frequency Drives, low voltage products and instrumentation (pressure transmitters).

The ethanol processing by-product – dry distiller's grain – is valued at 3.5 to 5 cents/lb. The oil currenty extracted from this by-product is worth 30 to 36 cents/lb after conversion to biodiesel.

The control system used in COES, a Compact Products 800, is an open control system based on standards that ensure it can be combined with other products on the automation market.

The integrated ABB system has helped Little Sioux reclaim corn oil that would otherwise have been wasted.

The ABB MS Manual Motor Protectors combined with the A-Line contactors used in this solution provide a compact and reliable method for switching and protecting motors against failures. Operators benefit from reduced downtime costs when utilizing these products in combination.

Unrivalled in its scope and applications expertise, ABB provides a wide variety of FOUNDATION Fieldbus, PROFIBUS and HART enabled instrumentation solutions certified to international standards.

At Little Sioux, an ABB 800xA Compact 800 workstation in the control room is connected to two non-redundant AC800M processors in the field. Two remote ABB Process Panels in the field provide the flexibility to control processes from either the control room or the field. The ABB system controls evaporators and the extraction system.

The extraction system consists of a specially designed pre-treat system, oil separation equipment and a storage system. The product is routed from the evaporators to the pre-treat system, then to a high-speed centrifuge which separates the oil from the by-products. The oil is then pumped into custom designed storage tanks for further purification. Remote ABB PLC's control the entire system and ensure a pure corn oil is ready to be pumped into semi-trailers.

GS-Cleantech is a technology developer that provides engineering and commercialization of technologies which improve the environment as well as the profitability of their customers. It is a part of the Greenshift Corporation portfolio of companies, which all focus on developing technologies that help companies utilize natural resources more effectively.

The Little Sioux installation is one of three installed COES systems. Several others are under construction. Improving the economics of ethanol production is a key objective in creating new ideas to process waste into useful products making this process more viable in the long term.

The objective for Little Sioux is to extract more fuel and more value from each bushel of corn it processes. The integrated ABB system has helped Little Sioux reclaim corn oil that would otherwise have been wasted. This product is now not only viable, but a desired commodity. The working relationship of GS Cleantech and ABB benefits their customers, but arguably the biggest benefactor of all is the environment.

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Biomass gasification and fuel synthesis

Biomass-derived fuels, chemical compounds, and power from renewable sources such as forests and farm land are foreseen to become important energy sources for a sustainable future. Advanced biomass conversion technology will play a crucial role in at least reducing, if not eliminating, oil dependence in some countries such as Sweden. At the same time it will mitigate the negative effects of greenhouse gas emission generated from the combustion of fossil fuels.

In late 2004, an EU sponsored research project for Clean Hydrogen Rich Synthesis Gas (CHRISGAS), based on biomass started in the town of Värnamo located in the forested area of southern Sweden. An existing research pilot plant built in the 1990ies by Sydkraft AB, a Swedish utility company, and later mothballed, will be retrofitted to enable thermo-chemical derived vehicle fuel research under the auspices of Växjö University. The formation of a non-profit company, the Växjö Värnamo Gasification Center, VVBGC, in 2003 to operate and maintain the plant initiated investments in the rebuild of the existing process for its new purposes. With EU's Framework 6 [1] and the Swedish Energy Agency as key sponsors, the CHRISGAS project commenced on September 1, 2004 as a national and European venture in research and training.

Main objectives

The objectives of the CHRISGAS research project are to develop and optimize a process for the production of hydrogen-rich gas from biomass in an energy and cost efficient manner. This gas can then be upgraded to commercial quality hydrogen or to synthesis gas for further refinement into liquid fuels such as DME, (dimethyl ether), methanol or Fischer Tropsch diesel.

The primary focus is to demonstrate by 2009 the economic production of an intermediate product for the manufacturing of vehicle fuel from renewable feedstock – a clean and hydrogen-rich gas based on steam/oxygen blown gasification of biomass. This

> The objectives of the CHRISGAS research project are to develop and optimize a process for the production of hydrogen-rich gas from biomass in an energy and cost efficient manner.

process step is followed by hot gas cleaning to remove particulates and steam reforming of tar and light hydrocarbons to further enhance the hydrogen yield. Two quantitative goals have been established. The gas generation capacity should reach 3500 Nm^3/hour [2] with an accumulated operating time of 2000 hours.

The process

The process steps are shown in 1. The heart of the process is a low-pressurized steam/oxygen blown gasifier cyclone 1c typically operating at 10–15 bar pressure and 950 to 1000 °C. To reduce the inert gas consumption of the fuel feeder, a piston based system is being developed with a performance that exceeds the current one by two orders of magnitude. The biomass fuel is fed at a maximum rate of 4 ton/hour and consists of roots and branches. Gas cooling takes place downstream of the gasifier 1d. The optimal temperature in this phase is a research topic in itself and will be determined during testing. The steam

Footnote

[1] The EU's Framework Programme for Research and Technological Development is a major tool to support the creation of the European Research Area. FP_6 is the sixth such programme.

[2] A Nm^3 is a cubic meter of gas at normal, ie, atmospheric pressure conditions.

reformer 1g, catalytic or thermal, follows and provides for the first stage of chemical upgrading converting hydrocarbons (mainly methane) and tars to hydrogen and carbon monoxide. The determination of the optimal balance between these two components to achieve high yield of synthesis gas is one of the crucial research tasks. To further enrich the hydrogen in the raw gas and provide for additional upgrading, a water-gas-shift and a hydrogenation reactor 1j is placed after the cooling. The optimal temperature for this stage will be identified as part of the research program.

Topics that the technical challenges are related to are the scaling of the process from laboratory size to semi-full scale, making critical filters work at high temperatures and identifying the operating points that provide maximum yield. But more than all this, the greatest question requiring an answer is: "Can biomass replace natural gas in producing a synthesis gas of the quality required for further processing into biodiesel at a cost compatible with commercialization?"

To allow necessary process changes, research tests and quick modifications, the new equipment must have a degree of built-in flexibility. This requirement led the plant manager, Ola Augustsson, to select a new control system to help him achieve freedom to change and reprogram the system when necessary.

The ultimate goal is to transform the synthesis gas into vehicle fuel at cost effective prices.

Control system from ABB

After an evaluation process, ABB's system Freelance 800F was selected – including the operator interface DigiVis. Communication with existing sensors and actuators as well as with existing cross coupling had to be prepared. As a safety feature, a process shutdown system was included in case anything should go wrong in an experiment. The installation and commissioning took place during the summer of 2006. "ABB performed this work very well", says Ola Augustsson. "It was not so easy because of the restrictions the old equipment caused. Now we have an operator-friendly and flexible system for our research plans." The plant was tested late 2006 with excellent result. Further testing will continue in 2007.

Vision

The ultimate goal is to transform the synthesis gas into vehicle fuel at cost effective prices. This process step will not be implemented for another couple of years. It is however a well understood and mastered process and no major research is required as long as the feedstock (the synthesis gas) is of high quality and high yield. However, when the old Värnamo factory starts commercially producing real diesel from roots and pine branches, the reduced effect on the climate is the real winner.

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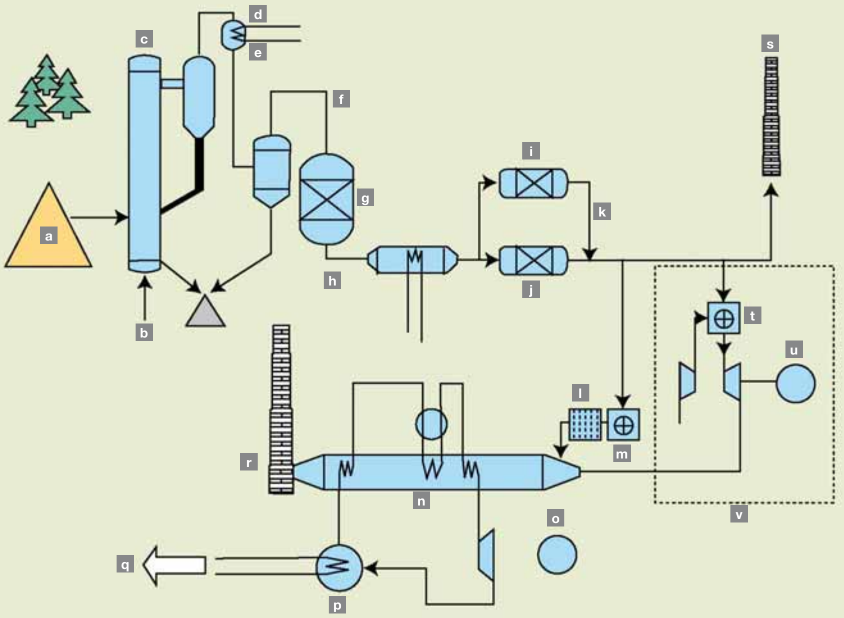
1 Ethanol production principles

Ethanol is an alcohol produced from a crop fermentation that converts starch into sugar (molasses) and again changes molasses into alcohol. Through distillation, a pure alcohol of 95 percent is obtained.



- a Biofuel
- b Steam + oxygen
- c Gasifier
- d Gas cooler
- e Hot gas filter
- f Steam + oxygen
- g Reformer
- h Gas cooler
- i Water gas shift
- j Hydrogeneration
- k Synthesis gas
- l Quench duct
- m Burner
- n Heat recovery boiler
- o Steam turbine
- p Condenser
- q Cooling to air
- r Stack
- s Flare
- t Burner
- u Gas turbine
- v By-passed processes

Alternative energies

Fuel additives go green

Eleven years after building a sugar factory in Zeitz, Saxony-Anhalt, Germany, Südzucker AG set another milestone by building a bioethanol plant in the region during 2006. The main ingredient used to make bioethanol at the plant is wheat, but Südzucker can also make use of the by-products that result from its sugar operation, along with other kinds of grain that exist in abundance around Zeitz. The new plant can produce 260,000 cubic meters of bioethanol per year. This takes about 700,000 tons of grain and requires a cultivated area of about 100,000 hectares.

Bioethanol is a readily available, clean fuel used as a fuel additive in making environmentally friendly gasoline for combustion engines. It can be made from grain, corn, some tubers, sugar beet, sugar cane or cellulose plant material such as grass or wood based products. Bioethanol is basically alcohol, resulting from a process of fermentation, distillation/rectification and dehydration.

Today's effective gasoline standard allows for up to five percent added bioethanol. On Feb 15, 2007 the EU proposed that this should be raised to 10 percent by 2020.

The European Union is promoting the use of biofuels and other renewable fuels to help meet the EU's climate change commitments.

The standard also permits as much as 15 percent ethyl-tertiary-butyl-ether (ETBE) – an octane improvement that can be made from ethanol. Both substances are excellent gasoline additives and have superb environmental properties.

Factbox The ABB contribution

For this project ABB supplied:
- The plant's process control system, consisting of 14 AC 800F controllers, seven operator control and observation units and two engineering stations. Its framework comprises about 16,000 I/O (input/outputs), most of which are decentrally equipped with S800 modules in more than 100 remote I/O housings
- A Motor Control Center (MCC) drives the entire building installation, including the layout for external and internal lighting
- The fire alarm system and the infrastructure for the IT data network
- Complete engineering, assembly, configuration and commissioning of all facilities

The European Union is promoting the use of biofuels and other renewable fuels to help meet the EU's climate change commitments, and to create environmentally friendly, secure supplies of fuel from renewable energy sources.

