ABB Review

Special Report

Power Services

ABB

Contents

Always by your side: how customers enjoy ABB's service.

In the wake of last year's major power outages in North America and Europe, reliability is once again the watchword of the electric power industry. The link between grid reliability and asset management is being increasingly recognized by utility companies.

This has to do with the high quality and long lifetime of the devices used in the utility industry. For more than 100 years, ABB has contributed to this high quality standard. ABB has driven some of the major breakthroughs in high voltage technology for both HVAC and HVDC, supplying equipment for the first 400 kV system, the first 765 kV system and the first HVDC system in the world. ABB delivered the first Gas Insulated Switchgear (GIS) in the 1960ies, (which today includes installations of up to 800 kV) and is the absolute dominating supplier of high current systems for generators.

This historical journey has given ABB a unique know-how as well as an impressive number of installed high voltage products. ABB Air Insulated Switchgear (AIS) for 72–800 kV including circuit breakers, instrument transformers and surge arresters are installed in more than 100 countries around the world. Some of these installations today include fully functional equipment, which is more than 30–40 years old. GIS from ABB is a more recent technology but is already installed in almost 100 countries around the world for 72–800 kV with some installations approaching an age of 30 to 40 years.

Such equipment, though still operating perfectly, will as everything else, age and finally reach obsolescence. Varying electrical, mechanical and environmental stresses mean individual installations of the same type will age differently. The technical and economical lifespan of high voltage equipment is also influenced by its location and importance within the system. Operating parameters may also change – resulting, for example, in a higher short circuit current.

Considering all these factors, it becomes clear that the overriding customer demand for reliability has to be addressed by the combination of two strengths: Quality products and quality service.

In this Special Report of ABB Review you can read how ABB addresses the utmost important aspect of service for grid installations. For each and every component, including devices from other suppliers, ABB has a proven concept for fast on-site service. This service goes beyond the components and covers the control systems that finally manage a distributed electrical grid.

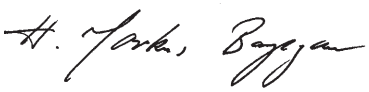
ABB's service portfolio stretches from early, preventive detection of potential failures and analysis of the best service strategy to instant repair – executed through the global network of service centres close to the customers.

A long-term service planning strategy also includes the design of new products based on a better maintenance requirement for replacing outdated equipment.

It is the fundamental strategy of ABB to provide its customers with all service required long after the original delivery of the equipment.

The loyalty of our customers proves that this is the right approach.

At your service!



Markus Bayegan
Chief Technology Officer
ABB Ltd

ABB Power Technologies is at your service

Grid reliability is on top of all of our agendas. It is a tribute to the ingenuity of those who created our power networks, as well as the tenacity and determination of the utilities that operate them, that the world's power grids are as reliable as they are.

Why? Because many of today's grids were built in the 50's and 60's and operate on a foundation of technology from that period. Think of how much technology has changed in half a decade. Imagine using 40 or 50-year-old technology to run any other modern business.

Yet that is how we supply our power-hungry world every day – our aging grids are regularly stretched to the limit of their capacity to perform reliably and predictably. And when a grid is stretched beyond this limit, the world soon pays attention: as with the massive blackouts of 2003.

In an ideal world, a massive injection of new technology would eliminate the risk of downtime, outages, brownouts and blackouts. However, the reality today is that new equipment isn't always a viable option. The political environment, business climate and regulations also determine investment in power networks.

As power equipment continues to age and power grids come under more stress as a result, new challenges are appearing in a specific area of our business: *service*.

At ABB, our power service expertise ranges from consulting services, including power system studies, to asset management services for power grids. It includes maintenance and field services, as well as retrofit and refurbishment projects. Provision of spare parts is also on the long list of services ABB offers power grid operators.

Service is a people business, and this is no less true in an industry like power transmission and distribution, which uses technology to provide services. Being active in about 100 countries, ABB can proudly say we are at home everywhere. For you, our customers, this means we are always nearby with experienced consultants, service engineers, and technicians. Sometimes they are called upon to be emergency problem solvers, and sometimes they can foresee and prevent problems before they arise.

Thousands of ABB products are installed every month and operate in power systems around the world, in conditions ranging from arctic cold to desert heat and everything in between. Our global presence is built upon local expertise – in most cases, ABB will be familiar with your power product, your application, and your system.

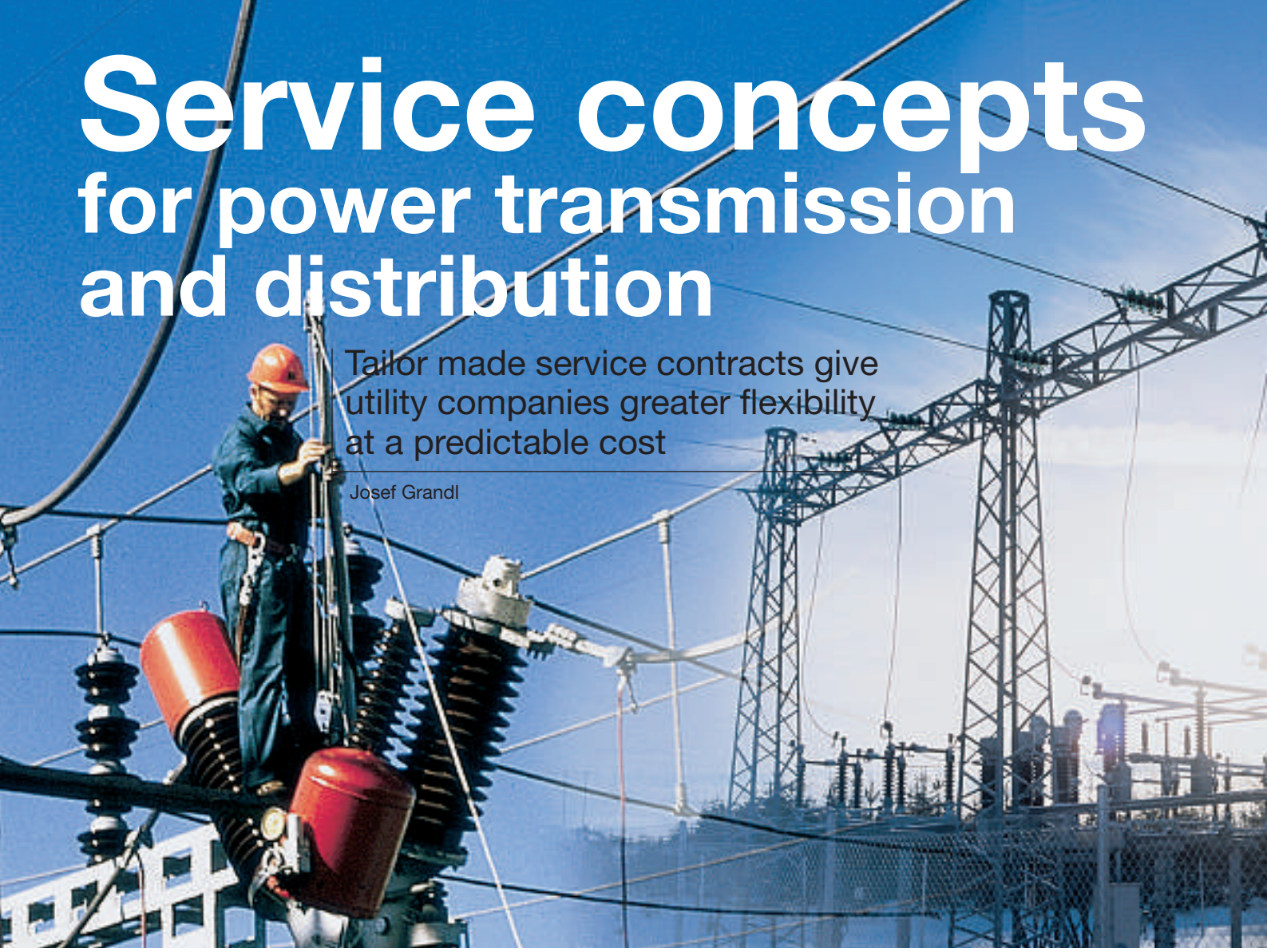
ABB is your reliable expert when it comes to sophisticated modern power technology and solutions. But ABB expertise is also supported by more than a century of power industry experience. Our ABB product and system heritage is unmatched and gives us the largest installed base in the power industry, including acquired brands such as Ansaldo, ITE, GE (Transformers > 40 MVA), Gould, National Industri, Strömberg and Westinghouse.

This means we own the intellectual and technical properties of a large part of the world's electrical power infrastructure, and can make this readily available to you. But even more importantly, we feel the responsibility of ownership and support and guide our customers over the lifecycle of their equipment – and beyond.

In this Special Report, we want to share with you some up-to-date examples of our service expertise. They will underline our dedication to the goal of ensuring the reliability of your power plant, transmission and distribution system. This is not always just a question of service, but service is always an important element in the smooth operation of any technology, particularly a vintage power grid.

Peter Smits
Member of the ABB Group Executive Committee
Head of Power Technologies division

Service concepts for power transmission and distribution



Tailor made service contracts give utility companies greater flexibility at a predictable cost

Josef Grandl

Until recently, it was a matter of course that power utility companies maintained their own equipment. A typical utility provider would have had maintenance staff and facilities as part of its operational structure. Over-capacity had to be provided to be able to deal with emergencies or work peaks. Maintenance was often integrated with other units and costs were seldom transparent.

The combined effects of market pressure in the face of liberalization and the introduction of more complex modern technologies are causing more and more utility providers to re-think their service strategy. In many cases, service agreements with original equipment manufacturers are an alternative to complete in-house sourcing. They offer cost efficiency, protect the utility provider from risks and facilitate budgeting. They also provide access to experts with extensive know-how and experience.

Maintenance contracts, long term service contracts, and asset outsourcing contracts represent different levels of relationship between a service supplier and a utility.

The supplier and customer jointly develop the content and level of a service partnership, dependent on the service strategy and the competences the utility wishes to keep in-house.

Key performance indicators (KPI) increasingly substitute detailed scope and work definitions shifting the focus from the input to the output. This permits the introduction of new methods and tools for increasing efficiency.

Besides all contractual issues, service is and will remain a people's business; success or failure is determined by relationships, qualifications and the flexibility to handle unforeseen situations.

Market developments

As a consequence of liberalization and privatization in the electrical utility sector, there have been fundamental service-related changes for power transmission and distribution systems.

Increased competition and cost pressure as well as the new focus on the reliability of electrical networks (blackouts) have lead to a reappraisal of service strategies, processes, organizational set-ups and the definition of core and non-core activities.

There is no uniform model fitting all demands. The following general trend can, however, be recognised: In the electrical utility sector reluctance towards service outsourcing is greater than in other industries. It can be said that the higher the degree of liberalization and privatization, the higher the degree of outsourcing. Contrary to expectations at the beginning of liberalization, transfer of asset ownership remains exceptional. There is however a strong move towards long-term service co-operations centred on performance based measurement and reward structures.

Motivation, concerns and opportunities in service outsourcing

Motivation

A utility's service strategy is influenced by the following:

- The degree of competition and the private investor's drive for cost reduction.
- Restrictions on outsourcing and personnel policy imposed by politics.
- Age and lifespan of equipment, loss of know-how due to retirement of specialists, increasing complexity of technology (software) that calls for economic re-evaluation of the case for maintaining in house expertise versus outsourcing.
- Reliability problems forcing the customer to incorporate external expertise due to political pressure and/or bottlenecks in in-house resources.

Prior to executing an outsourcing plan, a company must define where the borderline lies between maintaining its competences, processes, resources and assets in house compared with contracting them out.

Concerns

Any outsourcing decision must also consider concerns over the risk of allowing an external contractor to run a substantial part of the business process.

An extensive study on asset management and outsourcing practices of utilities, performed by ABB in 2001 and involving about 70 utilities, revealed the major concerns which are summarised below:

- Labour regulations impeding the ability to realize efficiency gains.
- Losing scarce talent.
- No separation of ownership, management, and execution.
- The perception that asset management is a core discipline to be kept in-house.
- Lack of comparable precedent.
- Lack of operating or contractual standards (e.g., assigning performance responsibility).

An equipment owner may also be concerned, that a manufacturer who is at the same time a service provider might not be impartial about effective asset management.

> Service is and will remain a people's business; success or failure is determined by relationships, qualifications and the ability to handle unforeseen situations.

These concerns must be properly addressed in the development of a service strategy.

Opportunities

For utilities willing to implement outsourcing concepts, several critical factors determine success or failure.

In the market study mentioned above, the following critical success factors were identified (in order of priority):

- Cost savings
- Access to up to date technology and process know-how

- Trimming peak resource requirements
- Shifting to a variable cost structure and reducing capital employed

Quotes from utilities:
"We have outsourced a great deal of our activities and have achieved significant cost reductions. If someone can offer further cost reductions, we would definitely consider outsourcing additional activities"

"If you're not going to be technically superior, there's no use being technical; outsource it!"

"Shaving of peak labour requirements reduces costs by moving from a fixed to a variable cost structure. Yes, this is important!"

Service as a relationship and trust business

A sustainable service strategy should be jointly developed by the utility and the service provider. A considerable investment of time in the clarification process is mandatory for the definition of a suitable service package. Otherwise a lot of time can be wasted in useless offerings not in line with the utility's core competence definition and in unrealistic demands not in line with the supplier's capabilities and scope.

The higher the degree and depth of outsourcing, the more interaction that must take place between the utility and the supplier. Compared to the delivery of a technical product, which is easily described in a specification, the description of service deliverables, non-deliverables and interfaces is more complex. Additionally, the number of pages describing a service agreement is not necessarily indicative of the clarity of the content or a guarantee against misunderstanding. Service works in a grey zone between defined scope and expectations having to be fulfilled. The deeper and longer the relationship must last, the more mutual trust is required.

The higher the degree and depth of outsourcing, the more interaction that must take place between the utility and the supplier.

Besides the supply of spares, products and tools, there are various stages of service agreements – typically these develop over time:

- Maintenance contract
- Long-term service contract
- Asset outsourcing contract

Maintenance contract

In a maintenance contract, the supplier provides an amount of dedicated work on specified equipment. The utility decides the nature and time of this work.

Typically maintenance contracts are frame type contracts, releasing the utility from a tendering process for every maintenance event. This arrangement provides a reasonable predictability for budgeting purposes. The contract stipulates the type of equipment to be maintained, the type of work to be performed and the hourly rates.

Advantages of maintenance contracts are predictability of service cost, saving the cost of keeping in-house specialists for all equipment types used and access to the manufacturers knowledge and experience. Work peak load shaving is another argument.

Maintenance contracts are mostly concluded with the original equipment manufacturer. The length of such contracts varies from one-time events to three-year frame contracts.

Long term service contract

The philosophy of service contracts is different to that of maintenance contract. In a service contract, the utility provider entrusts the supervision of day-to-day maintenance activities to the service provider. The latter also takes over longer-term monitoring and maintenance strategies.

In contrast to a maintenance contract, the philosophy for a long-term agreement is more production related. The agreement focuses on the customer's output requirements (which are the input requirements of the utility's customers). KPIs become a major element, measuring the service provider's performance rather than describing the scope of work and the details of how it should be done.

Despite the decision to outsource a strategic part of asset service and maintenance, the utility has a major interest in maintaining key competencies in house. Therefore, long-term service

contracts are often linked to education and on-the job training for key internal personnel. This permits them to be up to date technologically and always capable of controlling the process.

The nature of such a long-term contract is illustrated below using an example of a service agreement with a power transmission company.

History

This contract is the result of a long-term relationship starting with one-time events, repair and maintenance work and growing into frame contracts and retrofit projects. Facing the challenges of a liberalized market, the customer decided to outsource a larger proportion of service work to the original suppliers. The contract duration is for five years with an option to extend it for another five years.

Scope of system

This scope covers :

- Transmission substation equipment maintenance in a geographical area.
- Power transformer refurbishment for one third of the company's assets.
- Transmission line maintenance in a geographical area.
- Transmission line condition assessment in the same area.

This contract covers 30 transmission substations, 310 power transformers, 1000 km of transmission lines at 66 to 220 kV.

Scope of work

This covers:

- Managing the annual budget for maintenance in the geographical areas
- Reporting
- Internal auditing

The scope of work includes scheduled and unscheduled fieldwork, as well as condition assessment, fault repair and emergency management.

This highlights the fact that the customer transfers considerable responsibility for his assets to an external supplier.

How does the customer maintain control and how is a competitive environment maintained despite such a contractual relationship?

Securing performance

In order to ensure performance and continuous improvement, KPIs and benchmarking are used. KPIs cover system performance, service delivery, spending plan, contract performance, feedback and complaints from the customer's customers. All KPIs, including qualitative ones, are defined in detail and are measured regularly.

By benchmarking the work of the service providers, the utility can compare and challenge the suppliers. Performance failure can result in notice, not being invited for further project work (blacklisting), suspension and finally termination of the contract.

Through KPI measurements and benchmarking, the dependence on the service provider is limited. On the other hand, engaging the original manufacturer to serve and maintain his own equipment creates a high level of commitment.

Technology and processes

A main target in contracting service is the introduction of methods, tools and technologies that help improve system performance and increase productivity.

For a long-term service contract to be successful, service must be made clear and measurable. This requires the implementation of a management information system to render the service process transparent. This comes at the price of increased reporting and data handling.

A reporting structure is established to provide detailed information on the work performed, asset status, failure history, and the performance of the service provider in general. These data are used for investment planning and budgeting – helping to optimize the capital investment for maintenance.

The importance of long-term service contracts in the electrical utility sector is increasing. Contracts lasting around ten years are typical.

Asset Outsourcing agreements

The next level of outsourcing combines the elements of a service contract with the transfer of ownership of the assets and full operational responsibility. The duration of this type of contract is typically several decades.

Asset outsourcing agreements are attractive for enterprises defining their core competence outside electrical network ownership and management. These can be energy intensive industries, electrical distribution, energy trading, and railway companies.

In a real case involving a transportation company, the assets of the entire electrical network have been trans-

ferred to a special purpose company. This special purpose company owns, operates, maintains and renews the power distribution network on a concession basis for a period of 30 years. After that period, the assets must be returned to the original owner in a condition defined in the contract.

Organization

The consortium managing the contract comprises a utility, a construction company and ABB as engineering and equipment supplier.

The organizational structure implemented has to secure the balance of interests between the transportation company and its outsourcing partners. It ensures an efficient use of capital and provides access to private financing.

The transportation company controls the output of the special purpose company through a detailed reporting structure with a number of KPIs and availability, reliability and failure rate measurements. The following KPIs are introduced:

- Maintenance performance compared to a master plan (overdue time).
- Renewal projects follow up.
- Average failure rates per asset group.
- Average repair/restore time per equipment type.
- Availability of power supply.
- Average remaining life time and age profiles of asset groups.

The asset groups are, for example, transformers, switchgear, batteries.

Every year an annual report summarizes the measurements and the major trends of all the performance measurements.

This model of co-operation has now been in operation for four years. The model is seen as a success and has won several industry awards. Continuous efforts are invested into improving the measurement system.

A contract of this type, representing a value in the three digit million dollar range, requires an enormous amount of preparation work and legal clarifications. About two years of negotiations were needed before this contract was signed.

The clear separation of electrical asset management and transportation business requires an adequate interface management. The control of the process requires investments in data acquisition, handling and reporting. The payback achieved is full transparency on processes and costs, clarity on efficiency and payback on investments. Cross subsidy can no longer disguise inefficiency.

In order to ensure performance and continuous improvement, KPIs and benchmarking are used.

What is the best model for service co-operation?

There is no ‘one fits all model’ in the service market. The optimal model can only be created in close co-operation between service provider and customer, taking market environment, political influences and strategic considerations into account.

To create a successful service co-operation, the best approach is to take reference agreements and work out a contract based on experience and already working models. Combining ABB’s experience and references in service contracting on all levels, from maintenance to asset outsourcing, together with the customer’s service strategy leads to a custom made service agreement.

Essential for successful co-operation is the definition of required outputs. In case of a standard maintenance contract this is straightforward. There is, however, a clear trend towards introducing increasingly output focused KPIs as a basis for reward schemes. This allows the service provider flexibility on the introduction of new and improved methods and processes for increasing efficiency, while at the same time maintaining or improving reliability and availability.

Josef Grandl
ABB Power Technologies Ltd
Zürich, Switzerland
josef.grandl@ch.abb.com

Lifetime decisions

Optimizing lifetime costs for transformers through informed decisions

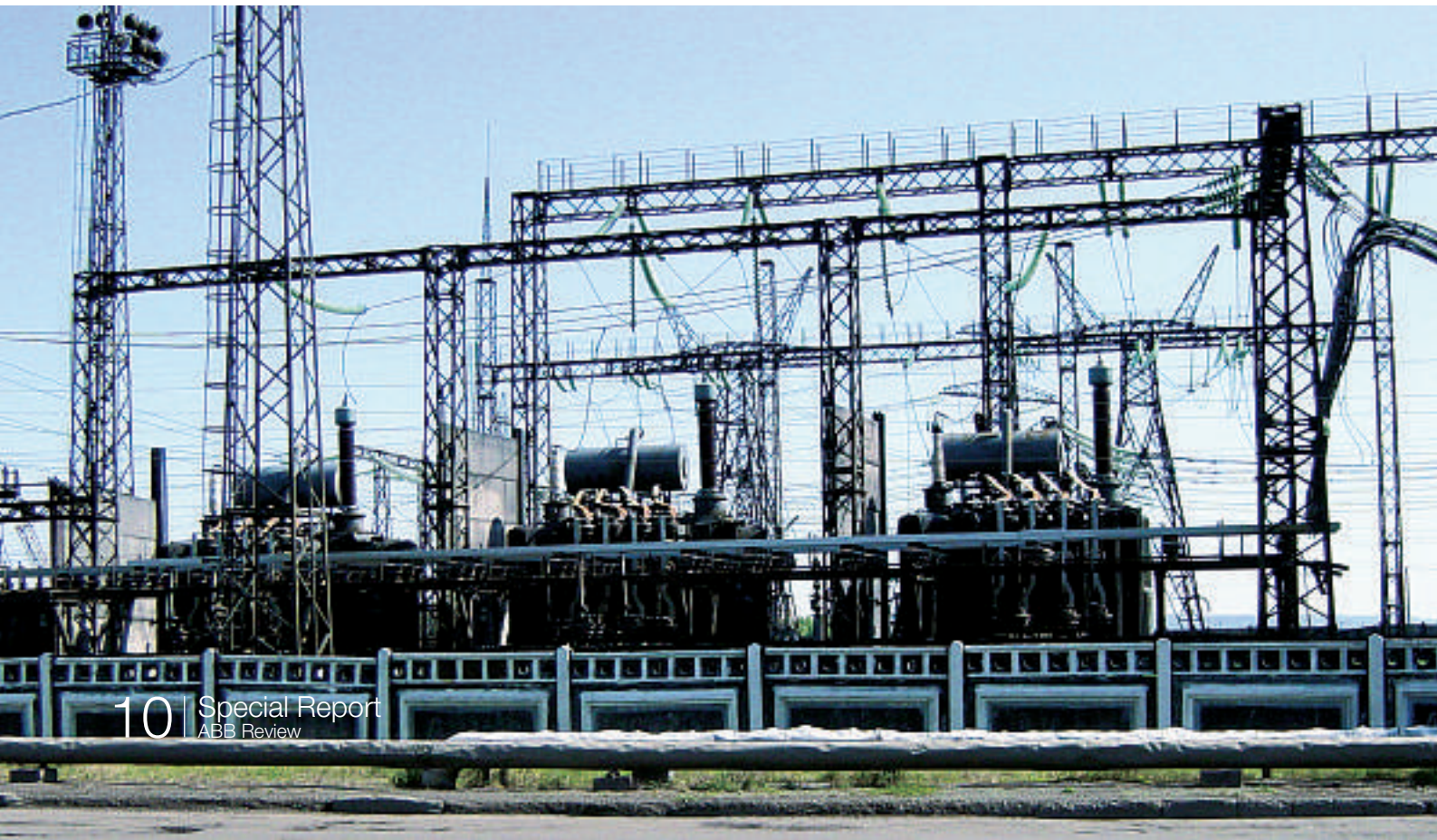
Pierre Lorin

Ageing assets, rising energy demand, and the need to deliver without outage are issues facing utilities and industries around the world. At the same time, financial constraints demand an increased return on investment over reduced maintenance budgets and spending.

These apparently contradictory demands can be met through optimized asset management. This, in turn, requires accurate and reliable models considering both technical and economical criteria. ABB provides a service portfolio furnishing this precise life-cycle analysis and the associated technological support.

A computer-based evaluation of different scenarios modeling different fleet management, maintenance and replacement strategies over longer periods of time can tell decision makers such facts as, when maintenance is more economical than replacement and how much has to be invested and when.

Investments can be planned, lifetime costs of equipment made transparent and decisions based on informed fact.



Over the past decades, asset related decisions were primarily based on accumulated experience. Capital expenditure was mostly trigged by a fast growth in energy demand and power assets were replaced by new and more powerful installations long before their reaching the end of their useful lifecycle. In today's rapidly changing environment, however, with its severe technical and financial constraints, assets managers must base their strategic decisions on reliable and precise facts to convince decisions makers.

One of the most frequent issues reported by transformer owners is the lack of reliable information on asset condition and the difficulty in defining improvements that are justified from both a financial and technical point of view.

The service portfolio 1 presented in this article is a combination of several products that provide both utilities and industries with the following advantages:

- It offers a clear understanding of the condition of the transformer fleet and accurate information on possible risks associated with every unit.
- It has the ability to draw alternative asset management scenarios based on the company's strategy and the condition of the fleet.
- It can define actions to be taken for each specific asset and evaluate payback or net present value for each scenario, considering technical and economical aspects.
- It can implement defined actions by using efficient maintenance and repair technologies.

Understanding the status of the assets: condition assessment

Condition assessment is a key ingredient for every asset management survey. It provides the base for any sound decision 3.

A statistical approach based on international data on transformer reliability can be useful as a first step in estimating maintenance and investment budgets. However, ABB's experience shows that each unit must be considered individually so that user can decide whether it should be maintained, relocated, retrofitted or replaced. ABB provides such assessments for a fleet of transformers or for individual units.

ABB has developed a modular approach to meet different expectation levels defined by the end-user in terms of population size, level of information requested and available budget.

The assessment methodology is based on three steps:

- *Step 1: Fleet screening:*

Quick scanning of a large population (20–200 units) using easily accessible data such as unit name plate data, oil and dissolved gas in oil data, load profile and history of the unit.

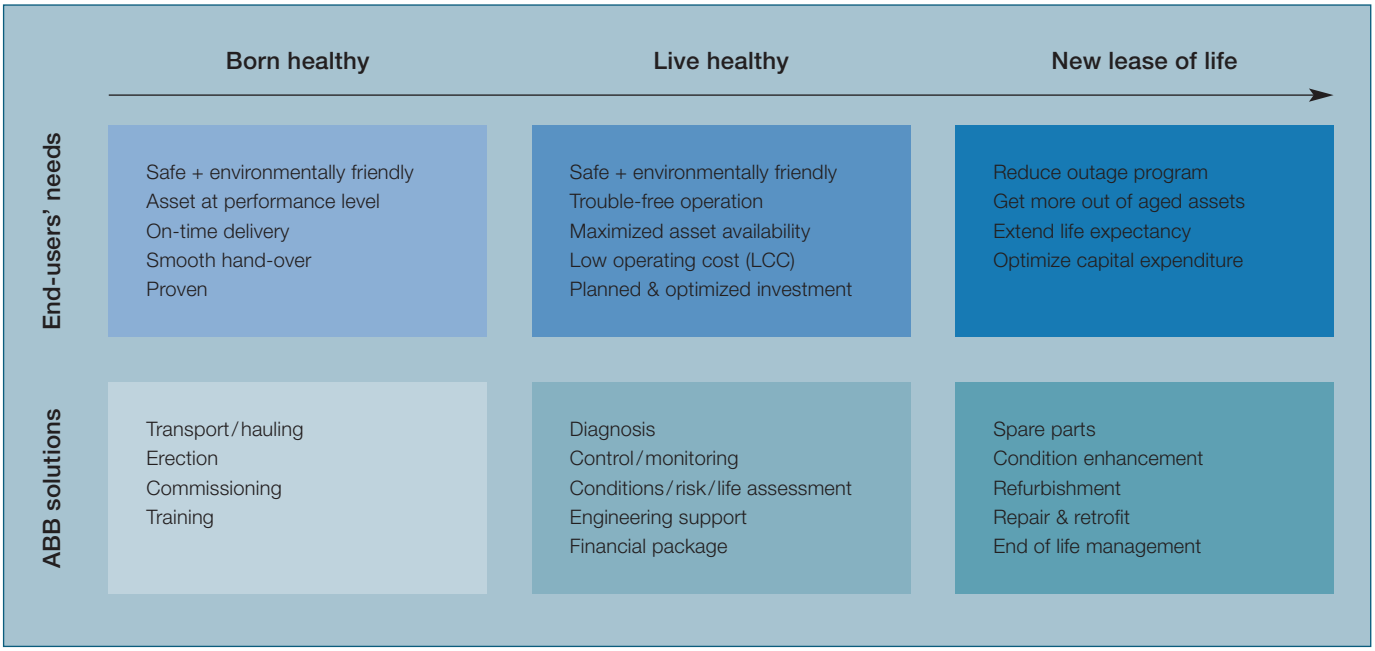
This first step provides higher-level management and asset managers with an overview of their assets. It gives relevant inputs for maintenance or investment budget strategy.

It is also used to select units that must be further investigated either because they are of strategic importance or because their status is critical.

- *Step 2: Condition assessment*

Here, experts focus on a smaller number of units (10 to 20) identified during step 1. Experts use modern design rules and

1 Overview of ABB service portfolio for transformers.



2 Result of a condition assessment survey (step 2: Normal evaluation) on eight transformers.

Unit #	Mechanical	Electrical	Thermal	Accessories	Overall	Actions
TFO 2	Winding	Arcing	Heating		95	Visual inspection and repair in factory/rewinding
TFO 5	Tank			OLTC heating	80	Repair on site and OLTC overhaul
TFO 1			Aged oil	Bushing	70	Oil regeneration/filtration and advanced diagnosis/change HV bushing
TFO 6		Arcing		Thermometer	50	Exchange TopOil – thermometer/on line monitoring of DGA
TFO 3				Silicagel	40	Exchange silicagel
TFO 7					25	Standard maintenance actions and controls
TFO 8					15	Standard maintenance actions and controls/10 % overload capabilities
TFO 4					10	Standard maintenance actions and controls/15 % overload capabilities

tools to evaluate the original design. Advanced diagnosis tests [1] are performed to assess each of the principal properties of the transformer in a structured way: Mechanical status, thermal status (ageing of the insulation), electrical status of the active part and the condition of the accessories such as tap changer(s), bushings, over-pressure valves, air-dryer system, pumps and relays.

Taking into account the results of this assessment, ABB defines the action for improving the reliability of every unit.

This part of the survey benefits asset, maintenance and operation management. Valuable inputs 2 strengthen daily decision making with factual support and explanations: Such inputs can be a list of spare parts to be kept in stock, a prioritized list of on-site maintenance measures, proposals to relocate units, decrease their load, repair or replace them.