Managed by its Leipzig office, ABB has been part of the Südzucker project since late March 2004. This is also ABB's first major Profibus-PA installation: There are about 1,000 Profibus devices at Südzucker. In Zeitz, ABB automation experts used the new visualization screen and Industrial[IT] 800xA Operator interface to connect to AC 800F controllers.

ABB has supplied cutting-edge process technology for the plant. The very short duration of the project presented a considerable challenge. Through close cooperation between all participating ABB partners, however, this challenge was turned into a success. The plant was commissioned in late 2006 and has been fully operational since early 2007 -contributing to a cleaner world.

Staff Report
ABB Review

1 Südzucker's new bioethanol plant can produce 260,000 cubic meters (260,000,000 litres) of the clean fuel additive per year.

Clean power from the sea

Large wind parks at sea replace new power stations on shore

Eskil Sörensen, Finn Nielsen

About one fifth of the electricity demand in Denmark is covered by wind power, which makes Denmark the leading wind power nation in the world. For many years, new windfarms were located on land, but today more and more of them are located at sea. Two large offshore wind parks, whose output can be compared to medium-sized power stations, now deliver almost four percent of Denmark's electricity demand or 25 percent of its wind power generation. ABB is an important supplier to these parks – providing transmission equipment, generators and low- and medium-voltage products and SCADA[1] systems.

Wind is in the eye of the storm over global warming and it is becoming increasingly relevant in the fight against CO_2 emissions. Denmark is a leading producer of wind turbines for electricity generation and two of the world's leading companies are based there – Siemens Wind Power (previously named Bonus Energy) and Vestas Wind A/S, the largest wind turbine producer in the world. This has created a knowledge base that other producers are eager to tap into; hence they are locating research units in Denmark. A network of sub suppliers to the wind turbine producers has emerged in the same area. This concentration of know-how and manufacturing skills is essential for the development of wind turbines into larger and larger units: Wind turbines now exist with wingspans of 60 meters and towers reaching a height of close to 120 meters. Parallel to this development is an increasing academic interest, which is reflected in the education and training of expertise at the surrounding universities and wind institutions such as Risö research center.

History of wind

ABB in Denmark is also a member of this knowledge-environment, and has over the last 25 years developed a substantial expertise in the area of power generation from wind. ABB's cables and transformers, generators and motors are but a selection of the products it delivers to the wind turbine manufacturers. Hence, when the Danish-based manufacturers export large wind parks to California or Spain, an important portion of the equipment often comes from ABB. As a matter of fact, wind contributes a large part to ABB Denmark's revenue.

> Denmark is a leading producer of wind turbines for electricity generation and two of the world's leading companies are based there.

Just a few years ago, 50 percent of the world's wind turbines came from Danish companies. However, today several other producers have entered the market such as General Electric from America and Suzlon from India. Wind power has become a global business with significant competition; Danish producers control 30 percent of the market. With an annual expansion of around 20 percent during the last few years, this market share is equivalent to a substantial growth in the local Danish wind industry. As a matter of fact, this sector is the Danish industry segment seeing the greatest boom, having grown from $ 500,000 10 years ago to today's figure of $ 4 billion (according to the Danish Wind Energy Association). This implies that the Danish wind industry is constantly in need of new employees. Today 21,000 people are employed by the industry in Denmark and it is getting difficult to find the necessary talents.

The Danish wind adventure commenced during the oil crises of the 70s. At first, small wind turbines were built, often by the local blacksmith. By the 80s the development had become more professional and industrially-produced wind turbines marked their breakthrough with the introduction of 55 kW units. Since these early days, several new generations have been developed and today's turbines are 50 times more powerful. The market offers 2 MW and even 3 MW turbines. The biggest commercially available unit today is 3.6 MW, but larger turbines are already in the pipeline.

Wind turbines at sea

There are good reasons why the energy industry is prepared to face the difficulties of building wind parks offshore. As the wing span and the height of the wind turbine have grown, it has become more and more difficult to find acceptable locations to erect these towers, especially in densely populated countries such as Denmark. There is a limit to how many wind turbines people are willing to accept in their landscape.

Footnote

[1] SCADA: Supervisory Control and Data Acquisition, a large-scale distributed monitoring and control system

1 The Nysted wind park consists of 72 wind turbines, each with a max capacity of 2.3 MW

The second reason for moving off-shore is related to the fact that the wind is somewhat stronger over the sea, which results in higher electricity production – in the best case as much as 50 percent more.

Countering these benefits is the higher cost associated with wind parks at sea such as constructing the foundation for the tower. The higher salt concentration requires corrosion resistant components. The tall towers are carefully treated with special paint. The machinery is often placed indoors where the humidity can be kept at a level of less than 50 percent. Maintenance cost is also higher since crews have to be flown back and forth with helicopters. The energy utilities are justifying these additional costs for offshore based wind farms by the increased electricity generation.

In Denmark, installed wind turbines produce an aggregated 3100 MW of power, which is equivalent to five large power plants, hence save the equivalent of four million tons of CO_2 annually.

Nysted off-shore wind farm

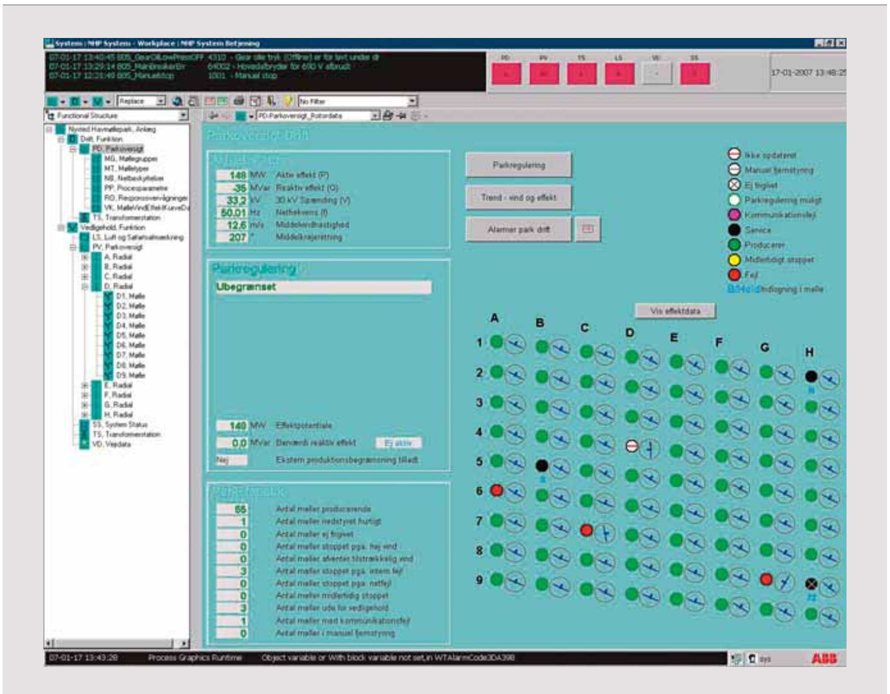
Based on a decision by the Danish Parliament (Folketinget), two large off-shore power parks were constructed as early as 2002 and 2003. Together these parks can meet almost four percent of Denmark's electricity demand. ABB was a supplier of essential equipment to both these installations. The Nysted sea-based wind park for power generation was commissioned in 2003. At that time it was the largest off-shore wind farm in the world 1. The 72 wind turbines produce a maximum power of 165.6 MW; the equivalent of a medium-sized power plant. Each turbine delivers its power to the aggregating center 2 by a 33 kV cable. Here the power is transformed to network voltage levels and delivered to shore by a 132 kV cable. This park can satisfy the power demand of 150,000 households.

The atmosphere is relieved of 500,000 tons of CO_2 annually, equivalent to one percent of Denmark's total CO_2 emissions. This is a significant contribution to the reduction of greenhouse gases. In Denmark, installed wind turbines produce an aggregated 3100 MW of power, which is equivalent to five large power plants, hence save the equivalent of four million tons of CO_2 annually. The Nysted offshore wind park was designed to produce 500,000 MWh annually. This goal has been more than met.

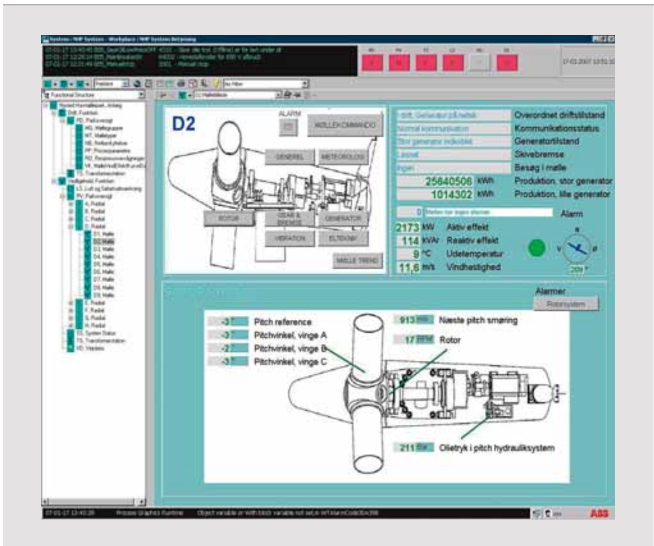
More off-shore wind power is in preparation. The Danish government has recently announced permission to build two new wind parks off-shore. These will be commissioned in 2009

2 Transformer unit for the aggregation of the 72 wind turbines of the park

3 The operators' overview of status information for all 72 wind turbines



4 "Drilling down" to the status details of an individual wind turbine



and 2010. DONG Energy A/S has been appointed to build the park located at Horns Rev and a consortium of DONG Energy A/S and E.ON Sweden AB are the winners for the construction of the park at Rödsand. ABB has already been awarded an order and several more are under way.

Off-shore wind park as power station

A network of 72 towers, such as Nysted offshore wind farm, requires a SCADA system for control and monitoring. The system supplied was based on ABB's System 800xA with built-in redundancy. The result was a very stable system with high availability. In addition, ABB delivered all 72 transformers and generators and 45 kilometres of 33 kV sea cables to the turbines, which are located 10 to 14 km from land. Also the on-shore cable link, which transports the power to the electricity network, was delivered and commissioned by ABB.

Factbox Nysted offshore wind farm

- 72 wind turbines, each 2.3 MW
- Combined maximum effect: 165.6 MW
- Electricity production: approx. 500,000 MWh, equivalent to the consumption of 150,000 households
- Wind turbines are produced by Bonus Energy, today Siemens Wind Power
- The towers are 69 meters high; the wings are 40 meters long
- The Wind farm was put into operation during 2003
- Owners of the wind farm are: DONG Energy A/S and E.ON Sweden AB

> Denmark, with its high percent wind based generation, has already seen situations where the wind power based energy supply has exceeded the electricity demand.

The SCADA system can be used to control the aggregated power generation of the wind turbines just as such a system would control a power plant. Wind turbines obviously generate electricity in relation to how the wind blows; however, the total power can be controlled. If the electrical network calls for 100 MW to be delivered by the park, the SCADA system can regulate the production to match this demand. The operator can easily enter the required production from the park and the SCADA system figures out how many wind turbines have to be taken out of operation (or added) to balance the demand and supply. The current status of the 72 turbines can be shown to the operator as depicted in 3. From this overview, the operator can "drill down" into individual turbines for detailed status information 4. Wind power has permitted the electrical network to reduce the use of conventional power stations. As the availability of wind power increases, situations will increasingly occur where production of clean energy will have to be throttled to avoid overloading the network. As a matter of fact Denmark, with its high percent wind based generation, has already seen situations where the wind power based energy supply has exceeded the electricity demand. Other nations will of course experience similar issues as their power production shifts to variable and unpredicatble sources such as wind and sun[2].