■ *Step 3: Expertise*

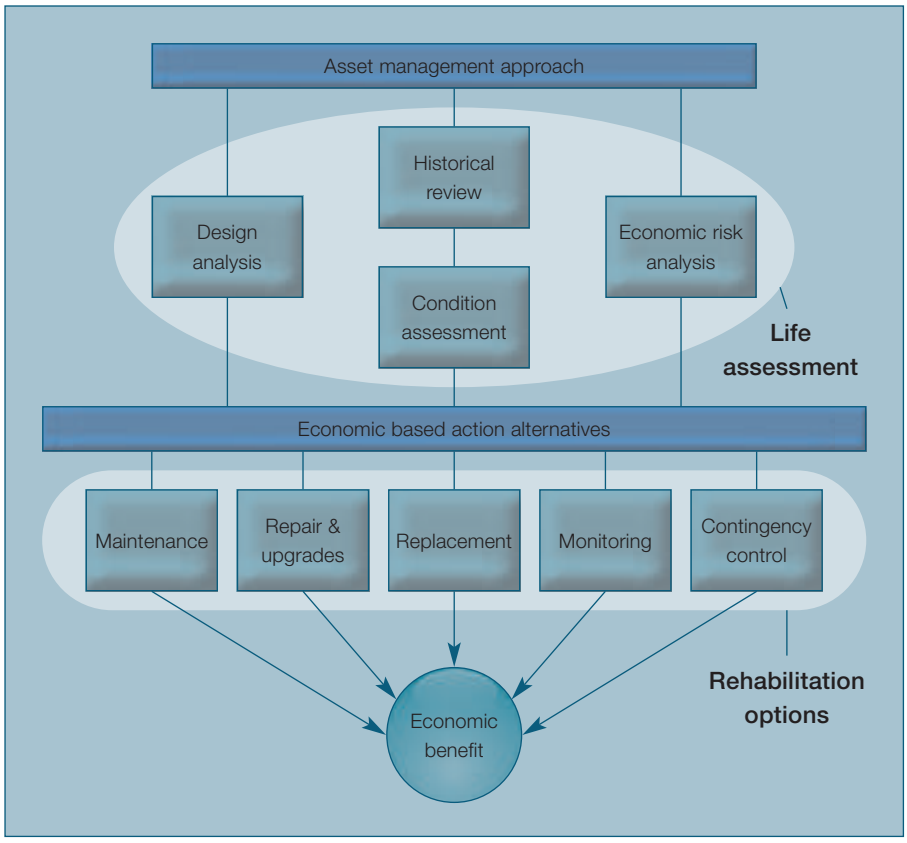
The number of units to be further analyzed is typically limited to two or three out of a population of 100 units. International experts using state of the art simulation tools are involved.

This third module within the assessment process provides accurate information to the end-user's engineering manager, for example when a transformer needs to be overloaded, nominal power or voltage rating increased or lifetime extended.

Maximizing the benefits at each management level

The modular assessment [2] provides valuable inputs to end-users at different management levels to ensure a high reliability and availability of installed assets. It reduces risks of unplanned outage, defines the right maintenance strategy and associated budget, improves the efficiency of maintenance investments by focusing on the right assets and optimizes capital expenditure by postponing investments. These data can also be used for discussions with insurance companies, aiming to setup the most appropriate insurance contract for the fleet.

3 Flowchart of ABB's approach to asset management.



4 Lifecycle costs calculation.

$$LCC = C_A + C_E + C_1 + \sum_0^n + (CP_M + CC_M + CO_P + CO_0 + CR) + C_D$$

where
C_A = cost of apparatus
C_E = cost of erection
C_1 = cost of infrastructure
CP_M = cost of planned maintenance
CC_M = cost of corrective maintenance
CO_P = cost of operation (load and no-load losses)
CO_O = cost of outages
CR = cost of refurbishment or replacement
C_D = cost of disposal

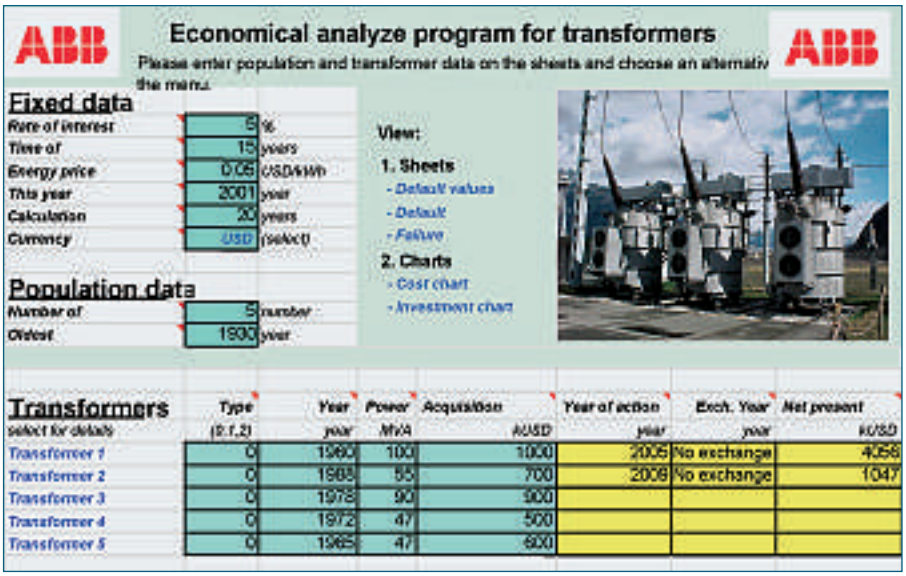
Economical analysis for pay-back of maintenance actions

The result of a condition assessment survey is a ranking of the transformer population according to the evaluated reliability of the unit. Priorities are then defined to take corrective or preventive actions on the most critical units to improve the overall reliability of the fleet and reduce costs associated with the risk of unplanned outage.

Priorities are driven by technical considerations related to the condition of the units but also by the overall strategy of the company that owns the assets. Several asset management scenarios are therefore possible. An important criteria directly linked to the strategy of the asset owner is to minimize the life cycle cost of the assets or the total cost of ownership.

For the condition assessment to provide more value to the end-user, and to support decision makers in defining which scenario is financially more attractive for the asset owner, ABB developed an economical model in cooperation with large utilities. This evaluates lifecycle costs of a transformer fleet over a given period [3]. The model can also be applied to an individual transformer.

5 Software to evaluate costs and benefits of maintenance actions or renewal of transformers.



The model takes into account four categories of costs related to the cost of ownership over the lifetime:
- Investment costs
- Maintenance costs
- Operational costs
- Costs of failure risk

The lifecycle costs caculation uses the formula 4. The criteria used in such an economic analysis also indirectly consider the following:
- Safety
- Condition of the assets
- Age
- Operation condition
- Availability
- Maintainability
- Environmental
- Environmental legistation
- Risk (consequential costs at fault)

Comparative investment scenarios and sensitivity studies can be run by varying the replacement year or maintenance of the unit. For each scenario, the software computes the associated net present value.

An optimization routine can also be used to automatically minimize the life cycle costs of the population. The software outputs a list presenting the optimum time to provide maintaince or replace the individual transformers or transformers groups.

The method permits two levels of investigation. A first approach that principally benefits asset managers provides a general view of fleet maintenance costs and forecasts the capital expenditure for the requested time frame (for example, 2004 to 2034). The condition of each unit is integrated in a generic way based on statistical evaluations. The software uses curves published by CIGRE, presenting the reliability of transformers versus their age.

The second approach principally benefits maintenance managers. The software 5 calculates the net present value of the whole population of transformers depending on the specific condition of each unit and the specific maintenance actions selected to improve their condi-

tion [4]. The method is also applicable for a single transformer. This more detailed approach assumes that the user knows the mechanical, thermal and electrical condition of the transformer (which can be taken from an earlier condition assessment).

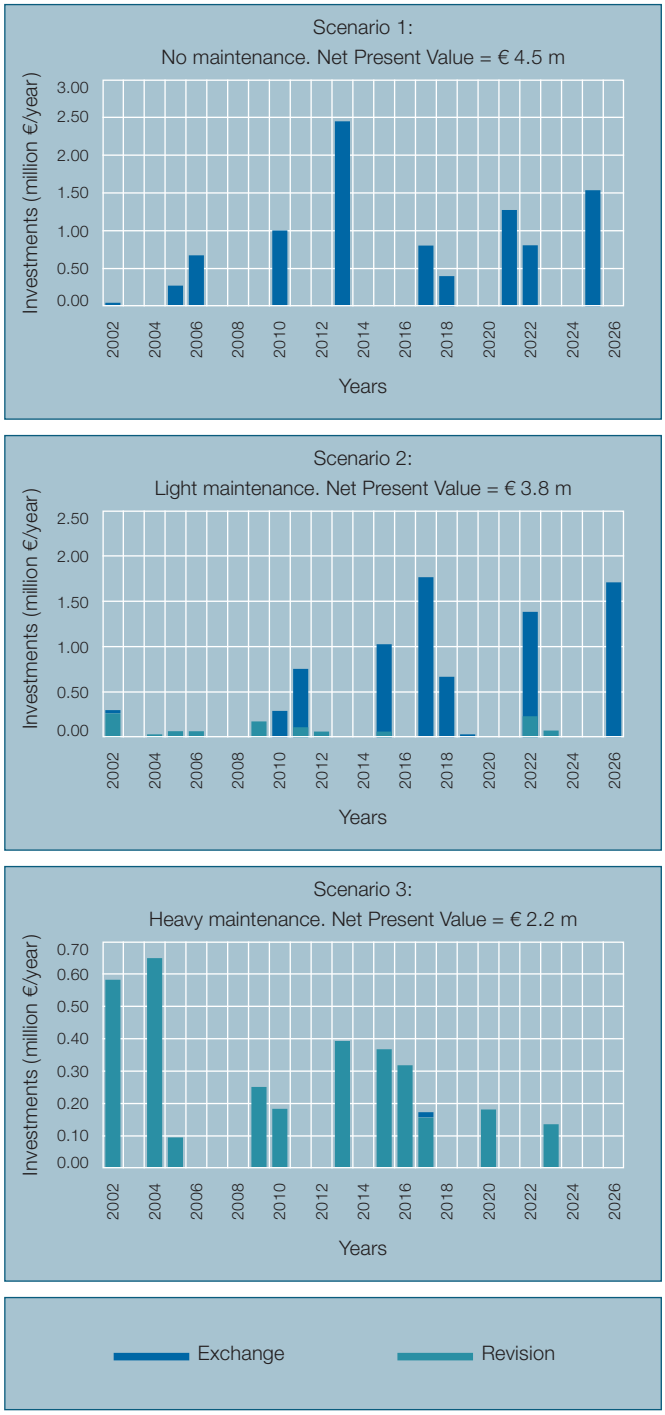
The maintenance manager can then evaluate different maintenance scenarios and obtain an evaluation of the payback of planned maintenance actions. The novel aspect of the method is that not only maintenance costs are considered but also economical benefits linked to the impacts of maintenance on the reliability.

To illustrate the benefit of such a survey, the results of a study made by ABB for a Swiss utility are presented. A condition assessment study and economical survey were made. The population studied is composed of 50 medium size (5 to 250 MVA, 50 to 240 kV) network and generator step-up transformers. The average age of the population is 29 years.

Three maintenance scenarios were considered:

1- No maintenance, except the very basic and mandatory actions such as fixing oil leakage or changing the air-drying compound.
2- Light maintenance: basic maintenance plus oil and gas analysis, oil filtering and drying, periodic on-load tap changer overhaul.
3- Heavy maintenance: mid life refurbishment – after 15 to 30 years in service (depending on the condition of the unit defined through the condition assessment survey). The transformer is untanked to permit work on the active part, complete check, electrical connections and winding block clamps tightened. If necessary, the oil is regenerated and the active part dried. Besides work on the transformer itself, bushings, tap changer and other accessories are checked and corrective actions taken.

6 Comparison of maintenance scenarios.



For each of these three scenarios, the optimization process was run to compare the costs of the individual strategies. The graphs 6 show the capital required per year for maintenance and replacement during 25 years of operation.

The present net value of the costs of operating, maintaining and renewing the fleet over a 25 years period varies from € 1.5 m to € 3 m depending on the scenario selected. In this specific case, refurbishing the transformers after 15 to 30 years (depending on their condition) is the soundest scenario economically.

Implementation of the maintenance action plan: Maintenance and repair technology

Depending on the condition assessment, the following corrective actions can be considered, evaluated and implemented:

- Refitting of gaskets, oil processing, oil regeneration, drying of active part to improve the general condition of the transformer and reduce the ageing process.
- Retightening connections of the active part, adding new shielding, cleaning the contacts of the off-load tap-changer to improve electrical performance.
- Reclamping the windings and the core, checking the cleats and lead structure to improve the mechanical condition of the unit.
- Overhauling the on-load tap-changer, maintaining the bushings, the cooling system, the fans, the pumps, the relays to increase the reliability of the accessories and thus of the transformer.

Besides the traditional maintenance and repair techniques in use, some new technologies adopted by ABB should be pointed out:

On-line oil regeneration [5] demonstrably has technical and economical advantages when applied to old transformers with aged acidic oil. The process is more environmentally friendly than oil replacement and shows a much better efficiency over a long time period.

On-site repair [6] using high voltage on-site testing capabilities [7] and a very efficient on-site drying method is an attractive approach to transformer repair in remote locations where transportation is difficult and costly. This approach has been used by ABB in several countries (especially in South America[1)]) on more than 100 transformers and shunt reactors. It is praised by end-users as a high quality solution and has already saved utilities and industrial users millions of dollars; reducing for example the lead-time to repair a transformer by two weeks, so saving 0,5 to 1 million US$ in lost production per day.

A low frequency heating system [8] is now also a proven solution for drying transformer active parts much faster without compromising quality. The remaining moisture content of the solid insulation is typically below one percent. The drying time can be less than half of that for a traditional hot oil and vacuum process. Lead time reduction when drying a wet transformer or repairing a failed unit on site presents significant owner benefits.

[1)] See also pp 59–62 of this issue of ABB Review Special Report

Last but not least, facing an increasing demand from end-users wishing to increase the power of their existing units, ABB proposes a concept for boosting existing transformers by rewinding the coils with Nomex® high temperature insulation material [9]. As a result, lifetime and reliability are significantly increased. Besides the cost advantage gains on the unit itself, side benefits worth consideration include: lower environmental impact than scrapping, no construction needed to prepare the site (the footprint remains identical) and the lower weight compared to a conventional unit.

Conclusion

The integrated and modular approach presented here supports the decision process of transformer owners in choosing between maintenance and replacement.

On a long term and strategic level, a significant benefit of such a study gives top management a clear picture of the maintenance and renewal investments required over the next twenty to thirty years to provide the required asset reliability and availability. It provides solid information to compare different asset management strategies and choose the approach that best supports the overall technical and financial strategy of the company. A program to extend the lifetime of aged units will, for example, postpone investments in new units and so improve the cash flow of the company.

In a medium term time perspective, assets managers obtain input on making best used of maintenance or replacement budgets. Funds can be allocated to units that show the best return on investment while reducing technical and environmental operation risks.

In the short term, the method allows the maintenance manager to quantify the benefits of each maintenance action and thereby optimize decisions considering technical and economical aspects.

The benefits of the integrated service portfolio developed by ABB for transformers aims to support transformer owners in optimizing their lifetime asset management strategy to minimize cost of ownership. New technologies developed to improve service quality and reduce asset downtime are made available through an impressive network of locally based service experts. State of the art tools, highly qualified experts and an efficient organization allow ABB to deliver services in more than 100 countries with an impressive responsiveness.

The portfolio can easily be combined with other service solutions from ABB to serve all kinds of power equipment.

Pierre Lorin
ABB Transformers
Geneva, Switzerland
pierre.lorin@ch.abb.com

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The ‘evergreen’ strategy

For power grid operators it pays to keep equipment and knowledge up to date

Marina Öhrn, Claes Rytoft, Tommy Carlsson

In the wake of the major power outages in North America and Europe, reliability is once again the watchword in the electric power industry. The utilities and other organizations charged with overseeing regional power grids are re-examining how they manage the components that make up their systems. Supervisory Control and Data Acquisition (SCADA), Energy Management (EMS) and Distribution Management Systems (DMS) are all of particular interest, especially from an ongoing maintenance standpoint. As a leading global provider of SCADA/EMS/DMS functionalities with its Network Manager™ system, ABB has developed a comprehensive service program aimed at maximizing the performance of these critical systems while reducing overall lifecycle costs.

The Brain of the Power Grid

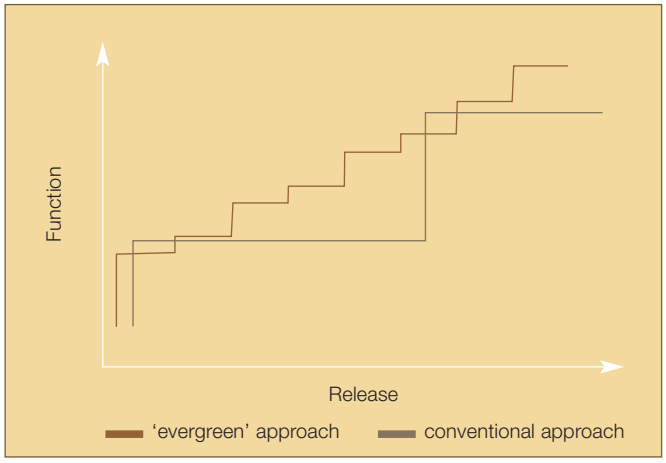
If the physical transmission system is akin to a body, then Network Manager™ is its brain and central nervous system. Its functionalities are embodied in highly complex monitoring and control systems with a variety of specific applications, all working to keep power flowing and to preserve the balance between generation and consumption. If a problem occurs here, it can affect the entire grid. This was illustrated by the August 14, 2003 outage in the U.S. and Canada, where one of the contributing factors to the blackout was the failure of an EMS component known as the state estimator. As reported by the New York Times, *"In the 65 minutes during which a sequence of power failures built up to a cascading blackout … the regional [grid managers] took no active steps to stop the progression, largely because they were unable to see the full extent of it."*

The implications of even minor malfunctions in these systems can be far-reaching. Fortunately, new computer technologies have done much to prevent such problems from occurring and to mitigate their effects when they do. However, this is a double-edged sword: As programs grow more complex, the high-tech systems that preserve the integrity of the grid also become increasingly susceptible to the vagaries of software. Not surprisingly, power system operators are placing a higher premium on service contracts than ever before. When it comes to performing 'brain surgery', it's best to have an expert nearby.

Service as a system component

Given the critical nature of SCADA/EMS/DMS systems, it's not surprising that ongoing maintenance agreements make up an integral part of the product as a whole. Indeed, in terms of importance, service agreements can be viewed as on par with the hardware and software they support.

1 The 'evergreen' approach to upgrading as compared to a more conventional method with fewer but larger changes.



Traditionally, however, these systems have been supported by a case-by-case approach to software maintenance. While the service agreement might cover call centers and similar user-support functions, the program itself would remain largely unchanged over the course of its life, save for bugfixes or other minor code changes required to keep it running according to the original specifications. If the customer wanted to add new functionality, he would most likely have to pay for it through costly change orders. In practice, this approach has led to a situation in which the gap between the needs of the customer and the capabilities of the system grows wider over time until it reaches a point where it becomes necessary to replace the system entirely.

In terms of importance, service agreements can be viewed as on par with the hardware and software they support.

Under the traditional service model, the focus is primarily on supporting the user. This is an important and necessary function, but neglects the ongoing maintenance of the product itself. Given the pace of technological advance, this can render a SCADA/EMS/DMS system outdated within a few years and obsolete after ten years. A wider 'maintenance' concept includes keeping pace with available technologies and matching system capabilities to meet customer needs.

The 'evergreen' approach

The alternative to serial change orders is to have software upgrades built into the maintenance agreement. This way, the customer pays a regular and predictable amount and in exchange is supported by an ongoing upgrade regimen. The vendor adds new functionality, streamlines processes and makes other enhancements to the software. The customer is assured the most up-to-date system.

1 compares the 'evergreen' approach to a more traditional method with larger but fewer steps. This is the essence of ABB's approach to service. The overarching objective with this so-called 'evergreen' model is to extend the life of the Network Manager system while preserving its value along the way. There are several specific benefits, most of which have direct economic implications for the system owner. The following sections describe these briefly and provide simplified breakdowns of the associated cost savings (the qualification of cost is specific to each power company).

Access to experts

This is probably what first comes to mind when one talks about support: system experts made available by the vendor either from the factory or on-site. Applying the expertise of these experienced individuals significantly reduces the time it takes to solve a given problem.

Assuming:
- 10 full time employees are working with the system (operators, engineers, service people, etc).
- The average cost of these employees is $100k per year.
- Having access to experts will save 15 days of work per year for the team.

The system operator can expect to save:
10 people × $100k/year ×
15/200 days/year = $75000/year

Guaranteed response time

Depending upon the parameters of a given maintenance contract, the vendor is committed to providing assistance within a given timeframe. The sooner a problem is addressed, the less downtime the customer experiences and the less it will cost. The large savings potential lies in keeping the supply lines open, which in turn keeps revenue flowing. However, additional savings are also readily available:

Assuming:
- The system operator can save 72 hours/year in downtime under the given maintenance scheme.
- The given system has a value of $3 million.

The system operator can expect to save:
72 hours/year × $3 m /
8760 hours/year = $25000/year

Preventive maintenance extends system life

This is perhaps the most straightforward example of the benefits of a good maintenance program, and indeed is representative of ABB's overall approach to service. Smaller investments in maintenance over the life of the system will not only extend the life expectancy of that system but also avoid larger, unplanned expenditures along the way. 1 and 2 show the value of this approach. For this example, we will focus on the value of extending system lifespan.

Assuming:
- A new system would require an investment of $5 million.
- 6% interest rate.
- Preventive maintenance will delay the need for a new system by 3 years.
- The old system is depreciated.

The system operator can expect to save:
$5m × 6% × 3 years = $900000 over three years or $300000/year

Evergreen service model retains system value

The examples above do not consider the option of maintaining the current system under a true evergreen agreement, in which upgrades keep the current system functionally competitive with a replacement system. Viewed from this perspective, additional savings can be realized.

Assuming:
- A new system would require an investment of $5 million.
- That new system would be paid off over the course of 5 years.
- The old system is fully depreciated.

The system operator can expect to save:
$5m in new system cost / 5 years =
$1m / year

Functional additions at lower cost

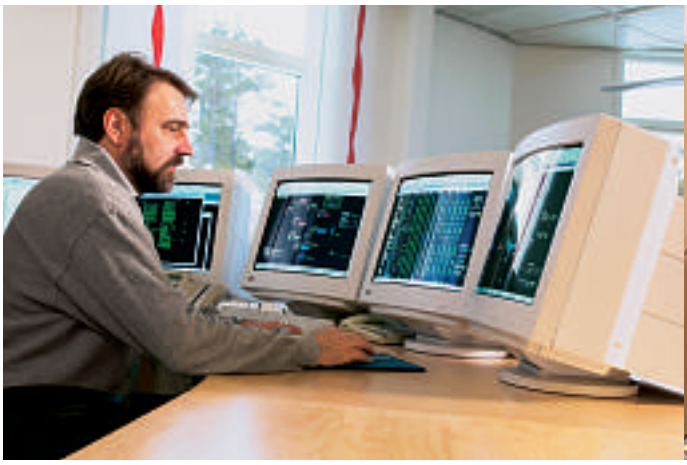
Any SCADA/EMS/DMS system, no matter how state-of-the-art at the time of installation, is bound to require additional functionality over the course of its life. As noted earlier, the costs of making these upgrades under a change order regime can be very costly. See 3.

Assuming:
- 3% of the System Value ($5m) will be added as New Functions every year.
- The cost for implementation will increase by 20% per year for an old system after one year.

The system operator can expect to save:
3% × $5m × 20% x (3–1) years =
$60000 in year three

Additional benefits of 'evergreen' service

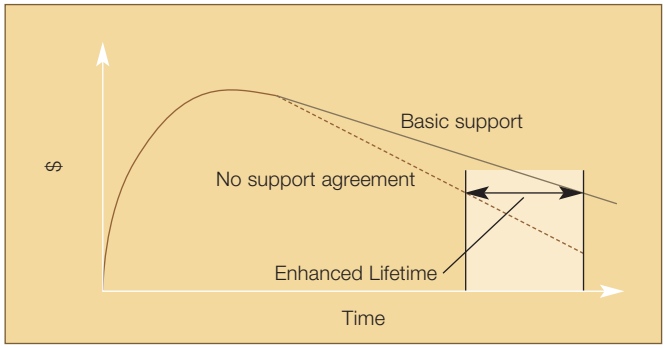
Employee turnover and training costs are well documented. Having a functionally up-to-date system in place can reduce these costs by reducing the rate of turnover thereby maintaining system experience. There are also less quantifiable benefits to retaining quality employees. Their experience, built up over years of working with the system, can be the difference between finding a problem in its early stages and discovering it when it already is causing a serious system disturbance.



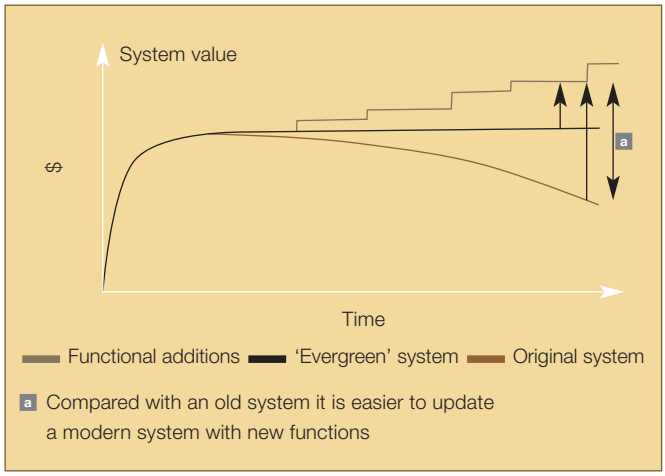
Avoiding manual operation, another advantage of the 'evergreen' approach, is desirable for several reasons. The cost of human intervention to otherwise automated processes cannot be overstated. In addition to the immediate cost of re-allocating resources, the organization must also incur the opportunity cost of what those individuals are not working on while they are dealing with the crisis at hand. Lack of experience in dealing with emergency situations is one significant example of the impact manual operation can have. This deficiency is mitigated to some extent by training using simulated events.

Another advantage associated with the application of an 'evergreen' service model to SCADA/EMS/DMS systems is the flexibility to handle change, which is designed into more modern systems. This is of particular importance as more of the world's energy markets undergo restructuring, placing greater demands on grid operators to keep pace with the impact of shifting power market economics. Utilities that apply the most advanced technology will be better positioned to adapt to operational changes brought on by changes in market structures.

2 Basic support enhances system lifetime.



3 Cost-comparison of functional additions under different maintenance schemes.



> The flexibility to handle change is of particular importance as more of the world's energy markets undergo restructuring.

Finally, developing an ongoing relationship with a vendor allows the operator to influence the future development of the software. Through user groups and interactions with the vendor's staff, they can provide useful input as the next generation of the system is planned and developed. They can also gain valuable insights by sharing their experiences with fellow users. ABB has worked hard to foster the growth of a vibrant user community, and its user group meetings are an important source of information for the company and customers alike.

ABB's 'evergreen' experience

Launched two years ago, ABB's 'evergreen' service model for Network Manager has been adopted by major utilities around the world. In Europe, where the concept was first introduced, many of ABB's customers have signed on to the service including:

- BKK (Norway)
- Elkraft System (Denmark)
- Interelectra (Belgium)
- Göteborg Energi (Sweden)
- Gävle Energi (Sweden)

More recently, Network Manager customers in other locations have seen the value in having an ongoing upgrade program and have signed evergreen maintenance contracts. CFE, the Mexican national grid operator is one example. ABB implemented the world's largest multi-tier SCADA/EMS system for them in 1999. Last year the company signed a four-year service contract to ensure the system remains state-of-the-art.

The economics of the evergreen service model are hard to refute, as evidenced by the experience of the system operators who have applied it. As the reliability imperative takes on an even higher profile, this approach is well suited to support grid operators around the world.

Marina Öhrn
ABB Utilities
Mannheim, Germany
marina.ohrm@de.abb.com

Claes Rytoft
ABB Power Technologies
Zürich, Switzerland
claes.rytoft@ch.abb.com

Tommy Carlsson
ABB Network Management
Västerås, Sweden
tommy.p.carlsson@se.abb.com

Call Doctor Switchgear!

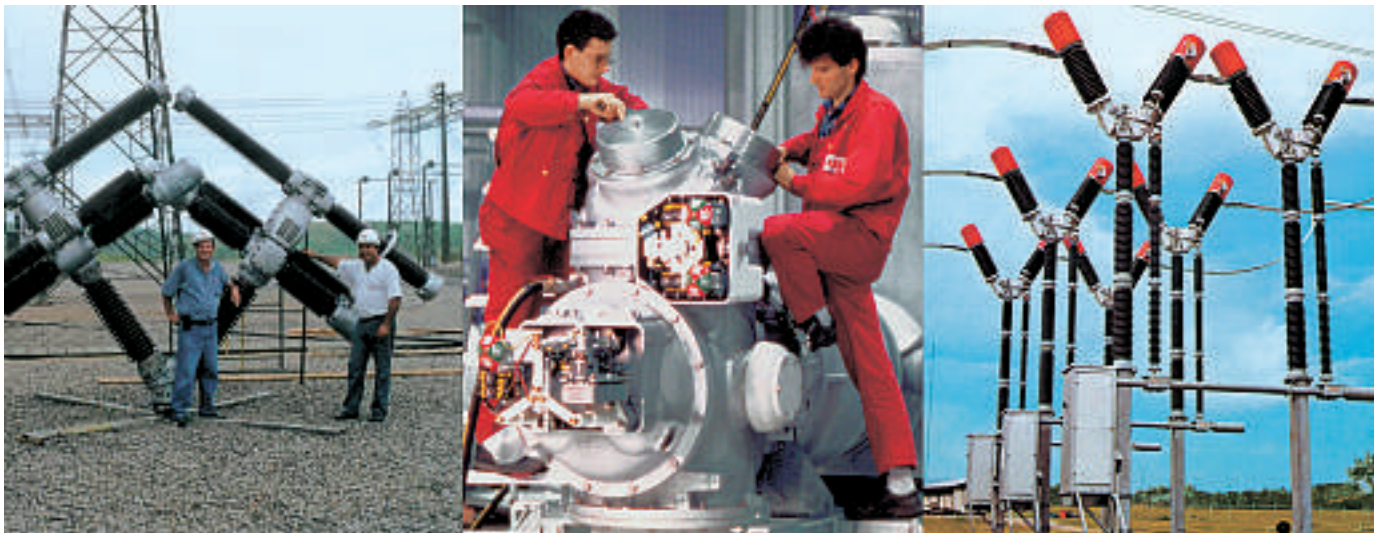
Lifecycle health care of high voltage installations assures that your power system will ‘keep on running’ without unwanted interruptions or sudden re-investments.

Carl Öhlen

Any equipment, once installed, will age and ultimately reach obsolescence – but its remaining useful life does not only depend only on its age. It also depends on factors such as usage, maintenance and economical considerations. ABB has access to a vast pool of knowledge on current and legacy switchgear and is supporting this with expertize, spare parts and upgrading solutions.