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Footnote

[2] See also "Harnessing the wind" on page 33 of this edition of ABB Review.

Saving energy through drive efficiency

Per Wikstroem, Jukka Tolvananen, Akseli Savolainen, Peter Barbosa

Of all resources on which modern manufacturing is dependent, energy is arguably the most fundamental. It is also a resource that has long been taken for granted. Rising energy prices and concerns over greenhouse gas emissions are increasingly leading operators to critically assess their energy usage.

In many sectors, the potential for energy savings is minor and gains of a couple of percent in terms of energy efficiency are celebrated as breakthroughs. Under such conditions, the prospects of achieving major energy savings seem bleak. There are technologies, however, that can deliver very significant reductions. Foremost among these is a device that – at first sight – lacks the spectacular note of high-power, high-volume processes. It doesn't make much noise or develop extreme temperatures or go through complex motions. In fact it sits in a cabinet and usually doesn't even get a mention when the overall process is explained. However, it can cut energy consumption by 42 percent, and if applied in all relevant plants worldwide, it can deliver energy savings that equate to the electrical consumption of a country such as Spain. This device is the drive.

The principle is simple: In the past, the motors that powered pumps were usually run at full power all the time, with the regulation of output being achieved through valves. A drive regulates flow through direct control of the electrical power fed to the motor, so permitting friction-based controls and the associated losses to be dispensed with. The following stories provide insight into several applications and show how drives technology can and do make a difference.

The lack of system standards

A lack of system standards for energy efficiency may result in up to 90 percent of pump installations being incorrectly sized – leading to wasted energy.

"Now hold it," you may say, "we have standards for everything". Alas, the world is not that simple and in the area of energy efficiency there are still important gaps. The authors of this article were shown an ACEEE[1)] presentation that made them aware of the fact that, whereas there are standards for pump designs[2)] and for many for the hydraulic data such as developed head[3)], efficiency and NPSH[4)], the search for standards providing guidance in system design is less likely to produce a result. To use an analogy, if somebody were to buy a three-ton truck for use on shopping tours, it would not be a demonstration of energy efficiency – even if the truck selected boasted the best efficiency figures for three-ton trucks.

The ACEEE presentation mentioned above refers to a study that looked into the internal practices of a leading chemical company and of two major engineering contractors that company used on recent projects. The focus of the study was to identify whether the size of the installed pumps matched the real need. The result showed that 90 percent of pumps were not correctly sized. This deficiency is a witness to the lack of standards or guidelines. If 90 percent of installations are incorrectly matched in this company, how many are equally so in other companies around the world?

1 illustrates the problem faced by system design engineers. When projecting a system, there is a degree of

Footnotes

1) ACEEE Summer Study on Energy Efficiency for Industry July 20, 2005 by Robert Asdal – Hydraulic Institute, Vestal Tutterow – Alliance to Save Energy and Aimee KcKane –Lawrence Berkeley National Laboratory

2) eg, HI, API, ANSI, ISO

3) The developed head is a measure of the mechanical energy per unit weight of fluid transferred by the pump. Numerically, the developed head is equivalent to the height to which the pump can elevate the fluid in a frictionless system.

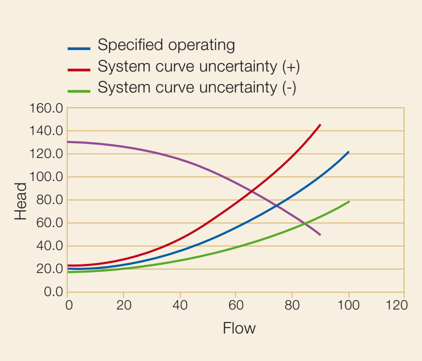
4) NPSH: Net Positive Suction Head

uncertainty as to the shape of the system curves (friction, pipe cross section changes and the number of 90° turns in the final pipe layout all take their toll). These factors all add to the risk that the expected operating conditions will not be met. There are three basic ways to address the changed operating conditions:

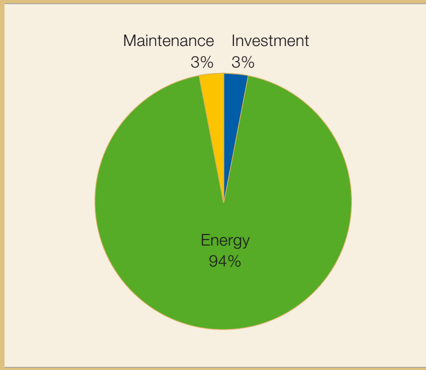
- If the changed condition is permanent, then the pump or fan size should be changed to match the load.
- The pump or the fan speed can be changed.
- A throttling device (such as a valve, damper or guide vane) can be added. This is wasteful of energy.

The cost of energy is the all-dominating part of the lifecycle cost of a pump or a fan motor 2. Energy consumption is the best place for optimization to start.

1 In designing a system, a certain degree of uncertainty in the pump curves must be taken into account



2 Energy costs account for the largest part of the total costs of operating a pump or fan motor



How systems get over-dimensioned

Through an example, ABB Review demonstrates how systems get oversized throughout the design process, and how variable speed drives can be used to conserve energy.

Despite careful analysis and design, many systems do not operate optimally. One reason is that many systems are simply sized too large to start with, resulting in higher operating and investment cost. To illustrate this, the case is considered of a system with a fan in a process industry.

In this example, it is assumed that the "true" condition of the application, 100 units flow, requires 4000 units of pressure 3a.

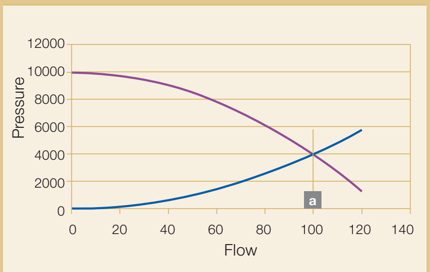
In order to be on the safe side concerning the maximum flow, the figure for the fan that is communicated to the engineer is 110 units of flow 4b. With the assumed system graph, this would require a fan with a higher capacity (dashed yellow line) that can deliver 110 flow units and 5000 pressure units.

It is rare that 100 percent of the design flow will be needed other than for very short bursts.

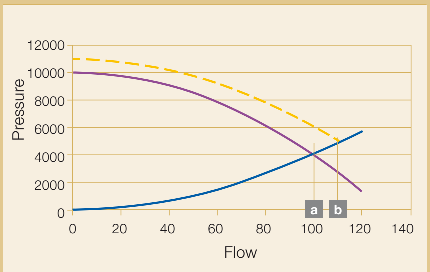
When establishing the fan capacity, the fan-system engineer estimates the overall pressure drop that these 110 flow units will cause 5c. The pressure drop value that is calculated is increased by a 10 percent margin 5d because is difficult to foresee whether the assumed number of 90° turns in the duct will conform to that estimated (possibly the contractor installing the fan will have to add turns to bypass other equipment). Also, the cross-section of the duct may be uncertain. A smaller cross section would lead to a higher pressure drop. Such a 10 percent margin is therefore not unreasonable.

So what data are finally sent out in the requests for tender? Flow: 110 units at a pressure of 5500 units 6e. If the original assumptions were correct, the fan is now grossly oversized. At 100 units flow the necessary additional pressure drop over the damper

3 The application for which a fan motor is sought: The pressure drop is shown in blue and the fan characteristic in purple



4 10 percent reserve b is added to the fan specification a

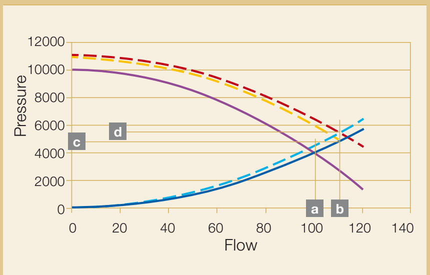


must be about 2800 units (6f minus 6g). This corresponds to 70 percent of the assumed correct total pressure. However, it is rare that 100 percent of the design flow will be needed other than for very short bursts. Assuming that most of the time, 80 percent of the flow rate will be required; the additional throttling needed in the damper will be about 6000 units (6h minus 6i). This corresponds to 150 percent of the assumed correct total pressure.

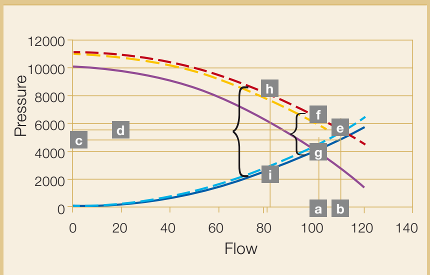
The steps illustrated in this example are more common than they may seem. An additional factor is that when it comes to the selection of a fan, this choice must be made from a standard range of fixed sizes. The next larger one will usually be chosen.

The correctly sized fan for this example should be 100 × 4000 = 400,000 power units. The case above produces a requirement for a fan of at least 605,000 power units (150 percent of the optimum). Correcting this with damper control leads to high levels of wasted energy. The additional losses at the 80 percent flow point amount to 480,000 power units (120 percent of the full power of a correctly sized fan). With a speed controlled fan instead of damper control, most of this energy can be saved

5 The corresponding pressure drop is also increased by 10 percent d



6 The system finally installed is heavily overdimensioned



Energy saving for medium voltage drives

227 TWh is the annual output of 144 fossil fuel type power plants[5], or equivalent to the total energy consumption in Spain. It is also the potential global energy savings that can be attained through the adoption of MV drives.

Energy efficiency is on everyone's mind today. It has taken a long time to raise the awareness to the level where it is now. Al Gore's movie, An Inconvenient Truth, has shaken many and given birth to the acronym AIT. Some readers may have had to cancel their skiing holiday due to lack of snow; such incidents also probably contribute to a raised awareness on global warming issues.

Under Kyoto, the EU's 15 member states committed themselves to an 8 percent reduction in emissions by 2008-2012 compared to 1990 levels. By 2004, they had achieved a reduction of only 0.9 percent, and if current trends continue the reduction will be just 0.6 percent by 2010. Such results make the prospects of success seem pessimistic.

The World Energy Outlook 2006 states in chapter 2, Global Energy Trends: *"Global primary energy is projected to increase by 53 percent between 2004 and 2030 – an average annual increase of 1.6 percent. Over 70 percent of this increase comes from developing countries."* So how are the reduction targets to be reached?

Fortunately, there are areas in which a huge savings potential exist. A few successful examples from industry are highlighted in Factbox 1.

In weighted average, these installations have slashed energy consumption by

7 Medium voltage drive ACS 6000 – such equipment can play a huge role in fulfilling the requirements of the Kyoto protocol

Factbox 1 Savings achievable through the use of drives in selected industries

Company	Industry	Application	Installed Power [kW]	Confirmed savings [kWh]	%-saved
Peña Colorada	Mining	Fan in palletising plant	1250	2'423'750	35%
China Steel Taiwan	Metals	Booster pumps	672	3'030'720	61%
Cruz Azul, Mexico	Cement	Kiln ID fan 1+2	1470	5'309'640	54%
Repsol YPF, Argentina	Petro-chemical	Blower (steam turbine replacement)	3000	7'560'000	43%
Daqing Plastic Factory, China	Petro-chemical	Mixer	1300	2'600'000	31%

Energy efficient products

42 percent. A third to three quarters of all motors operate pumps, fans or compressors. In these applications adjustable speeds are necessary for optimal operation, making them well suited for drives. Looking just at the MV motors and drives, it can be roughly estimated the potential savings are as in Factbox 2.