Doctor Switchgear personifies this unique resource and competence base. ABB´s switchgear ‘healthcare’ package supports equipment throughout its lifetime – and makes sure it operates at the reliability the customer expects, from the first day to the last.

Retrofit and refurbishment can further protect the customer’s investment by extending the equipment’s life expectancy and adapting old installations to meet modern standards. Equally important is knowing how, when and where to intervene. ABB offers fleet and lifecycle analysis and proposes appropriate and cost effective measures.



ABB's product and system heritage is unmatched in the industry and draws on more than 100 years of experience in the field of high voltage and high current technology. The company has actively participated in and contributed to some of the major breakthroughs in high voltage technology such as HVAC and HVDC. It delivered high voltage equipment to the first 400 kV system, the first 765 kV system and the first HVDC system in the world. The company's first Gas Insulated Switchgear (GIS) was delivered in the 1960's. Today this range includes installations of up to 800 kV. ABB is also the absolute dominating supplier of high current systems for generators.

This historical journey has given ABB an unsurpassed expertise as well as an impressive number of installed high voltage products. Air Insulated Switchgear (AIS) for 72–800 kV including circuit breakers, instrument transformers and surge arresters are in operation in more than 100 countries around the world. Some of these installations are still fully functional after run-times of more than 40 years 1. GIS, equally spread around the globe, covers the range of 72–800 kV and is a more modern technology – although some early installations are already 30–40 old. One important issue in managing AIS and GIS high voltage products is identifying the right time to hand over to the new generation.

The answer depends on many aspects such as the original design, the operating and environmental conditions and the importance of the installation. However, it also depends on service performed from the original commissioning, on regular maintenance and life extending retrofits. ABB continues to feel responsibility for equipment in the field long after delivery. Naturally, rapid support is provided in emergencies, but the company sees its task also in a broader perspective – to develop service strategies to prevent problems occurring in the first place.

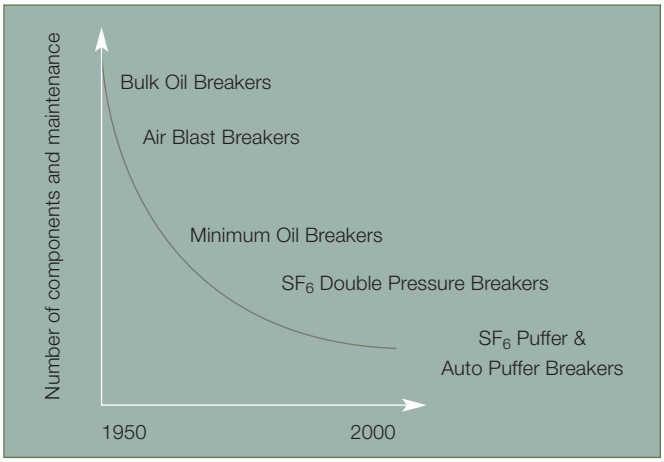
Reliability concerns both the performance of the specific function as well as the ability to withstand stresses without failing.

■ ABB is committed to providing first class service throughout the product life cycle – for new as well as legacy products of older brands (ASEA, BBC, ITE, Westinghouse etc.).

■ ABB acts fast, simply and professionally using global and local ABB expertise from service centres and factories whenever and wherever required.

■ ABB's goal is to provide complete product & service packages ensuring customer satisfaction throughout the life cycle of the equipment and to initiate retrofit, replacement or renewal when needed.

1 Development of breaker technology.



Our common goal: Reliability

Switchgear reliability is an essential component of system reliability and continuous energy supply. Reliability concerns both the performance of the specific function as well as the ability to withstand stresses without failing. Instrument transformers must accurately measure voltage and current. Circuit breakers have to open and close as required. Surge arresters have to protect high voltage equipment against voltage transients. *Reliability equals high quality products plus high quality service.*

2 Life Cycle Service.

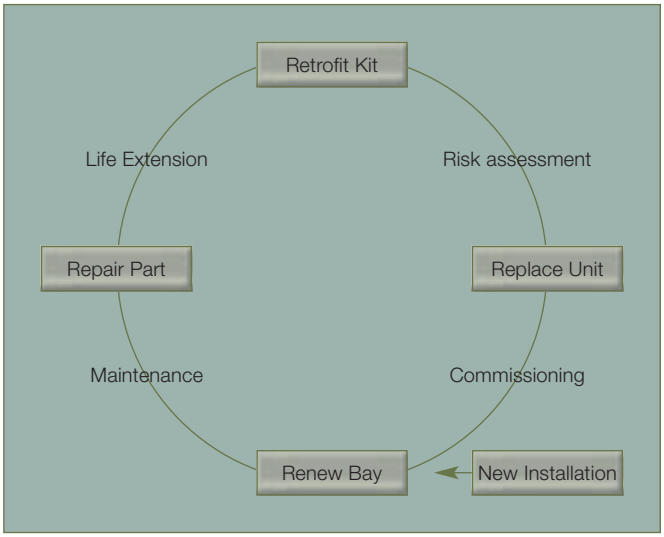


ABB designs and manufactures high voltage products in state-of-the-art factories, which all apply the same global design and modular concept to allow easy configuration of products to meet individual requirements. On-line monitoring of several applications minimizes maintenance cost.

However, the performance and reliability of an installation also depends on how it is installed, operated and maintained.

The unavailability (down time) of an installation depends on four main factors:

MTBF = Mean Time Between Failure
MTTR = Mean Time To Repair
MTBM = Mean Time Between Maintenance
MTTM = Mean Time To Maintain

Unavailability = MTTR/MTBF + MTTM/MTBM

Reliability centered design and maintenance of high voltage products is focused on minimizing downtime and disruption of the power system. The modular design strategy, with fewer but higher quality components, stringent testing and state-of-the-art manufacturing guarantees maximum quality at delivery. Furthermore, technical assistance and commissioning from certified field service engineers is assuring correct installation.

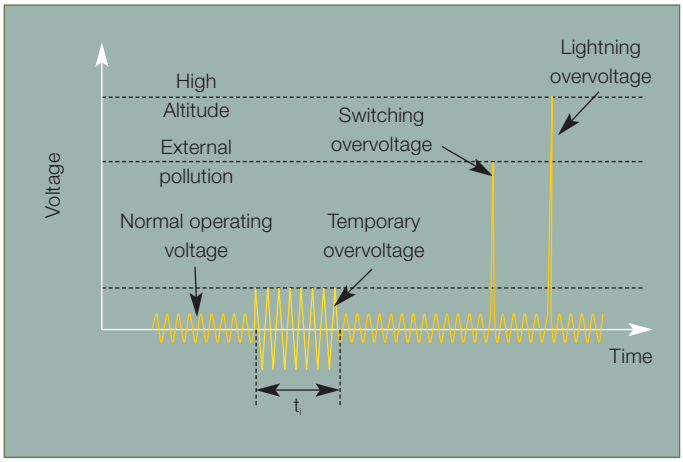
Call Doctor Switchgear!

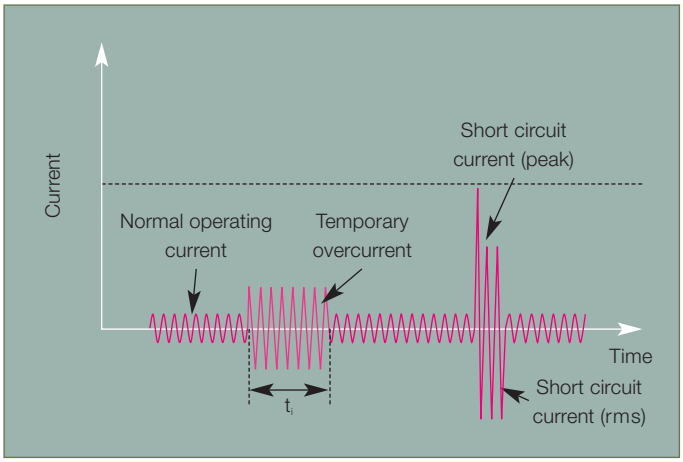
ABB high voltage equipment is known for quality and low failure rates. When a fault does occur, however, MTTR is minimized through fast response and spare parts delivery through ABB's service centers. Stocking strategic spares combined with some product training reduces the MTTR even further.

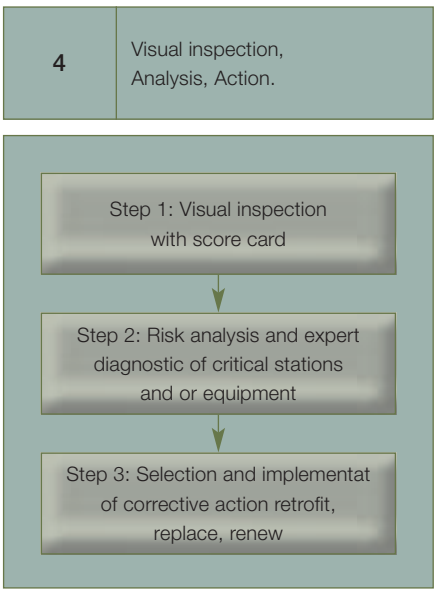
New products are designed to minimize maintenance, and if recommended procedures are followed, overall down-time is minimized. Condition monitoring for condition-based maintenance is also available.

Many utilities are outsourcing their maintenance and service. *Doctor Switchgear* is ABB's name for its unique resource and competence in high voltage technololgy. *Doctor Switchgear* is personalized by a senior expert who will work with the customer in the field

3 Current and voltage stresses.







and has all the back-up needed from global service centers. ABB can provide customized life cycle service 2 for every installation from day one. This can be tied with extended warranty for the equipment and can be seen as 'health insurance' with the advantages listed below.

The well-know bathtub curve shows that the majority of equipment failures occur during the initial phase of operation and at the end of its lifetime. High voltage equipment will, like everything else, age and finally become obsolete. Individual electrical 3, mechanical and environmental stresses cause installations of the same type to age differently. Shifts in system parameters such as short circuit current also affect equipment lifetime.

ABB can assist customers with an assessment 4 of installed equipment and recommend actions for retrofit, replacement/refurbishment or renewal of the complete installation. A first assessment is based on a scorecard using predefined inspection criteria. From this a risk assessment is made which identifies installations to be investigated further. The total risk derives from reviewing all possible events and combining the probability of every event occurring with its associated consequence. ABB's *Doctor Switchgear* can assist with the more detailed 'health check' and propose service measures in a three step process:

Level 1 Fleet screening: Inspection and measurement conducted on live equipment in order to screen the complete installed fleet or selected installations based on age and importance.

Level 2 Condition assessment: After risk analysis, the focus narrows to an identified problem area, which has to be disconnected for an in-depth inspection.

Level 3 Implementation: After selecting the suitable strategy (retrofit, replacement or renewal), the switchgear is disconnected and the work performed.

Life Cycle Service

A Life Cycle Service approach 2 offers a reliable, fast and simple way to safeguard the performance of high voltage assets. Different aspects of this service are:

Repair: Worldwide around the clock emergency response through a combination of service centers and localized customer support, which also provide emergency spare parts for rapid repair for a large range of products.

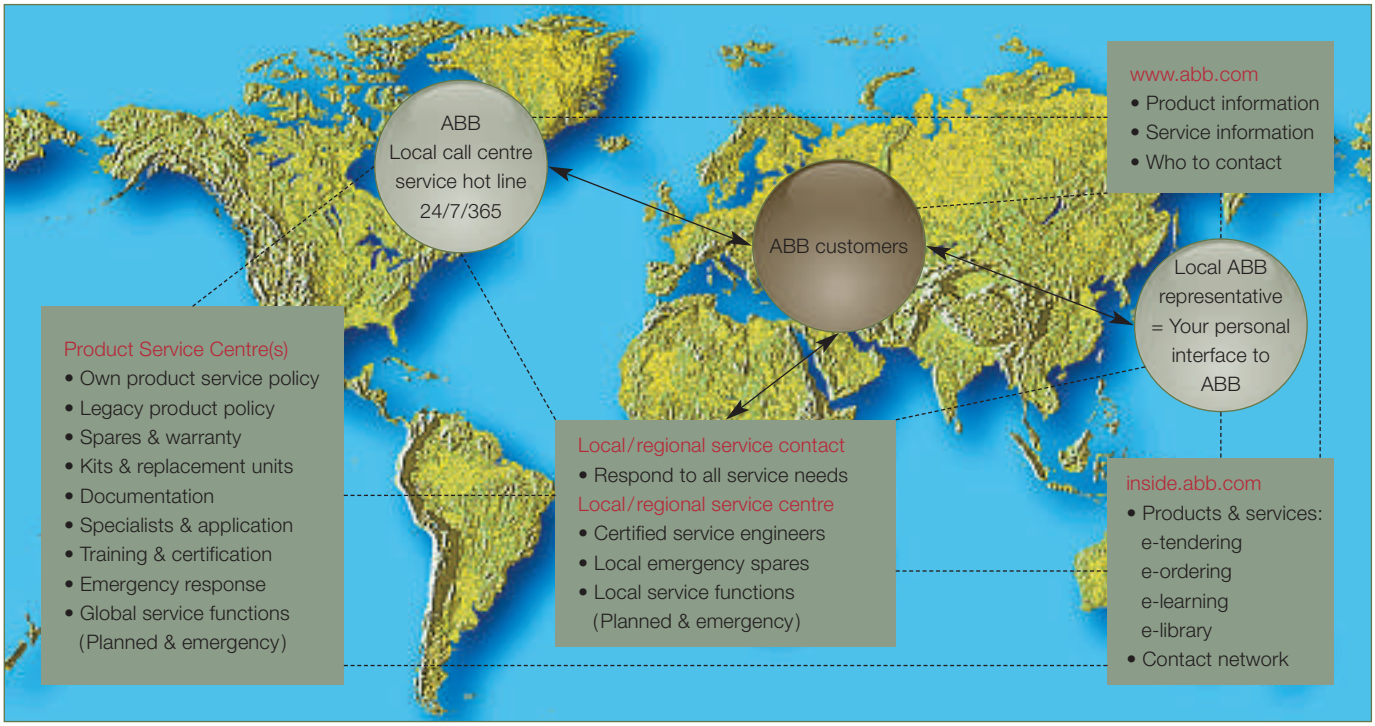
Retrofit: Life extension kits consisting of new parts, which may involve upgrading to restore and uprating to exceed original parameters.

Customer advantages of life cycle service on equipment:

- Complete installation and commissioning
- Periodical check up with report
- Hot line with help desk functions, 24 hours a day, every day of the year.
- Around the clock on-site service with express trouble shooting and replacement parts.

Not only is the current and past ABB product line fully supported, but ABB has the design information, expertise and technical records from manufacturers such as the old ASEA, Brown Boveri, Calor Emag, Gould, ITE, and Westinghouse. Millions of documents, drawings and instructions are stored in files reaching hundreds of meters in protected areas. With these records, ABB can assist in selecting the best remedy. ABB provides OEM (original equipment manufacturer) spare parts and life extending retrofit kits.

5 Your ABB service network.



Replace: Complete refurbishment service including remanufacturing or replacement, removal and scrapping of the old unit and installation of the new unit in the old location.

Renew: Rethinking the layout with a new solution for the complete switchgear bay using state of the art technology engineered to fit into the same or smaller space.

GIS has proven to have a high reliability with minimal maintenance as no parts are exposed. Conventional disconnectors have, for decades, been used in air-insulated switchgear to isolate breakers for maintenance. But these disconnectors have also turned out to be a source of failures and require substantial maintenance. ABB offers a replacement without exposed disconnectors based either on live tank breaker technology (combined disconnection circuit breaker) or dead tank breaker technology. (PASS multifunction hybrid switchgear). These solutions require a significant smaller area and can normally be installed in existing substations.

> The primary goal of maintenance is to prevent failures and preempt degradation as quickly and safely as possible and at the lowest feasible cost.