It is a remarkable coincidence that the EU15 target for drives is exactly 45 TWh per annum. This power corresponds to almost 30 power stations of fossil fuel type[5] or the complete electric energy consumption of Romania in 2000. However, this target comprises both LV and MV installations and the current calculation considers just MV installations! The cumulative installed LV motor power is close to 10 times that of MV motors.

A third to three quarters of all motors operate pumps, fans or compressors. These applications are ideally suited for drives.

So this article can close on the positive note that with an estimated savings potential of 45 TWh by MV drives applications only 7, there is hope that the 45 TWh saving target set by the EU under the Kyoto protocol can be reached.

Factbox 2 Medium voltage drives can deliver global savings of 227 TWh per year

Installed MV motors (world estimation based on 20 year lifespan of motor)	500,000	Pcs
Motors used for square torque loads (at least)	333,000	Pcs
Installed power used to drive square torque loads (average power 1500 kW per MV motor)	500,000,000	kW
Less than 4 percent MV motors have a frequency converter, remaining at least	300,000	Pcs
Assuming that only 30 percent of these motors have an energy saving potential in the same order of magnitude as the sample testimonies above	90,000	Pcs
These 90,000 motors consume *)	569	TWh
Assuming the energy saving potential of 40% (similar to the testimonies above)	227	TWh
The EU-15 share can be estimated to be 20%	45	TWh

*) Assumptions: 2/3 of the motors operate 7500h/yr and 1/3 operate 1850 h/yr. Average load 75 percent of rated power.

Footnote

[5] Assuming an average plant produces 350 MW for 4500 hours/year

Optimizing pump speed to save energy

A study by the Lappeenranta University of Technology and a Finnish paper mill reveals that the consumption of specific energy using throttling control may require up to three times the energy compared to a solution using variable speed drives combined with optimized pump control.

According to a study by Lappeenranta University of Technology (LUT) in Finland, pump control based on variable speed drives can deliver energy savings of up to approximately 70 percent in parallel pumping installations. The biggest savings can be achieved in situations where there are significant fluctuations in the flow. The project leading to this remarkable conclusion involved both computer simulations and practical work on laboratory-scale equipment.

The project was undertaken at the LUT's Department of Energy and Environmental Technology. It set out to quantify the differences in energy consumption in four applications with three different flow control methods. The simulations were performed with Matlab v 6.1 and Simulink software, and the results were verified with actual measurements. The control methods compared were throttle control, standard pump control and optimized pump control.

Throttle control: one pump is throttled and the others are on/off controlled.

Standard pump control: one pump is controlled by a variable speed drive (VSD) and the others are on/off controlled.

In optimized pump control, each pump has its own VSD and the required flow is divided evenly between all the pumps. As a result, their rotational speed is the same. This case differs from the standard model in that the pumps are switched on and off in an optimized way. Optimized pump control technology is

Factbox 3 Energy consumption at one Finnish paper mill, chemically treated water

Control methods	Energy consumption (J/24 h)	(%)	Flow (m³)	E_s (J/m³)
Throttle control	177 114	0.0	2254	78.58
Standard pump control	102 786	-42	2257	45.54
Optimized pump control	57 050	-68	2256	25.29

subject to a patent application by ABB.

The first simulated industrial example is typical of real-life industrial pumping situations where new control technology can be applied. The example was taken from a Finnish paper mill, where Ahlstrom APP22-65 centrifugal pumps are used to pump chemically treated water to a desalination unit. An energy analysis of the pumping facility was used as the basis for the simulations. In this case, a lack of background information made it difficult to draw the system curve.

The simulations, which relied on simplified system and duration curves, showed that in this case, throttle control uses considerably more energy than the other control methods. Optimized pump control is by far the most energy efficient method. The difference between standard and optimized pump control is over 45 percent. The consumption of specific energy with throttling is almost the threefold of that used with optimized pump control Factbox 3.

Mallorca's wastewater pumping system

An above-ground wastewater storage and old pumping station required modernization and eliminaton of odors. Intelligent Pump Control delivered energy savings of at least 20 percent.

EMAYA SA, the water supply and waste utility for the Spanish city of Palma de Mallorca, recently launched a project to upgrade its wastewater pumping stations. The capital city of the holiday island of Mallorca has 380,000 inhabitants. Its sewage system consists of a chain of tanks in which wastewater is rapidly transferred from one tank to the next and finally to a treatment plant. At the first pumping station to be upgraded, the wastewater was previously stored in a tower. This has now been replaced with a 15,000 liter underground holding tank – inconspicuous to most tourists and residents alike 8.

8 Inconspicuous to most – but making a huge contribution to the comfort of holidaymakers and residents: The holding tank of Palma de Mallorca's wastewater system

> The four drives and pumps provide an unprecedented level of fail-safety. If a pump should fail, another one immediately takes over.

Four 60 kW submersible pumps have been installed at the station. Each pump is operated by an ABB industrial drive running intelligent pump control (IPC) software. "This pumping station was old, and there were also odor problems. Simply put, the local environment needed improving," says Lorenzo Mestre, industrial engineer at EMAYA. The four drives and pumps provide an unprecedented level of fail-safety. Even at peak times, only two pumps are required to empty the tank, and one pump can cope during lighter loads. Two pumps are always ready to start up if necessary. Thus, if a pump should fail, another one immediately takes over. The pumping station is also equipped with a diesel generator to ensure a continuous supply of energy in case of a power outage.

Intelligent pump control saves energy

IPC software can significantly improve the energy efficiency of a pumping system. Compared to conventional methods of controlling sewage pumps, IPC can easily deliver energy savings of 20 percent. IPC also includes a number of other features specially designed for pumping systems. The pump priority control function balances the operating time of all the pumps over the long term. All four pumps are run (two at a time) and maintenance can be scheduled so that all the pumps can be serviced at the same time.

The software anti-jam function enables the drive to perform preventive maintenance on the pump. When the function is triggered, the pump spins at high speed and is then either reversed or stopped in a number of user-defined cleaning cycles. This helps prevent congestion through the build-up of particles, and therefore helps to further reduce pump maintenance needs. IPC also enables the drive to monitor the motor temperature more closely than standard systems, further enhancing the overall system reliability.

Straightforward system

The system consists only of ABB drives and pumps, with no need for a dedicated control unit that would introduce additional wiring and complexity. ABB worked together with Cobelsa SA, a panel builder, to deliver an easy-to-use solution to EMAYA. Cobelsa designed the system layout and took care of the installation, and also offers engineering support to the customer. ABB additionally provided assistance during the implementation stage.

Energy efficient products

ABB drives UPM Shotton to a greener future

Paper manufacturer UPM's plant at Shotton (UK) has achieved its goal of producing its entire output from waste paper, rather than using virgin wood. And it is powered by ABB variable speed drives.

The so called "100% Shotton" project involved the building of a new recycled fiber plant, a sludge plant and modifications to two paper machines.

In this process, ABB drives are used mainly on pumps – matching the speed of the pump to the production rate 9. Drives are additionally used on chemical dosing pumps to accurately add chemicals to the pulp. Some conveyors on the process also use ABB variable speed drives.

The drives help achieve a better control of the process, adjusting the inputs to the plant to maintain the correct pressure and temperature conditions. The drives also make it easier to control the production rate. Additionally, they contribute to energy savings by reducing the power drawn.

Ray von der Fecht, Project Automation Manager on the "100% Shotton" project says, "we chose ABB variable speed drives because ABB is a respected name, well known in the paper industry. Also, we know the products and the people. Overall, ABB offered a very good solution along with the best price."

So well did the implementation phase work out, that the drives and automation system could be started-up, not only according to plan, but at the exact minute scheduled. "It was like switching on a light," says von der Fecht.

9 ABB drives at UPM's recycled-paper plant, Shotton (UK) – ABB drives save energy by matching the pump speed to the production rate

One of UPM's major criteria for the drives was maintainability. The drives had to be capable of being exchanged quickly in the event of failure and also had to be easy to move. Interchangeable cards were also considered an advantage, allowing the company to keep drives running by simply changing some of the critical components.

Compact size was also part of the demand to be able to save on space, improve efficiency and heat loss and cut cooling costs. ABB's drives scored on all these points. Another useful feature was their ability to communicate using Profibus – the communication standard in the paper industry. The drives also feature input line chokes to reduce harmonics fed to the network and output filters to reduce the electrical stresses on the motor windings.

High reliability was the most important criterion. Von der Fecht says, "we have had good experience with the ABB drives. They are certainly reliable and fulfil our needs".

Fertilizing with low energy

A project to upgrade five process fans at a Kemira GrowHow fertilizer plant in Finland has delivered a reduction in annual electricity consumption of more than 4000 MWh. The project involved installation of new ABB motors and ABB industrial drives to replace the existing motors and mechanical flow control systems. The equipment is paying for itself through the energy it saves!

Based in Finland, Kemira GrowHow Oy is one of Europe's leading producers of fertilizers and animal feed phosphates 10. With net sales of EUR 1.26 billion (2005), the company has 2,700 employees and production sites located throughout Europe.

The Kemira GrowHow plant in Uusikaupunki on Finland's south-western coast has two fertilizer production lines and two nitric acid production units. The project to upgrade process fans in one of the plant's fertilizer lines was undertaken in 2005. Following a comprehensive energy analysis at the plant, Kemira GrowHow turned

10 Kemira GrowHow's Uusikaupunki plant in Finland produces industrial chemicals and fertilizers. ABB drives installed here cut the plant's energy bill by 4000 MWh annually

to Inesco Oy, an energy service company (ESCO), to study the potential for energy saving with special reference to the air and gas flows in the fertilizer plant.

The new motors and drives permitted savings of more than 4000 MWh a year. This equates to € 150,000 or 2800 tonnes of CO_2.

Accurate speed control with drives

Like many other processes in the chemical industry, fertilizer production lines 11 feature numerous fans for moving gases, fumes and air. Inesco examined nine fans rated 132– 630 kW, and selected five for more detailed study. The five fans in question were operated by electric motors connected directly to the mains power supply and running at full speed. Inlet vanes were used to provide mechanical control of the rate of flow. Some of the vane installations were approaching the end of their service life and would soon need replacing at a cost of tens of thousands of Euros per fan.

Faced with this considerable investment, and based on the results of Inesco's energy efficiency pre study, Kemira GrowHow opted instead to replace the mechanical flow control systems on the five fans by retrofitting them with AC drives and new motors. ABB was selected to supply the new motors and drives to control the motor speed according to actual flow requirements.

Significant energy savings

"Since installing the new ABB motors and drives we have been saving more than 4000 MWh of electricity a year", says Jari Lintula, Head of Automation at the plant. This equates to an annual saving of some € 150,000, calculated on the basis of local electricity tariffs for industrial users, or a reduction of CO_2 emissions by 2800 tonnes.

A further benefit of the project derives from the fact that the ABB drives deliver an improved power factor[6]. This has resolved an overheating problem in one of the transformers used to supply power to the fan motors.

Realistic forecasts

The upgrade project was carried out during scheduled plant downtime and caused little disturbance to production. It required only a minimal contribution from the plant staff. Jari Lintula emphasizes that real savings have been achieved:

"The new motors and drives have logged thousands of operating hours, so we know how they perform. The forecasts showing how much energy we could save have proven very realistic. In fact, we've been amazed at the accuracy of the calculations. It seems that the energy saving potential of drives in this type of fan application can be predicted with a high degree of reliability. The savings are real – they are not just claims by equipment vendors eager to make a sale."