Knowing exactly *what* to do

The first important step towards a reliable network is selecting the right equipment for the right application. ABB offers support through application guides and expertise. The next step is to have the equipment correctly installed and commissioned. Many deregulated utilities have been downsizing and are therefore outsourcing this competence area. ABB provides instruction manuals and training but can also tailor different *Made by ABB* services to match the need of the customer. Service operations based throughout the world 5 can help with the commissioning tests or take a turnkey responsibility, including the disposal of the old equipment, or any variation of these.

Installation: An ABB field service engineer is present during the installation to ensure that this is done correctly.

Commissioning: An ABB field service engineer is on-site for equipment commissioning tests.

Turnkey installation: ABB is responsible for the installation of the equipment through the commissioning test.

Turnkey Replacement: ABB is responsible for the removal and recycling of the old equipment and installation of the new through the commissioning test.

Knowing exactly *when* to intervene

The primary goal of maintenance is to prevent failures and preempt degrada-

tion as quickly and safely as possible and at the lowest feasible cost. The main objective of maintenance programs is to optimize the functionality of the switchgear. Maintenance programs generally need to be planned on a customer-specific basis. There are basically three different maintenance principles:

- Time based maintenance (TBM)
- Condition based maintenance (CBM)
- Reliability centered maintenance (RCM)

Maintenance procedures for ABB high voltage equipment are recommended in the product manual.
For equipment in continuous operation but available for planned periods TBM is suitable, but not necessarily always: a breaker used for capacitor or reactor switching is operated frequently and soon reaches thousands of cycles. Other breakers may only operate once or twice per year. Condition based maintenance consequently provides better judgment for what is needed and when.

With reliability centered maintenance, the consequences of a failure are additionally evaluated. RCM is the right amount of maintenance for the right equipment at the right time. Unfortunately RCM sometimes is reduced to a fourth principle: No maintenance. This is the least desirable option and leads to costly disturbances in the long run.

Knowing exactly *where* to focus

Knowledge and experience are required to define an infrastructure investment strategy that sustainably operates at required performance levels while minimizing costs. Such an asset management strategy includes:

- Ensuring high reliability and availability to avoid loss of revenue.
- Extending the lifetime of existing installations to avoid large investments.
- Optimizing performance to increase revenue.

Some issues must be assessed during the ageing process of high voltage infrastructure: Is spare parts availability guaranteed? Is safety endangered? Are investment budgets limited? Must outage rates be minimized? Are maintenance activities too costly? Have the system ratings changed? Are there ecological issues to be addressed? Have standards changed?

ABB has the most comprehensive expertise in the industry based on over 100 years of experience. This knowledge and experience is available to customers through its service network.

The complete design of the installation must also be assessed to review possible upgrading or uprating measures. The goal is to optimize the technological, safety-relevant, economical, and ecological aspects.

Knowing exactly *how* to stay young

ABB designs and delivers high voltage products for almost every application anywhere in the world. Its equipment is tested for the

most stringent conditions and standards. High voltage switchgear operates in extremely cold climates, tropical heat, dusty deserts, seismic regions, ocean-fronts, crowded cities and polluted industrial areas. Switchgear is designed for generator-, transformer-, reactor-, capacitor-, filter-, cable- and line switching, measuring and protection. Solutions for HVDC and HVAC up to 800 kV are in service. ABB has the most comprehensive expertise in the industry based on over 100 years of experience. This knowledge and experience is available to customers through its service network.
Selection: The first important step is to select the right product for the application. ABB provides application and selection guides as well as application expertise.

Configuration: ABB high voltage products can be configured to meet specific requirements. The customized design is stored in the ABB e-business system and ensures speed, simplicity and quality for each order.

Operation: Operating and maintenance procedures are recommended in product manuals and service training courses. But the depreciation of equipment depends on operating and environmental conditions. Here, ABB advises different solutions from point-on-wave switching to integrated switchgear modules.

Assessment: ABB assists with the screening of high voltage equipment based on a defined risk policy and scorecard 4 as well as proposals for life extension, migration and replacement with new technology. This may include testing of switchgear using state-of-the-art equipment for travel curves, finger printing, dynamic resistance measurement, infrared measurement, gas and oil sampling etc. On-line condition monitoring equipment is also offered. ABB can additionally provide complete asset management studies.

Knowing exactly *which* part to use

The policy of ABB is to maintain an inventory of emergency spare parts for immediate shipment. Not only is the current and past ABB product line fully supported, but ABB has the design information, expertise and technical records from manufacturers such as the old ASEA, Brown Boveri, Calor Emag, Gould, ITE, and Westinghouse. Millions of documents, drawings and instructions are stored in files reaching hundreds of meters in protected areas. With these records, ABB can assist in selecting the best remedy. ABB provides OEM (original equipment manufacturer) spare parts and life extending retrofit kits fitting the original design. ABB can manufacture replacement products at short notice or pull them from existing production in order assist customers quichly when a serious failure has occurred.

Knowing exactly *who* will do the job

Field commissioning, overhaul & repair work is performed through ABB service centers with certified personnel. ABB is furthermore committed to premier training solutions for the high voltage equipment industry. A variety of training packages are available for customers. These packages range from courses conducted on a specific breaker in the factory to specific job or general training at the customer's site. Standard courses typically cover general theory, application, assembly, installation, commissioning, operation, testing, maintenance and troubleshooting.

Knowing exactly *whom* to contact

ABB provides a contact network for customers providing quick, simple and reliable service. Customers reach the high voltage and dedicated service contacts through the 'contact us' pull down menu of the *www.abb.com* page.

ABB service centers have access to an internal around the clock service hotline supporting all products. ABB representatives can access tendering and ordering tools and confirm availability and inventory.

Knowing exactly why to do business with ABB

ABB is the largest manufacturer of high voltage products today and has been for more than 100 years. ABB has a broad expertise but also a considerable responsibility for the impressivels boad base of installed products.

The ABB service offering includes:

- *Installation services* from commissioning to turn-key delivery as well as de-commissioning and turn-key replacement and re-cycling of obsolete equipment.
- *Corrective services* utilizing ABB's unique spare part inventory for new and legacy products and our world wide service network to support our customers around the clock.
- *Preventive services* are recommended in product manuals. Maintenance and overhaul periods depend on a combination of operating duty, system & environmental conditions and age. ABB recommends that overhaul is carried out by its licensed service expertise and using original parts to ensure best performance
- *Value added services* includes ABB's 'Doctor Switchgear' assessment and advice on how best to modernize are switchgear to fit customer needs. Retrofit and upgrading kits for life extension, one to one replacement of critical parts or complete renewal of the switchgear.

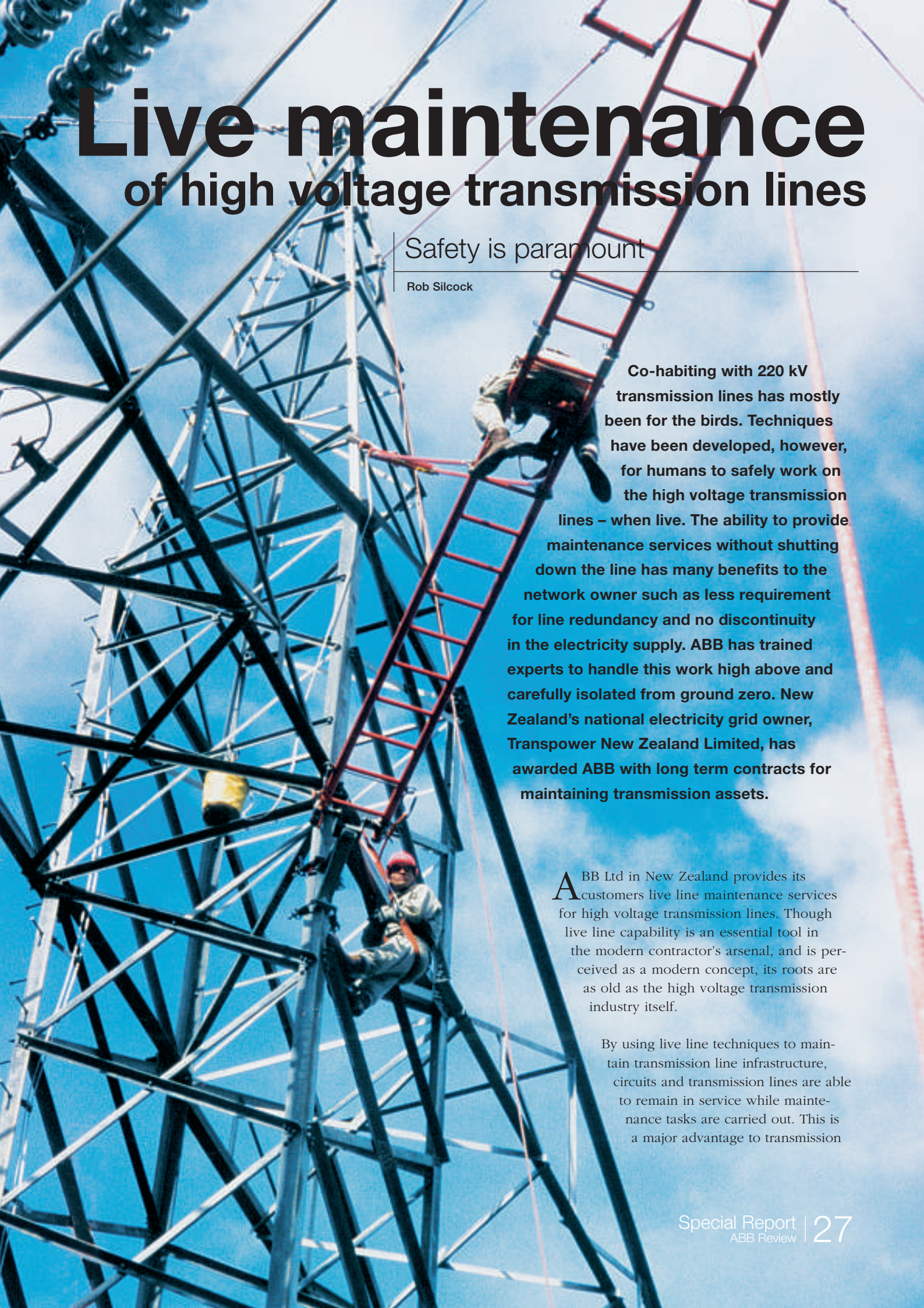
ABB's goal is to ensure satisfied customers throughout the product life cycle of the installation and initiate retrofit, replacement or complete renewal when needed. We will act fast, simply and professionally utilizing the global and local ABB expertise wherever and whenever required.

Carl Öhlen
ABB High Voltage Products
Switzerland
carl.ohlen@ch.abb.com

Live maintenance
of high voltage transmission lines

Safety is paramount

Rob Silcock



Co-habiting with 220 kV transmission lines has mostly been for the birds. Techniques have been developed, however, for humans to safely work on the high voltage transmission lines – when live. The ability to provide maintenance services without shutting down the line has many benefits to the network owner such as less requirement for line redundancy and no discontinuity in the electricity supply. ABB has trained experts to handle this work high above and carefully isolated from ground zero. New Zealand's national electricity grid owner, Transpower New Zealand Limited, has awarded ABB with long term contracts for maintaining transmission assets.

ABB Ltd in New Zealand provides its customers live line maintenance services for high voltage transmission lines. Though live line capability is an essential tool in the modern contractor's arsenal, and is perceived as a modern concept, its roots are as old as the high voltage transmission industry itself.

By using live line techniques to maintain transmission line infrastructure, circuits and transmission lines are able to remain in service while maintenance tasks are carried out. This is a major advantage to transmission

asset owners because less redundancy is needed in the transmission network. Electricity consumers who are supplied by spur lines (single circuit supplies typically in rural areas) also benefit from live line work. They do not suffer the inconvenience of a cut in their electricity supply every time maintenance is carried out on their supply lines. Given the high cost of transmission lines and the impact that transmission lines have on the environment, there is a major advantage in being able to avoid duplication of assets purely for maintenance purposes.

History of live line maintenance in New Zealand

New Zealand's national electricity grid owner, Transpower New Zealand Limited, has been carrying out live line transmission line maintenance since 1989. At that time a major insulation replacement program was undertaken on the inter-island HVDC link from Benmore power station in the South Island to Hayward's sub-station in the North Island. Because the inter-island transmission link is such a critical component of the New Zealand electricity grid, the de-energized alternative to live line maintenance for this project was untenable – the circuits would have been required to be out of service for between two and three months to complete the work.

Since then, live line maintenance has become commonplace on the New Zealand Electricity Grid as it is around the world. Almost all line maintenance tasks can be undertaken with the circuits in service. In the 1920's and 1930's, live line work was carried out in New Zealand on the on the 110kV transmission lines from the newly commissioned Mangahao and Arapuni hydro power stations. As the electricity network was expanded, with duplicated circuits common, outages for maintenance purposes became readily possible, and live line maintenance was discontinued in New Zealand until the late 1980's.

Basic methods of live line maintenance

There are two basic live line methodologies for high voltage work, which in industry terminology are called 'hot-stick' and 'bare-hand' methods.

Using hot-stick methods, direct human contact with live components is avoided. Line workers use tools fastened to insulated fiberglass poles to carry out the work, and always keep themselves at a safe distance from the live components.

In contrast, when using bare-hand methods the line worker is positioned in direct contact with the live components, and is livened or raised to the electrical potential of the conductor being worked on. For transmission voltages in New Zealand, this is 110,000 volts (110kV) and 220,000 volts (220kV). This may sound chilling, but for well-trained live line mechanics it is all in a day's work – much like the birds that land on power wires all the time and survive.

The same principal applies to bare-hand live line workers. The complex part of the job is getting the line mechanic on to and off the wires safely. Though this sounds simple in theory, in practice live line work is potentially very hazardous, and must be undertaken in a very methodical manner with highly trained workers in a carefully planned and controlled work environment.

When accessing live conductors for bare-hand work, it is critical that the live line mechanic does not at any time bridge the gap between the live conductor and any earthed object (including the tower or pole that supports the conductor). There are several ways of achieving this. One way is to raise the live line mechanic from the ground or a part of the tower below the working position using live-line (insulating) rope. Using this method, the live line rope is run from the ground, up to a pulley block on the tower, and back down to the worker, where it is attached to the worker's body harness. The worker is then raised by pulling the rope up using an electric capstan (winch). The live line rope can contact the live high voltage conductors without risk to workers operating the winch or working on the tower. To ensure that all

parts of a bare-hand worker are raised to the same potential as the live conductor he/she is in contact with, the worker wears a special conductive suit complete with hood and conductive socks.

When he/she gets into position adjacent to the live conductor, a solid electrical connection is made to the live conductor using a conducting 'wand' to bond to the conductor. It is not unusual to raise an electrical arc between the wand and the conductors when first making contact.

Safety and process

To ensure the safety of workers involved in live line work, a rigorous set of rules and guidelines have been developed, and made mandatory in New Zealand under the Electricity Act 1992 in the form of the New Zealand Electrical Code of Practice for High Voltage Live Line Work. The code of practice has been developed with inputs from all areas of the industry, including employers, industrial unions, asset owners and professional interest groups. In New Zealand, Transpower New Zealand Limited also sets specific requirements for contractors to meet before granting them approval to undertake live line work on the national electricity grid. Both the Code of Practice and the Transpower Standard require contractors to have comprehensive management systems to control all aspects of live line work, including tool management, training of staff, weather conditions and their impact on the work, and the development and approval of work procedures. All work tasks must have a fully documented work procedure that has been trialed and proven before being approved for use on live assets.

ABB New Zealand live line work

ABB Limited was first awarded transmission line maintenance contracts in New Zealand by Transpower in 2000. This was a three-year term contract commencing in July 2000 for the provision of transmission line maintenance services for the West cost of the South Island. The contracts include maintenance activities on transmission lines, condition monitoring, undertaking routine maintenance and providing a fault response service and managing and undertaking vegetation control adjacent to transmission lines. Commencing in July 2003, ABB was given the opportunity by Transpower to enter into a five plus five-year maintenance contract covering the same area, with expansion to include the northern part of the South Island.