He also confirms that the use of AC drive control within a chemical production process is extremely trouble-free from the control engineering point of view. In addition to reliable process control, he stresses the importance of energy efficiency:

"We are actively seeking new opportunities to save energy – I'm sure we can utilize AC drives elsewhere as well."

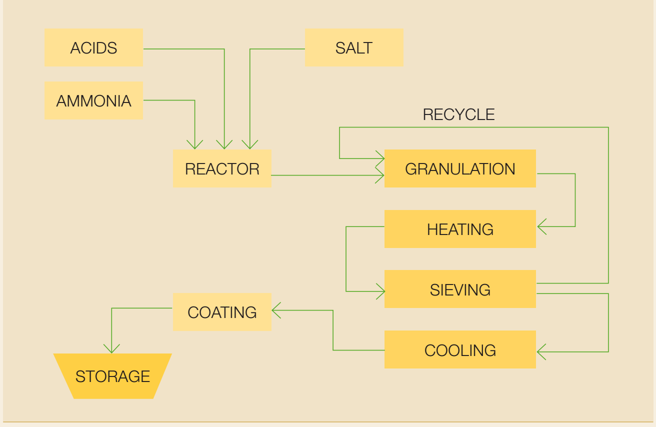
Efficient ESCO model

From the various alternatives available, Kemira GrowHow opted to implement the upgrade project on an ESCO basis and chose Inesco as its ESCO partner. ESCO companies develop, install, and finance projects with the aim of providing increased energy efficiency and lower maintenance costs for their customers' facilities over a period of several years.

Inesco is a pioneer in its field in Finland and has already completed successful ESCO projects in various sectors, including the energy-intensive pulp and paper, metal, and chemical industries.

For Kemira GrowHow, the main advantage of the ESCO approach in this case was the opportunity to outsource most of the engineering work, procurement and associated routines. An additional element of the ESCO agreement is that the fan upgrade project is being paid for by the energy savings it realizes. During the three-year term of the agreement, Kemira GrowHow will pay a service fee to Inesco, which is calculated as 80 percent of the reduction in energy costs achieved. At the end of the three-year agreement Kemira GrowHow will take full ownership of the installed equipment and all the savings.

11 The fertilizer production process (courtesy of Kemira GrowHow)



For more information about Kemira GrowHow, visit www.kemira-growhow.com. Information about Inesco can be found at www.inesco.fi.

Footnote

[6] Power factor is the ratio between real and apparent power. High power factors lead to lower losses

Energy efficient products

University saves millions through boiler retrofit

An emissions-control project provides 746,000 kWh in electrical energy savings a year, and hundreds of millions of BTUs [hundreds of gigajoules] in fuel. The investment outlay was completely recovered in less than a year

The University of Texas at Austin, UTA, is the flagship institution of the University of Texas system. Academic home to 50,000 students, the campus is contained on 424-acres [170 hectares] adjacent to downtown Austin. The University's heating and energy demands are supplied through the boilers and gas turbines at the Hal C. Weaver Power Plant, which provides power, steam, chilled and demineralized water, and compressed air to approximately 200 campus buildings.

Savings from boiler retrofit

In the process of satisfying state air-quality compliance requirements for its power plant emissions, UTA reaped an unexpected windfall – $ 500,000 annually in energy savings. The savings are the result of a retrofit of one 150,000 lb [68-tonne] boiler with an innovative system called Compu-NOx™. This controls emissions of nitrogen oxides, commonly referred to as NO_x, a group of gases that cause acid rain and other environmental problems. Prior to the upgrade, Boiler 3 alone emitted 151.7 tons [137 tonnes] of nitrogen oxide per year. Following the upgrade, the emission rate was reduced to 21.0 tons [19 tonnes] per year.

12 Variable frequency drives provide precise airflow control. This in turn permits optimal combustion control in the boiler's forced-draft system

> The investment payback for UTA is less then 12 months. The system will continue to produce savings for years to come.

Compu-NOx is a state-of-the-art patented combustion control system developed by Benz Air Engineering of Las Vegas, Nevada. "Our objective as we began the boiler retrofit was to reduce NO_x emissions, but the process resulted in us producing more energy with less gas by improving our combustion efficiency. This allowed us to bank our standby boilers saving us hundreds of thousands of dollars per year," said Juan M. Ontiveros, director of Utility and Energy Management at UTA.

"Initial projections targeted a savings of $ 500,000 annually for the first boiler retrofit, but due to ongoing fuel price increases, the university stands to save an additional $ 1 million from the retrofit of Boiler 3 alone" says Robert Benz, president of Benz Air Engineering Company.

Drives provide control of airflow for combustion air

For precise metering of airflow, Benz Air's Compu-NOx control platform uses variable frequency drive (VFD) technology for fans 12, rather than attempting to achieve the same with dampers. "The Compu-NOx control system utilizes the absolute linear relationship of fan speed to fan airflow as the basis of combustion control," explains Benz.

With ABB drives, a very precise control of the airflow is achieved, which makes all the difference in terms of fuel efficiencies and emissions. Emissions from Boiler 3 were reduced from 175 ppm NO_x to less than 25 ppm without installing new burners. With the use of the ABB ACS800 AC drives, savings are projected to be 746,000 kWh per year in electrical and 320,000 million BTUs [338,000 GJ] per year in fuel.

The investment payback for UTA is less then 12 months. And the system will continue to produce savings for years to come from the flue gas recirculation and variable frequency drive fan-control.

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Factbox **Drives and ABB**

ABB is the world's largest manufacturer of electric drives. In close cooperation with its channel partners, ABB provides a complete line of energy-efficient electric drives and drive systems to a wide range of industries and applications. Products manufactured include AC and DC variable-speed drives from 180 W to 100 MW (1/4 to 135,000 hp), and application-specific drive system solutions to meet diverse customer needs. This line of products is complemented with a comprehensive set of services to make sure ABB's customers get the highest possible return on their investments.

For further information on energy efficiency contact energy@fi.abb.com (LV Drives) or mvdrives@ch.abb.com (MV Drives).

Motor efficiency

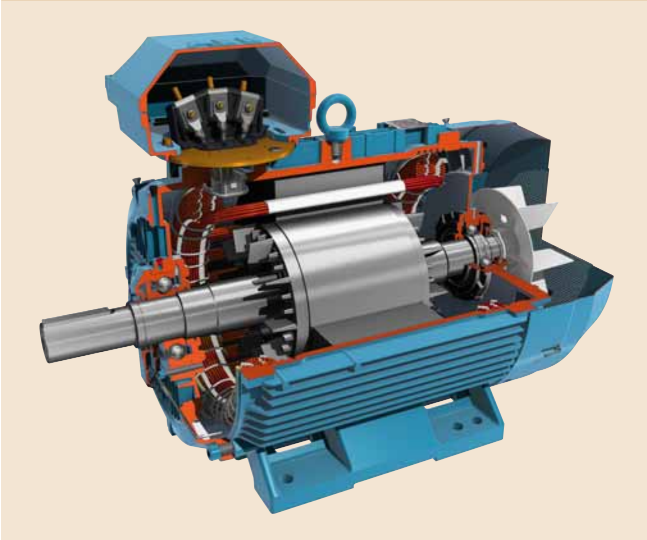
Focus on optimizing lifetime performance on motors

Roelof Timmer, Mikko Helinko, Ritva Eskola

High efficiency motors can deliver significant savings in energy consumption. In addition to efficiency, however, when optimizing a motor's performance over its entire lifecycle other important characteristics must also be considered. These include the product's overall suitability for the application, correct dimensioning, and bearing and winding reliability. ABB manufactures quality motors that are not only highly efficient but also provide superior reliability and availability.

Energy efficient products

M3BP motor



High efficiency motors can provide significant benefits, including helping to cut energy costs and limiting carbon emissions. In the EU, the introduction of the European efficiency classification scheme has focused attention on energy efficiency. The scheme divides motors into efficiency levels EFF1 to EFF3, where EFF1 is the highest. The scheme has been very successful in reducing the numbers of low efficiency motors in the market, and the EFF1 classification has come to be seen by some not only as a mark of efficiency but also as a general badge of quality. At present the scheme is being further developed to harmonize the efficiency testing methods so that motors from different manufacturers can be compared more easily.

ABB is a long-standing advocate of the need for efficiency in motors and from the outset its policy has been to offer high efficiency motors as standard, ie available from stock with no price premium. As a result, when the EU scheme was introduced, all ABB motors achieved classification in the two highest efficiency classes, with the EFF1 motors coming from ABB's standard product range.

Designing and manufacturing reliable motors with good starting and running performance involves a delicate balance between a number of factors which include not only efficiency and cost, but also bearing, slot and fan design, temperature rise, vibration, and noise. Only the correct balance will result in high quality motors which are efficient and reliable and will provide a long service life, while also being of optimum weight. Rather than focusing on efficiency alone, ABB prefers to take a lifecycle approach and seeks to maximize the benefits and minimize the costs associated with its products over their entire lifetime. In addition to efficiency, the lifecycle approach also emphasizes the importance of reliability and availability.

Energy is generally the biggest lifecycle cost, and soaring energy prices have put energy costs and efficiency firmly in the spotlight. In many parts of the world, authorities are introducing schemes to encourage industrial users to specify high efficiency motors. This situation has led some manufacturers to boost the efficiency level of their products without looking at other areas of performance.

Designing for efficiency

In ABB's view, the key to making efficient motors while minimizing overall lifecycle costs is to ensure that every stage of design and manufacture is based on high quality.

The efficiency of a motor is a measure of how well it converts electrical energy into useful work. Energy which is lost is emitted in the form of heat. These losses have to be reduced in order to increase efficiency.

Factbox 1 Distribution of losses in an ABB M3BP motor

no-load losses	iron losses in core	18%
	windage & friction losses	10%
load losses	stator copper losses	34%
	rotor losses	24%
	stray load losses	14%

Motor losses can be divided into five main categories. Two of these categories – iron losses in the core, and windage and friction losses – are classified as no-load losses because they remain constant regardless of the load. Load losses, which vary with the load, are stator copper losses, rotor losses, and stray load losses Factbox 1. All motor losses can be influenced by design and construction considerations, ie by the quality of the design and manufacturing processes.

Iron losses in the core are due to the energy required to overcome opposition to changing magnetic fields in the core material. Designers can decrease these losses by using better quality steel and by lengthening the core to reduce the magnetic flux density.

Reliability is also an important factor for OEMs that build motors into their own products. If a motor breaks down it will be the OEM's equipment which is perceived as unreliable.

Windage and friction losses are caused by air resistance and bearing friction. In high quality motors these are reduced by improved bearing and seal selection, air flow and fan design. The fan must be large enough to provide adequate cooling, but not too large as this reduces efficiency and increases noise. In ABB motors the blade size and pitch are varied between models for optimum results.

Of the losses which vary with the load, stator copper losses (also referred to as I^2R losses) are caused by heating due to the current flow through the resistance of the stator winding. Techniques for reducing these losses include optimizing the stator slot design. The stator laminations should be of low loss steel, and as uniform and thin as possible to maximize the strength of the magnetic fields. They should be carefully aligned to ensure the channels are straight. Naturally, the thinner the laminations the more expensive they are to produce, and accurate alignment requires more specialized production techniques.

Rotor losses are caused by rotor currents and iron losses. In high efficiency motors these losses are reduced by increasing the size of the conductive bars and end rings to produce a lower resistance. Stray load losses are the result of leakage fluxes induced by load currents. They can be decreased by improving the slot geometry.