Transpower's transmission line network covered by ABB's current line maintenance contract includes more than 1000 km of transmission lines, comprising approximately 3,110 pole structures and over 1,240 steel towers. The lines are of 66kV, 110kV and 220kV design. Wood pole structures are the most maintenance intensive types of transmission line and the high number of wood poles in ABB's region ensures many complex live line challenges for the ABB teams.

The type of work routinely undertaken by ABB using live line techniques includes; replacement of complete pole structures, replacement of individual poles on two pole structures, replacement of cross-arms, replacement of insulation only (carried out on tower and pole lines), and enhancement works such as installation of vibration dampers onto live conductors.

The training and work experience requirements for budding live-line mechanics is rigorous. New Zealand Codes of practice require a worker to have documentary evidence of two years of general line work experience after certification as a line mechanic, before being accepted as a trainee for live line work. A certified trainer must give training in live line work methods, and only a certified trainer can confirm competence. Competency certificates with a twelve-month validity period are issued to workers who meet the training and work experience criteria and have passed the competency evaluation. These must be re-issued annually after refresher training and evaluation of fieldwork. It costs an employer about $18,000 to $20,000 in training before a line mechanic is able to be certified as a live line mechanic. That money is well invested!

Rob Silcock
ABB Ltd.
New Zealand
rob.silcock@nz.abb.com

New life for old switchgear

Medium voltage switchgear modernization – an alternate choice for customers

Stephen Pearce

The pace of technology makes today's cutting edge seem old hat tomorrow, but age need not equate to obsolescence. Modernization can protect the customer's investment by extending the equipment lifespan while raising safety, reliability and performance standards.

In ABB's refurbishment and retrofitting options for medium voltage switchgear, equipment is returned to as-new condition. The integration of advanced sensors, protection and control gear improves reliability and safety. The shorter downtime as compared to total replacement ensures a better protection of productivity.

Whether the switchgear customer opts for modernization or replacement is often a question of economics, with modernization offering advantages in many cases. Questions the customer must consider include: Is it meaningful to install state of the art switchgear in a plant with reduced life expectancy? How much downtime can be justified? Does the overall budget allow for major investment?

In today's competitive business environment, companies constantly focus on asset optimisation through cost reduction, and increasing safety, reliability and utilisation. In utilities and industrial plants, operators of electrical distribution networks face the challenge of achieving optimised utilization of their facilities: They must balance investment in new equipment against maintenance costs, safety and down time. Performance of medium voltage switchgear within the network is a main factor influencing overall reliability of the system, and consequently it is a key element for optimization.

A traditional equipment management strategy followed by plant operators, was to replace switchgear when it had reached the end of its economic lifecycle. This choice provided maximum equipment lifespan and the latest technology and safety features on replacement, but usually implied high economic investment. Such a replacement strategy does not necessarily fit with the overall needs of a plant:

- The life expectancy of the plant as a whole may not match that of the new switchgear.
- The downtime of the plant to enable replacement of the switchgear may not fit with operational and production commitments.
- The timing of the switchgear replacement may not match the capital expenditure plans of the business.
- Such a strategy does not necessarily represent the optimal life cycle costs.

Accordingly, medium voltage switchgear manufacturers have developed a number of alternative solutions to help customers find the best safety and life cycle management option for their equipment. Having more choices, each with different advantages and costs, enables customers to select the specific solution that best fits the overall business strategy of the plant. Alternative choices for customers include:

- Refurbishment: The existing switchgear is fully overhauled and restored to an as new condition.
- Retrofit: One or more main elements of the switchgear are replaced with modern equivalents. Elements with the highest maintenance cost and failure risk can be targeted specifically.
- A combination of the above.

1 Circuit breaker refurbishment at the ABB Product Support Center in Florence, USA.

> Performance of medium voltage switchgear within the network is a main factor influencing overall reliability of the system

Refurbishment

Refurbishment of medium voltage switchgear offers customers a life extension for their equipment at low cost. This option is attractive for customers with no imminent need to modernize, but wishing to maintain acceptable performance over a short to medium term life extension.

Refurbishment of switchgear can take place in a number of ways:

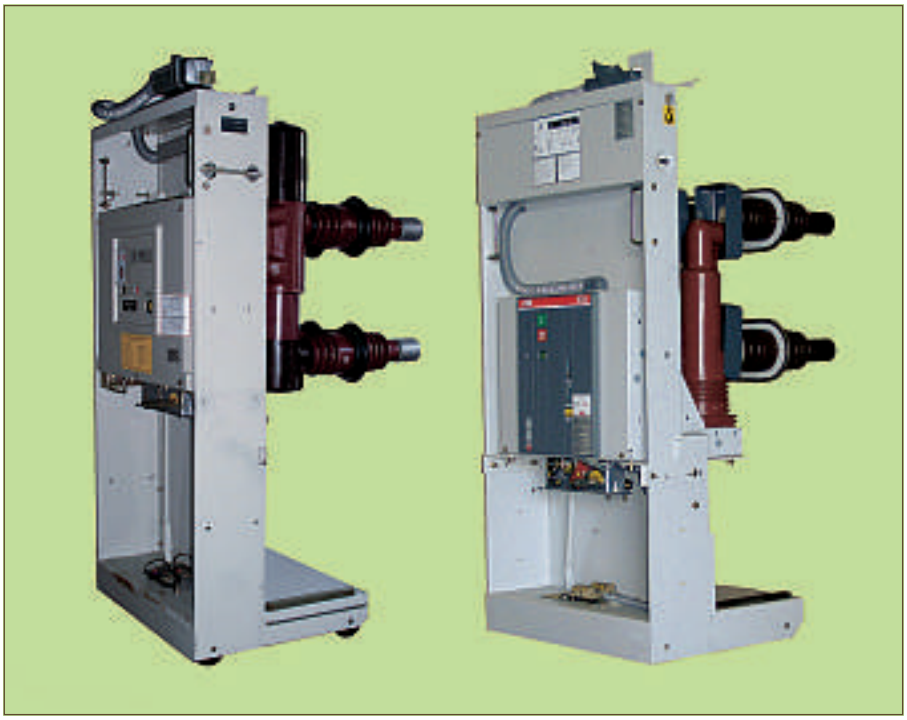
- Refurbishment of the switching devices.
- Refurbishment of the complete panel.

Refurbishment of switching devices

Switching devices such as circuit breakers, contactors and switches are typically candidates for refurbishment. The devices are removed from the switchgear, sometimes on a rotational basis in order to maintain continuity of supply, and returned to the manufacturer.

For refurbishment, each breaker is completely disassembled to the smallest components 1. In general, bearings, cotter pins and other selected components are totally replaced. All other parts are thoroughly checked for wear and damage and are replaced as needed. Each component is cleaned and re-plated if required. Product enhancements that have developed since the original manufacture are implemented to bring the breaker up to the latest production standards. When such a refurbished breaker leaves the factory it has a new lease of life and a full new warranty.

2	Calor Emag OD3 breaker (left) and retrofit using ABB VD4 vacuum breaker (right).



A large utility recently recognised the value of extending the life of their aging ABB/ITE breakers by awarding ABB a 6-year blanket contract for refurbishing nuclear safety-related and commercial breakers in their power plants. This customer will enjoy the advantages of as-new breakers with the latest enhancements, without the costly prolonged down time associated with complete switchgear replacement.

Panel refurbishment

This option normally applies to customers who intend to decommission an existing switchboard and re-use it at a different sub-station. Such a life extension choice is typically made where the switchgear application must provide short-term power supply, for example in the construction and mining industries.

Refurbishment of the switchboard can be performed at the customer's site. The board is stripped and key components are replaced as necessary. Where more extensive refurbishment is required, the board is normally decommissioned and removed from site and shipped to the manufacturer. Here the switchboard is completely stripped, and components cleaned and repainted. Insulation is inspected, tested and replaced if necessary. Switching components are refurbished as described in the previous section.

Customers are increasingly using retrofit of MV switchgear as a means of economically increasing the operational life of their equipment and improving safety.

Optionally, refurbishment can also include some form of retrofit, such as an upgrade of protection and control equipment.

Retrofit

Customers are increasingly using retrofit of MV switchgear as a means of economically increasing the operational life of their equipment and improving safety. Retrofit of the switchgear can take many forms, based on the needs of the customer:

- Retrofit of switching devices, where the existing device is replaced by a more modern equivalent.
- Retrofit of the switchgear panel, where components of the panel are replaced to enhance the safety of the equipment.
- Retrofit of protection and control, where protection and control devices are replaced - providing increased functionality, data communication and safety.

The advantage of retrofit over replacement are especially strong when:

- Special shut down of the plant to replace the switchgear cannot take place due to operational commitments.
- Physical constraints of the existing site limit replacement.
- Existing cable systems are old and it is preferred not to disturb and re-terminate cables on new switchgear.

Where a retrofit design is developed, type testing to verify ratings and ensure safe operation is a key requirement. This should be performed by the manufacturer.

Circuit-breaker retrofit

Retrofit of a circuit breaker involves complete replacement of the original circuit breaker truck with a roll in replacement, incorporating a modern vacuum or SF_6 interrupter. The retrofit includes all interlocking facilities supplied with the original panel design, as well as racking mechanisms for inserting and withdrawing the breaker from service. The interface for secondary control is also maintained to enable simple swapping of the old breaker with the new retrofit. 2 shows a typical example of a retrofit design, where an old Calor Emag OD3 breaker is replaced with a modern vacuum design.

This retrofit option provides customers with a fast upgrade of their switchgear.

The down time is minimised, as the only on-site activities are those of racking out and removing the old breakers and inserting the new retrofits. This can be performed during a normal shutdown of the switchboard.

One specific benefit of circuit-breaker retrofit exists where the original breakers are of an oil-insulated type and there is a need to reduce fire risk in the sub-station for safety or insurance purposes. The breaker can easily be replaced with a non-oil design, enabling the switchboard to reach its full lifespan.

ABB has a long history of supplying different circuit breaker types to customers around the world. Table 1 lists major breaker manufacturers for which ABB already offers retrofit designs.

Panel retrofit

Development of medium voltage switchgear panel technology has led to more compact designs and more safety features. Even so, rare and generally unpredictable events can take place – such as failure of switchgear due to an internal flashover. An internal arc has two phases:

- First, there is an extremely rapid build up of pressure within the panel. The time frame is within the first 10ms of the arc being established, which is beyond operation of conventional protection systems.
- Then, burning occurs as the arc consumes insulation, copper and steel components of the panel.

Panel designs capable of safely containing an internal arc are relatively new; the majority of switchgear installed around the world does not have this feature.

3 Example of an arc vent retrofit fitted to a Reyrolle type LMT panel.

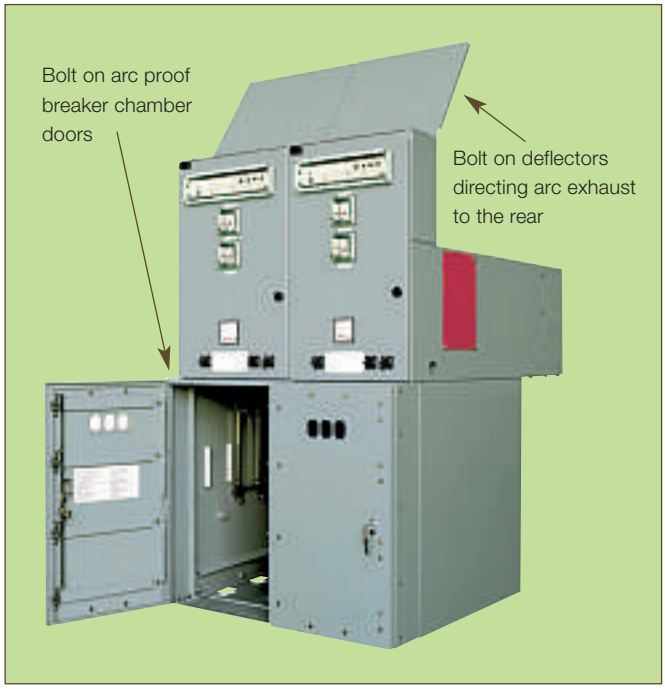


Table 1

Existing retrofit designs available from ABB

ASEA	Magrini
ASEA Brown Boveri (ABB)	Merlin Gerin
Brown Boveri (BBC)	NGEF
Calor Emag	Panel Gardy
Cutler-Hammer	Radaconsher
EJF Brno	Reyrolle
Energo-Invest	Sace
Gardy SA	ABB Secheron SA
General Electric	VOLTAS
Gould, Gould-BBC	ZWAR Warszawa
ITE, ITE Imperial	

Plant operators must also comply with health and safety legislation, which increasingly requires electrical equipment to meet higher standards.

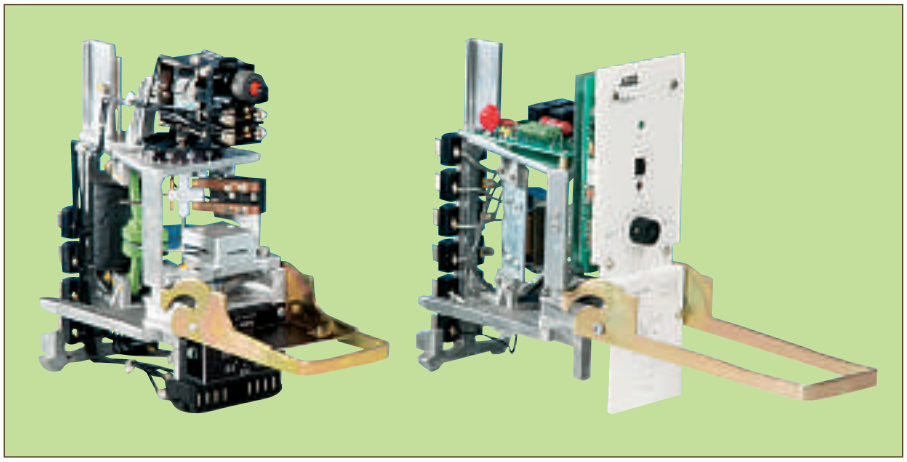
Another consequence of a panel failure is the resultant damage to the substation, and the ensuing downtime of the switchboard. In plants running continuous processes, such downtime and the consequent loss of production can be of significant cost.

Accordingly, upgrade solutions must be provided which both improve safety for operators and also minimise downtime following an internal arc.

A number of options exist for retrofitting solutions to improve internal arc performance of panels. To cater for the first phase of the fault and the resultant pressure build-up, the following retrofit solutions can be applied:

- Retrofit of remote switching – this is a simple and low cost measure improving operator safety. Analysis of switchgear failures, indicates that failure typically occurs during a switching operation. If operation is external to the substation, operator safety is automatically improved. This solution, however, does not cover all possibilities of failure, as some failures take place independently of switching operations (eg, lightning strike), and personnel within the substation may be exposed.
- Retrofit of arc proof covers and doors. This measure involves replacement of the panel doors and covers to provide arc protection and fitting of pressure relief flaps. During the rapid pressure rise following fault inception, the doors and covers withstand the pressure rise. Pressure relief flaps then release the build up in a controlled way. 3 shows an example of this design.
- Retrofit of the circuit breaker compartment: This involves complete replacement of the original circuit breaker compartment by a modern cassette design. With this approach, a standard breaker can be used: Operator safety is assured by arc proof doors, pressure relief of the breaker compartment, and proven interlock systems. A connection to the original busbar and cable system must be provided.

4	Electronic over/under voltage relay. The electronic relay (right) can replace the electromagnetic relay (left).



To limit the duration of arcing, a relevant protection system may be retrofitted:

- Retrofit of internal arc detection: This solution uses light emitted from the arc and current detection to establish the faulted section of the switchgear. The breaker feeding the fault is then switched off. Fault detection is extremely rapid and arcing times can be limited to 50 ms, significantly minimising damage to the switchgear.
- Retrofit of modern protection systems: Using electronic relays, tripping times of 60 – 100 ms can be achieved. Replacement of older relay designs allows fault times to be reduced minimising panel damage.