Lower temperatures mean better reliability

Motors that operate only occasionally or in non-critical applications do not necessarily have to be ultra-reliable. Of course a breakdown is always a nuisance, but the consequences may not be too serious. In some industries and processes, however, reliability is paramount. In continuously running processes such as cooling applications in the oil and gas industry, or paper machine drives, unplanned downtime has to be avoided at all cost. A stoppage of just a few minutes can cost as much as a new motor.

Reliability is also an important factor for OEMs that build motors into their own products. If a motor breaks down it will be the OEM's equipment which is perceived as unreliable and it will be the OEM's reputation for reliability that will suffer.

ABB's approach to reliability is the same as its approach to efficiency: high quality forms the basis for reliability, especially the quality of the materials used. On average materials account for 55 percent of the cost of a motor. As more than half the total cost goes on materials, it is clear that manufacturers who try to cut costs too aggressively will skimp on materials and the reliability of their products will be affected.

The two most common causes of motor failure are bearings and windings, and these components therefore play a pivotal role in determining overall reliability. In the case of both bearings and windings, the operating temperature within the motor has the greatest impact on the component lifetime. A high quality, efficient motor running at full load can have a normal temperature rise of 60–80 °C but this figure can be up to 100 °C for lower quality motors. The temperature rise can be higher only in motors which have been designed for higher temperature rise and thus have an appropriate insulation system that can withstand higher temperatures.

> It is estimated that motors use 65 percent of the electricity consumed by industry, and that generating the electricity to drive these motors produces 37 million tonnes of CO_2 annually.

For maximum reliability, it is important to ensure that high quality bearings are used Factbox 2. The designers have to select the right type of bearing for the application and load, and then draw up a greasing regime appropriate for the application and operating conditions. As grease is degraded by high temperatures, it is important that the temperature rise is not excessive. A reduction of 10–15 °C in the operating temperature should, in theory, double the working life of the bearing grease.

Excessive internal temperatures also affect the lifetime of windings. In this case, it is the insulation on the copper wire that is degraded by high temperatures. A 10 °C rise in operating temperature can halve the life of the winding. For this reason most motors are manufactured with Class F (155 °C) insulation but designed to operate no hotter than Class B (130 °C). Temperature rise is one aspect of motor performance that is the focus of on-going research Factbox 3.

Another factor in winding reliability is the withstand voltage, which measures the integrity of the winding. Windings usually have a withstand voltage of around 1200 V, but motors can be supplied with a withstand voltage around 1400 V or above if the winding must withstand higher voltage spikes, as produced by some variable speed drives 1.

It should also be kept in mind that reliability can also take on a slightly different emphasis in different environments. In motor applications in the oil and gas industry, for example, safety is a primary concern for the process owner. Motors are often operated in very harsh conditions, having to withstand extremes of heat or cold,

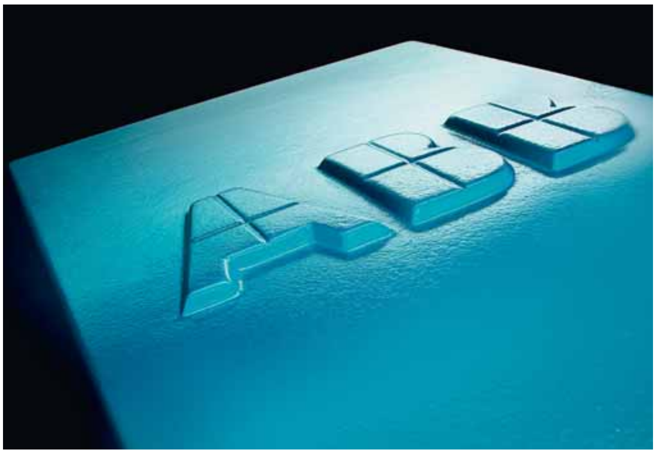
Factbox 2 Bearing checklist

For optimum motor reliability the bearings should
- be supplied by a reliable manufacturer
- be dimensioned appropriately for the load and speed
- have an internal clearance suitable for the operating temperature
- use grease suitable for the operating temperature
- be re-greasable if there is a suitable maintenance infrastructure in place (otherwise sealed-for-life bearings are generally preferable)

1 Characteristics of a good winding

Characteristics of a good winding include:
- compact winding with a good slot fill ratio
- small overhang
- high quality copper wire
- high quality winding systems
- high quality slot insulation, impregnation systems and phase insulation systems

Energy efficient products



for instance, or dusty or moist environments. ABB has built up a great deal of experience in supplying motors both for conventional process industry environments and for extreme conditions. This experience is utilized in the development and manufacture of high quality motors which not only meet official requirements and safety specifications but also perform efficiently and reliably for their whole lifetime.

High quality motors perform better

Electric motors, the "workhorses" of modern industry, can play an important role in efforts to cut energy consumption and carbon emissions. It is estimated that motors use 65 percent of the electricity consumed by industry, and that generating the electricity to drive these motors produces 37 million tonnes of CO_2 annually. Given the magnitude of these figures, even a small increase in each motor's efficiency has a positive impact on a global scale.

Users also have strong financial incentives to purchase efficient motors. Even though high efficiency models command a price premium of 5 to 7 percent (larger sizes) or 15 to 20 percent (smaller sizes), this investment is quickly recovered through reduced energy consumption. The energy used by a motor over its lifetime can cost as much as 100 times the motor's purchase price.

Efficiency represents only one area of performance, however, and energy costs are only one element of overall lifecycle costs. Reliability – and the maintenance costs and downtime that result from poor reliability – can be even more significant in some applications. ABB's experience and expertise give the company a thorough understanding of the complicated relationships that exist, within optimum starting and running performance, between efficiency, weight, temperature rise, noise and vibration. By building high quality products and seeking to minimize their overall lifecycle costs, ABB ensures that its motors will deliver excellent all-round performance.

Factbox 3 Three ways to further improve energy efficiency

Avoid rewinding
Rewinding usually causes a reduction in the efficiency of a motor. Rewinding a motor over 30 kW can reduce rated efficiency by 1 percent, while the figure for smaller motors can be 2 percent. The efficiency reduction on high quality motors is less significant than that of lower quality products.

Avoid oversizing
For a variety of reasons, companies often procure oversized motors. Field tests in process industries indicate that on average motors operate at only 50 to 60 percent of their rated load. Among other disadvantages, running a motor at less than its rated load is inefficient (part-load efficiency). Replacing significantly underloaded motors with smaller, energy efficient motors generally improves system efficiency.

Use VSDs for speed control
There is no point using a high-efficiency motor if the overall drive system is inefficient.*) In many pump and fan applications, for example, throttling is still used to regulate flow. Running motors at full speed when only lower speeds are required is extremely wasteful. Variable speed drives (VSDs) provide optimal speed and control accuracy, delivering major energy savings. A recent study performed at the University of Lappeenranta in Finland showed that using drives in parallel pumping installations can produce energy savings up to approx. 70 percent. In addition to its motor business, ABB is also a leading supplier of VSDs.

*) See also "Saving energy through drive efficiency" on page 73 of this edition of ABB Review.

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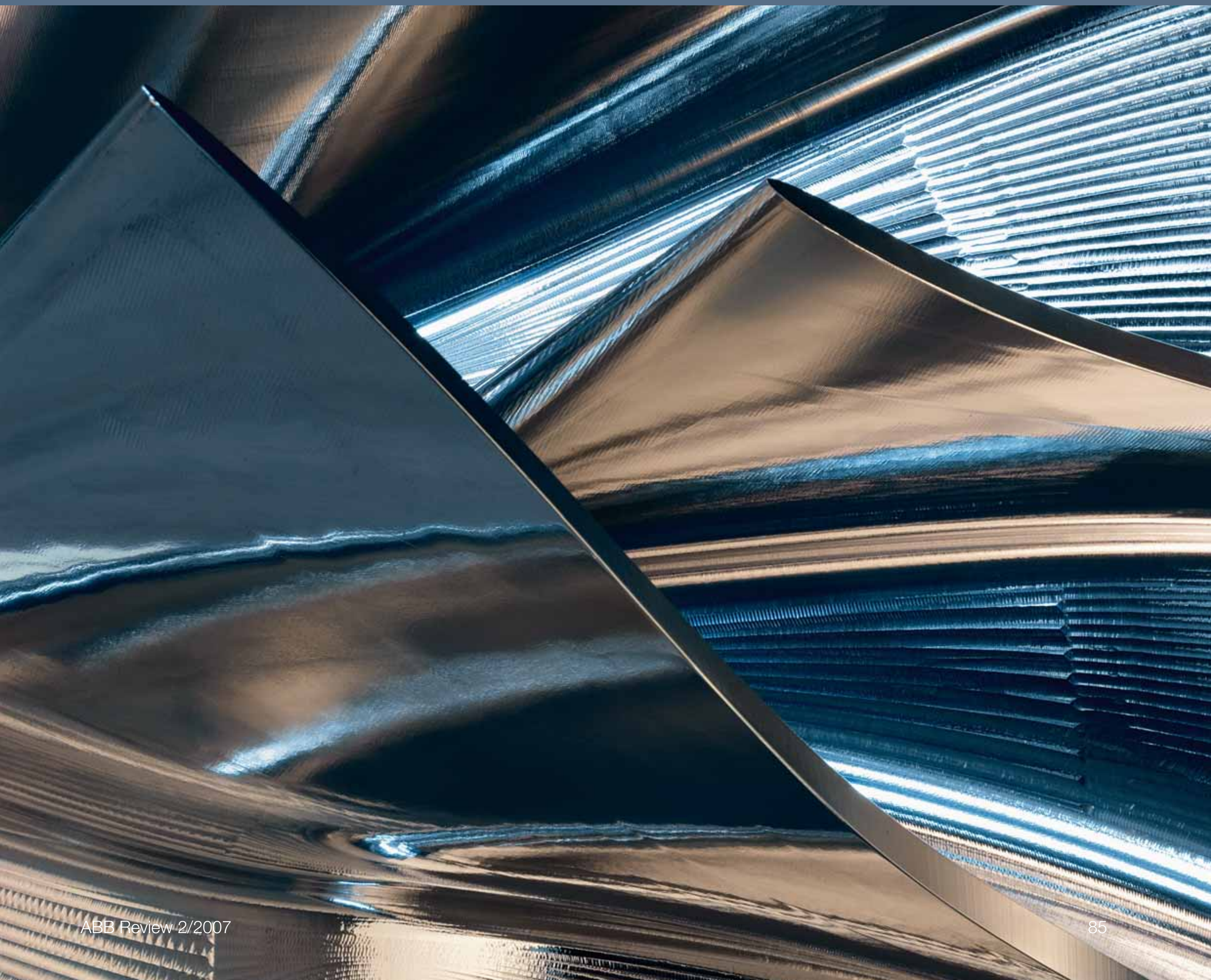
ABB turbochargers – history and milestones

Malcolm Summers

ABB exhaust gas turbochargers are hard at work all around our planet – on the world's oceans and high in the Himalayas, from the icy Arctic wastes to the simmering Australian outback. Out of an idea born a century ago has grown a high-tech product that is efficient and reliable in the extreme.



PERPETUAL PIONEERING

Like so many other innovative ideas before and since, the exhaust gas turbocharger was initially slow to progress after its announcement to the world in 1905. In a patent filed that year, Swiss engineer Alfred Buechi [1] described a “highly supercharged compound engine” with diesel engine, axial compressor and axial turbine mounted on a common shaft. While Buechi continued to develop his idea, inventors elsewhere were having some success with mechanical superchargers. But Buechi had like-minded competitors, too. By 1920 small exhaust gas turbochargers were being used in aircraft in France and the USA. Heavy-duty turbochargers were not yet considered to be economically viable.

[1] Alfred Buechi. His 1905 patent is recognized as the starting point for exhaust gas turbocharging.

Progress at last

Things changed in 1923 with the publication in Germany of a report on successful low-pressure supercharging trials with a four-stroke diesel engine. Brown Boveri, one of the two founding companies of ABB, now made the decision to apply its extensive know-how in building turbines and compressors to the development of turbochargers.

> The period between 1945 and 1960 saw the world’s merchant fleet double in size, and marked the final breakthrough for turbocharging.

That same year Swiss Locomotive and Machine Works (SLM) had a two-stroke experimental engine under test which needed bringing up to a higher power level with better fuel consumption. Brown Boveri recommended using an exhaust gas turbocharger that would feed into the scavenging blowers, and SLM subsequently placed an order for such a machine. In June 1924 turbocharger VT402, the world’s first heavy-duty exhaust gas turbocharger, left the Baden works of Brown Boveri [2].

Interest was also high in the maritime community. One year earlier, in 1923, the Vulkan shipyard in Germany had ordered two large passenger ships, each to be powered by two turbocharged 10-cylinder, four-stroke MAN engines. The turbochargers were designed and built under Buechi’s supervision. Launched in 1926, these two ships were the first in maritime history to have turbocharged engines.

The “Buechi Syndicate”

In 1925 Buechi took out a new patent in his own name that would win him world-renown. Detailing the advantages of pulse operation for low-pressure supercharging, it was the breakthrough that everyone had been waiting for. A new company, popularly known as the “Buechi Syndicate”[1)], was set up the following year. Buechi was put in charge of engineering and customer relations, Brown Boveri was to build the turbochargers and SLM would provide the diesel engines for tests and trial runs.

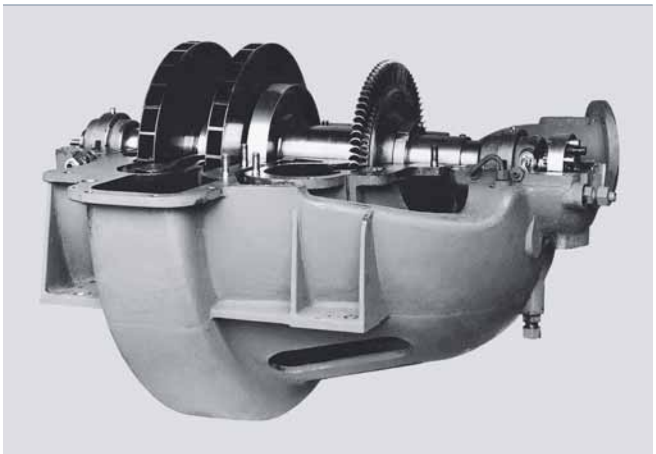
An improved, larger turbocharger designated VT592 was supplied to SLM in 1927 for a second experimental engine. The results were impressive. Licensing agreements were now being concluded between the syndicate and leading engine manufacturers. First test runs on diesel-electric locomotives took place [3]. Turbochargers were also recommending themselves for more economic operation of stationary diesel power plants.

In 1932 specifications were formulated for a standardized range of turbochargers. Nine sizes were chosen, cor-

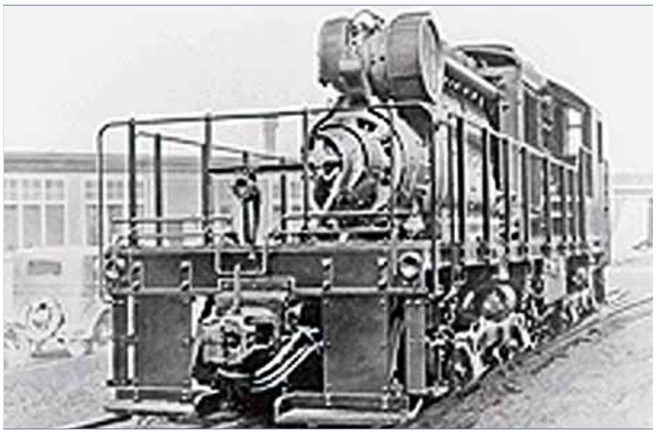
Footnote

1) The syndicate was dissolved in 1941.

[2] World’s first turbocharger for a large diesel engine, delivered in 1924



[3] This ALCO 8-cylinder, 900 horsepower engine was typical of the engines being supercharged by Brown Boveri in the late 1930s (here with a VTx 350).



responding to compressor diameters from 110 to 750 mm. Wide use of modules and as many standard parts as possible allowed fitting to an enormous range of engines. Design features included externally mounted ball bearings, which made service work considerably easier.

The VTR..0 is launched

From 1940 on, Brown Boveri had a new range of turbochargers under development. Denoted VTR, these had an open radial-flow compressor (hence the R) and light rotor, flexibly mounted external roller bearings and a self-lubricating system. Component standardization allowed large-scale production. The market introduction of the VTR..0 series in 1945 is a significant milestone in the BBC/ABB turbocharger story. With a compressor efficiency of 75 percent for a pressure ratio of 2, it was only the start of what was to come, but the VTR..0 marked the beginning of a new era 4.

Turbocharging's triumphant march

The period between 1945 and 1960 saw the world's merchant fleet double in size, and marked the final breakthrough for turbocharging. Boost pressures increased slowly but steadily during this period. The original VTR turbochargers could be equipped with either a low-pressure or a high-pressure compressor, but the latter was hampered by a restricted volumetric flow rate. Compressor development in the following years would erase this disadvantage, pushing the pressure ratio at full load steadily towards 3.

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Continuous refinement of turbocharging technology had, by the early 1950s, set the stage for the next pioneering act. In October 1952, the 18,000 tonne tanker Dorthe Maersk was launched. Built by the Danish shipyard A. P. Møller, it was the first ship to be powered by a turbocharged two-stroke diesel engine (B&W, 6 cylinders). Two VTR630 side-mounted turbochargers raised the engine's output from 5530 to 8000 horsepower. Dorthe Maersk was the first milestone in two-stroke marine turbocharging.

There were several important collaborations with engine builders during this period, showing once again the importance of the relationship between the engine OEM and turbocharger supplier. It was important to explain the new technology and how to make the best use of the exhaust energy in pulse operation, especially how the exhaust pipes were to be designed.

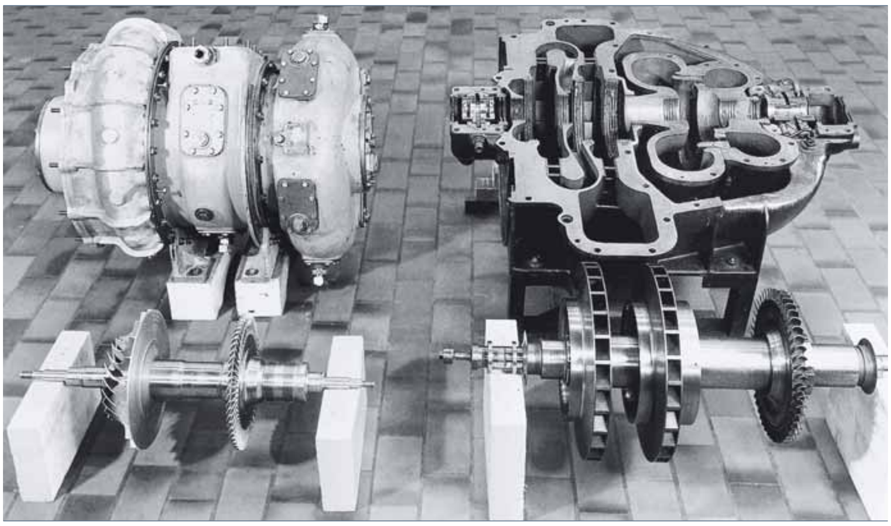
From 1955 on, Brown Boveri signed a number of important licence agreements. One was to have special significance: In 1958 a licence was granted to Ishikawajima-Harima Heavy Industries (IHI) in Japan to manufacture BBC/ABB turbochargers. IHI, which was then building engines under licence from Sulzer, went on to expand throughout Asia, and in doing so secured a dominant position for ABB turbochargers in that region.

Shipbuilding was now at a record level, crude oil prices were low and fuel costs had become insignificant. The diesel engine industry was booming. The VTR..0 was in its heyday, with overall turbocharger efficiency at around 56 percent. Engines with BBC/ABB turbochargers were continually breaking records for output and efficiency.

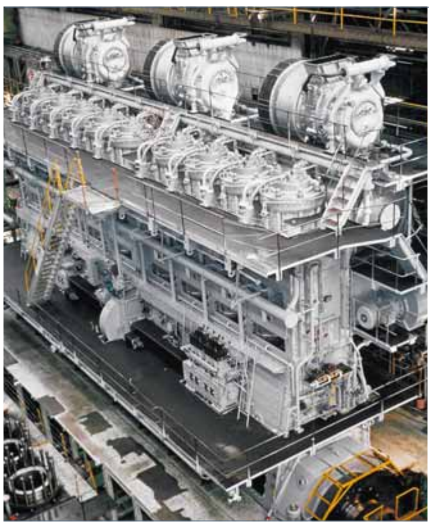
Enter the VTR..1

The 1950s and 1960s saw the development of new compressors with higher efficiencies and pressure ratios as well as increased air flow rates. Bearing designs were improved and mount-

4 Progress of turbocharger technology from 1924 to 1945. Designed for the same engine size, the more compact VTR320 on the left achieves a much higher boost pressure than the earlier VT402.



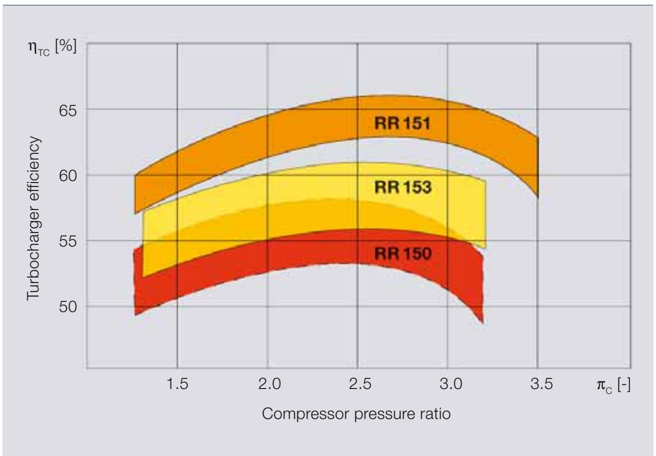
5 Sulzer 32,400 horsepower 9 RLA90 two-stroke diesel engine with three VTR714 turbochargers, manufactured by IHI, Tokyo



ings were reinforced. In 1970, compressors with an even higher air flow rate were introduced and the gas outlet housing was enlarged. The turbine intake was also reworked.

All of these improvements were incorporated in 1971 in a new series – the VTR..1. From now on, Brown Boveri could offer turbochargers with an overall efficiency of almost 60 percent for a wide range of applications. In the past, efficiency had risen steadily but slowly. This was the first big leap.

6 RR..1 turbocharger with mixed-flow turbine and compressor wheel with backswept blades



VTR..4 gives a further boost

By the mid-1970s the VTR..1 had taken the original VTR concept as far as it could go. A new turbocharger range with completely re-designed components was on the drawing board. Following prototype tests, the VTR..4 was introduced to the trade press in late 1978 and launched on the market the year after. Freed from the constraints imposed by the first VTR, it ramped up efficiency by five percent and more and increased the maximum compressor pressure ratio to over 4. The VTR..4 contributed to the spectacular rise in thermal full-load efficiency of large engines at this time from 38–40 percent to peak values of 44–46 percent 5.

The need for a compact version with as many of the VTR..4 turbocharger's components as possible was answered in 1980 with the VTC..4. This opened up new opportunities in the US market and was successfully deployed on locomotives in India, later also in China. Changing market conditions subsequently called for the development of an uncooled version of the VTR..4.

Another breakthrough came in 1985 with the RR..1 6. Mainly intended for high-speed four-stroke engines, the RR..1 set new standards of efficiency for small turbochargers, an area of business Brown Boveri had first entered seriously in 1968 with the RR150.

In the years that followed, the RR..1 contributed to the popularity of the high-speed engine in applications ranging from emergency gensets through marine propulsion to off-highway vehicles. Designed for an engine output range of about 500 to 1800 kW, it can also take much of the credit for the wide use of turbochargers on gas engines in Europe and in the USA.

Further development of the VTR..4 turbocharger was meanwhile also under way, producing peak efficiencies close to 75 percent with the VTR..4E in 1989 and pressure ratios of more than 4 with the VTR..4P, introduced to the market in 1991.

The TPS/TPL generation leap

In 1989, following the merger of ASEA and BBC to form ABB, ABB Turbo Systems Ltd was set up to handle the new group's turbocharger business. The change of name coincided with another development: Market studies in the mid-1980s had shown that new, benchmark turbochargers were needed in all the main areas of business. The engine-building industry was consolidating. Fewer, but stronger and more innovative companies were developing new generations of diesel and gas engines. For these engines, more efficient turbochargers capable of higher pressure ratios and flow rates were essential.

In the early 1990s, ABB began to develop a new generation of compact, lighter high-performance turbochargers as successors to the VTR, VTC and RR. Two new families, the TPS and the TPL, were designed from the ground up.

7 Container ships are an important market segment for the largest ABB turbochargers.

The TPS debuts

Since the launch of the first RR turbochargers in 1968, the high- and medium-speed diesel and gas engine market had been changing fast. ABB therefore set about developing an entirely new generation of small heavy-duty turbochargers in four frame sizes to cater to the foreseeable needs of this sector. Two compressors were initially developed, achieving pressure ratios of up to 4.5 and peak efficiencies of more than 84 percent.

Developments in the diesel and gas engine markets also led in the mid-1990s to a version of the TPS with variable turbine geometry (VTG). An "adjustable" turbocharger was seen to be the ideal solution for diesel engines with the increasingly popular single-pipe exhaust systems as well as for gas engines, which require precise control of the air-to-fuel ratio, so-called "lambda regulation".

Launch of the TPL

The TPL turbocharger family was developed for large modern diesel and gas engines with outputs from 2500 kW upwards. For this range, ABB's engineers designed new axial turbines, a new, innovative bearing assembly and two new centrifugal compressor stages.

The first of the new-generation TPL turbochargers to be introduced to the market was the TPL..-A. This was developed for four-stroke diesel and gas engines in the power range of 2500 kW to 12,500 kW and became a runaway success soon after its market launch in 1996. Five frame sizes cover the requirements of applications that range from main and auxiliary marine engines to stationary diesel and gas power plants.

Three years later ABB launched the first of its TPL..-B turbochargers. These were developed primarily for the large, modern two-stroke marine diesel engines rated from 5000 to 25,000 kW (per turbocharger) being built for large ocean-going vessels 7.

> The steady improvement in turbocharger and engine efficiency has always relied on close cooperation between ABB and the leading engine-builders.

Initially, four frame sizes were considered to be enough to satisfy market demand in the medium term. However, it was later decided to develop a fifth, even more powerful turbocharger (TPL91) to take account of shipbuilders' plans to build even larger "post-Panamax" container vessels. ABB's engineers were challenged once more: The turbocharger was to be designed for use on engines with power outputs in excess of 100,000 brake horsepower and yet still be compact. This was achieved by designing a new, shorter rotor and a new constant-pressure turbine and diffuser. Mounting of the engine was also made easier by an integrated oil tank 8.

A new turbocharger for the traction market

The TPL was also the basis for the TPR, a new railroad turbocharger launched by ABB in 2002. Designed specifically to meet demand for extra power and robustness as well as better environmental performance in traction applications, it features an integral high-efficiency turbine, an improved single-entry gas inlet casing and a unique foot fixation.

The pressure ratio benchmark is raised again

The continuing trend in engine development towards higher specific power is accompanied today by an urgent need to reduce emissions, and this has led to most modern engines having some version of the so-called Miller cycle[2)] incorporated. For these and future advanced engines ABB has developed the TPS..-F family 9. Three new series cover the engine power range of 500 to 3300 kW and achieve full-load pressure ratios of up to 5.2 with an aluminium-alloy compressor wheel.

The TPS..-F was also the first ABB turbocharger to feature recirculation

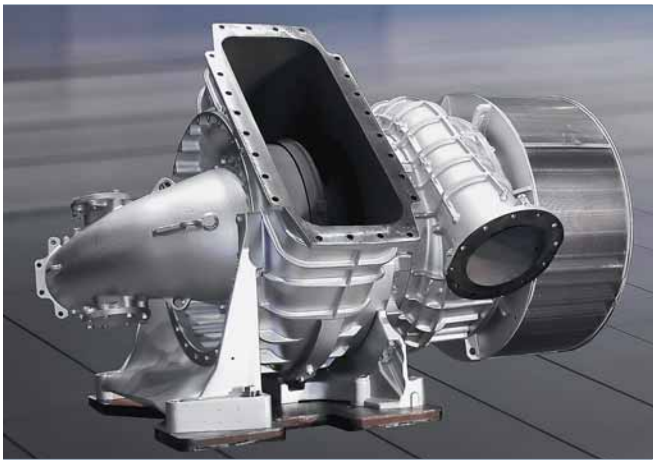
Footnotes

[2)] The basic principle underlying the Miller process is that the effective compression stroke can be made shorter than the expansion stroke by suitably shifting the inlet valve's timing. If the engine output and boost pressure are kept constant, this will reduce the cylinder filling and lower the pressure and temperature in the cylinders, thereby reducing the emissions.

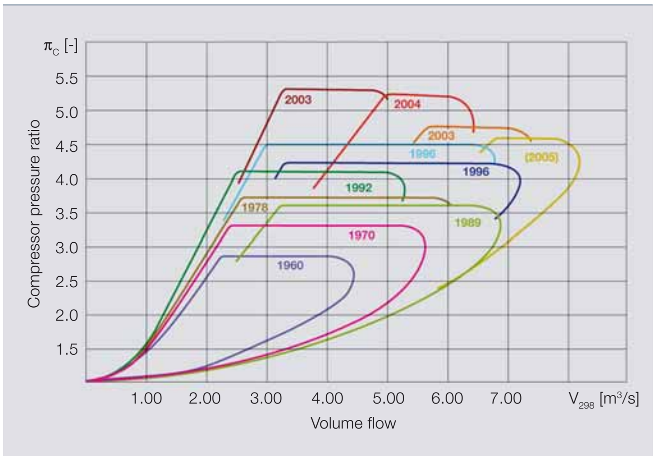
8 Assembly of the TPL91-B turbocharger

9 TPS..-F turbocharger

PERPETUAL PIONEERING



10 The TPL76..-C turbocharger has been developed for advanced four-stroke engines



11 Progress in the compressor performance of ABB turbochargers since 1960 (full load, with an aluminium compressor)

technology – a bleed slot around the compressor wheel which, by improving the flow field, increases the surge margin. The effect of this slot is to enlarge the map width without compromising the compressor's high efficiency.

A turbocharger for advanced four-stroke engines

The new millennium has seen the four-stroke engine market continue to push for more output and lower emissions. ABB therefore decided to make use of the TPL's modular platform to introduce new components and innovative technologies in a new series – the TPL..-C – that caters especially to this future market 10.

Developed for advanced four-stroke, medium-speed diesel and gas engines in the power range of 3,000 to 10,000 kW (per turbocharger), the TPL..-C offers two different turbines: one for quasi-constant pressure as well as pulse-charging systems, and one specifically for quasi-constant pressure systems. An innovative feature of the compressor is optional air cooling. This extends the field of application for aluminium alloy wheels, offering users an economic alternative to titanium impellers when very high pressure ratios are required.

Factbox How turbocharging works

The output of an internal combustion engine is determined by the amount of air and fuel that can be pressed into its cylinders and by the engine's speed. Turbochargers supply air to the engine at a high pressure, so more air is forced into the cylinders and is available for combustion.

The engine's exhaust gas, at approximately 600 °C, is directed at high velocity onto the blades of a turbine, which drives a compressor wheel mounted on the same shaft. As it rotates, the wheel sucks in air through a filter-silencer, compresses it and feeds it via an after-cooler to the air receiver, from where it passes to the cylinders.

A century of progress

In the 100-plus years since Buechi's 1905 patent[3], the exhaust gas turbocharger has become indispensable to the diesel and gas engine industry. Investment in research and development over the decades has brought quantum leaps in technology and design – well documented by the progress demanded, and achieved, in turbocharger performance over the years 11.

> The continuing trend in engine development towards higher specific power is accompanied today by an urgent need to reduce emissions.

The steady improvement in turbocharger and engine efficiency has always relied on close cooperation between ABB and the leading engine-builders. It is this cooperation that sets the development goals and which will, in all probability, become closer as the demands made on the "turbocharging system", and not just the turbocharger as a component, increase.

In the technologically advanced TPS and TPL turbochargers, ABB has worthy successors to the highly successful VTR and RR series. With the market continuing to demand higher boost pressures and efficiencies, not least because of the contribution they make to reducing engine emissions, the future belongs to turbochargers that combine these qualities with highest performance and long times between overhauls.

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Footnotes

[3] A complete history of the BBC/ABB turbocharger can be read in the centenary issue of Turbo Magazine, no. 2/2005, published by ABB Turbo Systems.

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Collaborating for results

Many of ABB's top innovations have been realized through joint efforts with customers. The company has formed strategic agreements with these to help define and to "test drive" new developments early in the cycle. The mutual trust that makes such efforts possible has provided benefits for entire industries. Likewise, supplier partnerships are important, as they permit both partners to focus on their technological strengths while working towards a common goal.

In the field of research, ABB cooperates with more than 50 leading academic institutions, including the Massachusetts Institute of Technology, Carnegie Mellon University and China's Tsinghua University. Such partnerships engage some of the world's leading young minds in research efforts while expanding ABB's product palette.

Beside a large number of cooperation success stories from all ABB divisions, the next issue of ABB Review will discuss some basic principles of collaboration among the partners involved in industrial research.

Nils Leffler, who joined ABB Review as Chief Editor in 2003, will now leave the journal with the current issue being his last. During his editorship, the magazine received a modernized look and its editorial content shifted from a business-area orientated structure to themes cutting across all ABB businesses. This redefinition has been rewarded by a steadily growing readership reflected in over 60,000 copies being distributed quarterly. It is a great tribute to the quality of the magazine that numerous articles are being reprinted in the trade press in many countries around the globe.

Friedrich Pinnekamp will take over as Chief Editor from issue 3/2007.

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