To achieve the dual objectives of better safety and reduced down time, retrofit of both panel and protection system should be considered.

Protection and control retrofit

Technology of protection and control devices is rapidly advancing: Modern devices have better communication and control capability and can provide more diagnostic information. Equally, plants increasingly incorporate process automation software systems, which require higher levels of electrical plant integration for operation. Adoption of this technology optimises utilisation and permits increased plant performance.

> Modifications to protection and control systems can be accompanied by replacement of conventional current and voltage transformers by equivalent sensors. Such devices are compact and provide linear output without saturation.

Historically, protection devices were of an electromechanical design. This technology has provided reliable performance for many years and is still accepted today. Usually devices were specific to their function – with protection relays for protection functions, whilst separate devices provided control and indication functions. With the development of microprocessor based relays, many of these functions are now combined into single sophisticated devices providing a range of protection, control and indication functions.

Retrofit of protection and control systems can be adapted to customer need. Some electronic relays have been developed with the same draw-out features and case dimensions as their electromechanical predecessors 4.

An alternative approach is the replacement of the protection scheme: Normally a number of discrete protection and control devices are replaced by a single multifunction microprocessor relay.

Modifications to protection and control systems can be accompanied by replacement of conventional current and voltage transformers by equivalent sensors. Such devices are compact and provide linear output without saturation.

Conclusion

Advances in refurbishment and retrofit techniques have provided customers with a range of options for economically improving safety and extending the life of their switchgear. Analytical comparison of these options allows plant operators to identify the most suitable way of improving the performance of their electrical assets and so maintaining a sustainable competitive advantage in the market place.

Stephen Pearce
ABB Medium Voltage Switchgear
South Africa
stephen.pearce@za.abb.com

New components, old products, no problem

Old installations are given a new lease of life with state-of-the-art high voltage components

Per-Olov Andersson, Michael Hendrich, Carl Öhlen

Customers are always concerned with getting the most from their equipment. But they are equally concerned about time consuming and costly maintenance. This usually means relatively long downtimes and increased costs. ABB has an impressive record of supporting old and new installations around the world and this is especially true for the company's Air-Insulated and Gas-Insulated Switchgears (AIS and GIS), and generator breakers.

This article presents three examples of how ABB has replaced old components with new ones in old high voltage installations. The end result is helping customers achieve even longer lifecycles, and improved safety and performance with significantly reduced maintenance costs.

AIS renovation in Sweden

As part of its maintenance contracts with customers, ABB supports all global AIS installations past and present, ie, including earlier deliveries under the ASEA, BBC, ITE and Westinghouse name. With more than 100 000 bays with circuit breakers from 50 to 800 kV delivered during the last 50 years, ABB supports all of these by providing spare parts, retrofit and replacement – depending on condition and life length – for all air blast, oil and SF_6 breakers.

ABB's current AIS offering includes live tank and dead tank circuit breakers, instrument transformers and state-of-the art surge arresters which are high in reliability and have very low maintenance requirements. The combined Disconnecting Circuit Breaker (DCB) is based on the group's well proven SF_6 live tank breaker design, but it has been developed to withstand both breaker and disconnector requirements. In other words, the DCB can replace a complete bay containing both a circuit breaker and disconnector. In addition, it is possible to include a current transformer and a line entrance module with earthing switch.

Time for an upgrade

The Swedish grid was one of the earliest grids in the world to develop because of the need to deliver hydropower energy from the north to the south of the country. These developments included the world's first 400 kV system, which came into service at the beginning of the 1950's.

Currently, Svenska Kraftnät is responsible for the Swedish 230 kV and 420 kV national grid (sub transmission and distribution networks are handled by different utilities). Another company, Sydkraft, is responsible for several hundred substations from 132 kV downwards.

These two companies realised, independently, the need to renovate an older substation in the south of Sweden where Svenska Kraftnät operated the 420 kV part and Sydkraft the 132 kV part.

This need arose because the old disconnectors had been giving problems which had, in part, caused major disturbances. In addition, these disconnectors required high level maintenance. Therefore, it was decided to remove the conventional disconnectors and to substitute them, along with the breaker function, with the combined DCB concept.

Completed in stages, the renovation carried out by Svenska Kraftnät has resulted in a 420 kV station that now uses a double busbar layout, with every transmission line connected to each busbar via a combined DCB 1. As the DCB layout requires considerably less space, it was not only possible to expand from one to two busbars, but also to include a capacitor bank. Overall, both the transmission capacity and the operational reliability have increased significantly.

1	A 420 kV combined Disconnecting Circuit Breaker (DCB) installation.

Sydkraft systematically screened their substation using a scorecard model together with a risk analysis. The evaluation identified component and substations that needed to be replaced or renovated. Subsequently, the 132 kV substation was rebuilt and 30 conventional disconnectors and oil breakers were removed and replaced with DCBs.

2	Retrofit with a new state-of-the-art breaker into an existing Gas Insulated Switchgear (GIS).

GIS retrofit in Germany

As well as supporting AIS installations, ABB also supports old and new GIS installations around the world. Since 1967, over 5,500 bays of different 110 kV SF_6 switchgears have been sold by ABB.

ABB's GIS switchgear stands apart from the competition because of its high quality and extremely long lifetime. In addition, these switchgears are corrosion resistant. In recent years, however, the first generation of GIS products have been slowly approaching the end of their natural lifecycle time. It is worth remembering, though, that most parts of any switchgear component can be considerably prolonged by regular maintenance.

> The use of DCBs in substations significantly increases transmission capacity and operational reliability.

When the first generation of SF_6 gas-insulated switchgears was launched, they were equipped with two-pressure power circuit breakers and were operated with

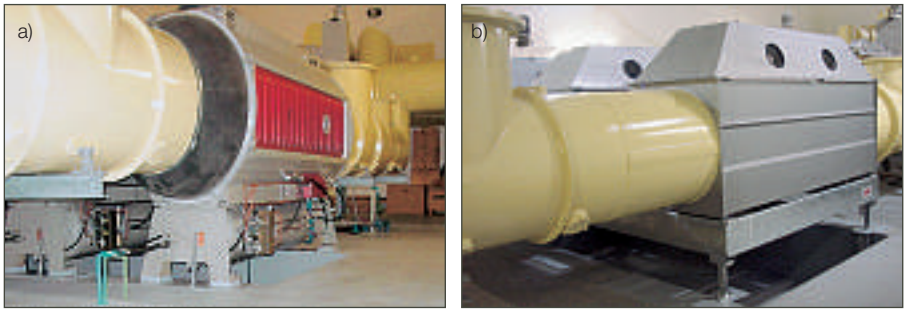
oil hydraulic power circuit breaker drives. As this technology is now outdated compared with current state-of-the-art designs, relatively intense servicing is required to keep them operating satisfactorily.

The circuit breaker, the most critical component of the switchgear, is exposed to frequent operations and stresses. The design of SF_6 breaker technology has constantly been improving since 1967, and consequently ABB has developed a retrofit solution for the old GIS production series, EBK 010 / 020 / 030. This solution means that modern SF_6 auto-puffer circuit breakers, with hydraulic spring-operated drives, can replace the older technology in the existing switchgears. Control secondary technology will be adjusted to the new requirements.

By interchanging the existing complete circuit breaker with one component from the latest GIS circuit breaker design, ie, case and interrupting chamber, the performance of the circuit breaker will significantly increase. On top of this, the combination of a hydraulic spring drive with the new circuit breaker will increase the overall value of the switchgear.

This solution has already been used by a German utility, Stadtwerke, in Baden-Baden. ABB field service engineers replaced a circuit breaker, based on an early design, with the new series EBK-SW21 2. As well as increasing performance, overall operational safety and availability has been enhanced. But perhaps one of the biggest advantages of this retrofit solution is that now, maintenance works can be completed in less than three working days.

3 Retrofit project in Häusling, Austria
a) Old Generator breaker (Type DR36 sc 501) before replacement.
b) New breaker (Type HGC-3) after replacement.



SF_6 generator breaker retrofit in Austria

In 2002, Austria Hydro Power AG needed to replace two air-blast generator breakers. The primary motivation for this was the rather time-consuming and costly maintenance work that had become necessary to keep these breakers, type DR 36 sc 501, operational. Such maintenance entailed relatively long downtimes for the Häusling pumped-storage power plant.

According to the customer, the remaining power plant operating time of the power plant is estimated at 70 years. In the light of this consideration combined with a guarantee to extend maintenance intervals by 100 percent, installing state-of-the-art switchgears, ie, ABB's new SF_6 generator breakers type HGC3, will surely pay off in no time.

> One of the biggest advantages of any retrofit solution is that maintenance works can be completed in significantly less time than before.

In 2003 and 2004, Austria Hydro Power AG has installed the SF_6 generator breaker into two different machines. Compared to the former switching device, this breaker contains less wearing parts, making it the ideal solution for a system with a notably higher rate of operating cycles.

In general, replacing old components with new ones requires some form of innovation to correctly integrate it into the main product. And the situation was no different at the Häusling plant. After removing the old air-blast breaker, the SF_6 circuit breaker had to be integrated into the geometry of the single-phase isolated high-current busduct. This problem was solved by the use of new connection elements designed and manufactured at ABB's production site in Großauheim, Germany.

The SF_6 breaker unit was taken apart in the turbine hall so that the individual subassemblies would be available separately. After welding the base frames, the breaker frame was installed. Finally, the separate subassemblies were brought to their final location and installed one at a time 3. The new connection elements were fitted onto the generator busduct and the cabling work and electrical commissioning was started. The most crucial commissioning step was the successful high-voltage test applied to the new generator breakers and the generator busduct.

The on-site work per breaker was completed within three weeks in 2003 and two weeks in 2004.

Per-Olov Andersson
ABB Power Technologies
Sweden
per-olov.e.andersson@se.abb.com

Michael Hendrich
ABB Utilities GmbH
Germany
michael.hendrich@de.abb.com

Carl Öhlen
ABB Power Technologies
Zürich, Switzerland
carl.ohlen@ch.abb.com

Guarding the grid

Advanced monitoring systems protecting power lines

Cédric Carnal, Joachim Bertsch, Marek Zima

The gradual but continuous growth in electricity consumption and increases in cross-border trading activities combined with restrictions on transmission line extensions due to environmental concerns are pushing many grids towards their capacity limitations. Especially the relatively new trading aspects are creating significant fluctuation in line flow patterns placing stress on the networks thereby reducing their throughput. Advances in communication and computation technologies in combination with phasor measurements are today cost-effective solutions to real-time monitoring of electricity flows in such networks. When operating close to capacity constraints even marginal improvements are of significant value.

This article describes the contribution of phasor measurement techniques to wide area monitoring (WAM) of power systems. A commercially available WAM system is briefly introduced and the result of its pilot implementation in a real transmission network presented. Possible future extensions and applications are discussed in the last section.

PSGuard, a WAM platform

PSGuard with its modules PSG8xx is a platform for wide area monitoring, control and protection developed as a scalable solution and suitable for step by step installation, starting with the basic platform PSG830. 1 presents the modular design and the options available from data acquisition to stability monitoring and advanced real-time control and protection.

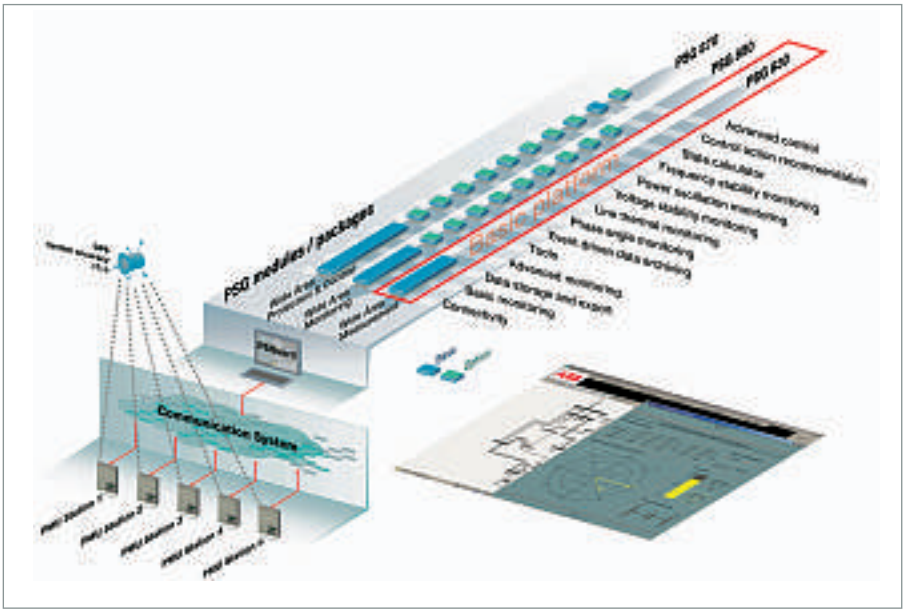
By utilizing a signal from a satellite based Global Positioning System (GPS) the Phasor Measurement Units (PMUs) are synchronized with an accuracy of one microsecond. This technology permits system dynamics to be observed regardless of the large geographical distances between the locations of the measurement points. With the application of different software analysis tools the PSG8xx modules are capable of providing information regarding various line stability parameters such as frequency, voltage and power oscillations. Interpreting these dynamics to recognize early signs of grid instabilities is providing valuable early warning of potential network-stresses and ample time to identify suitable remedies.

Guarding the Swiss transmission network

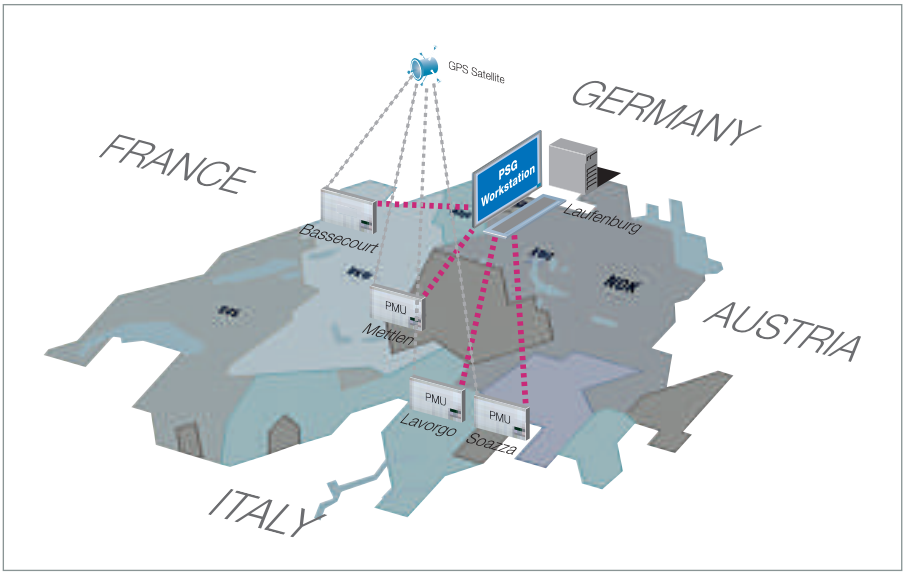
The goal of the pilot deployment of the WAM system in the Swiss transmission network is to monitor the impact of heavy power transfers on the north-south axis. Four PMUs have therefore been placed along this transmission corridor as shown in 2.

The PMUs measure voltage and current phasors and continuously send their data in intervals of 100 ms to the System Monitoring Centre (SMC), where they are stored and then processed in various ways. The data (both direct measurements and calculation results) are displayed on a user-friendly Graphical User Interface (GUI, 3). The GUI is composed of a main view, which can be the single line diagram and/or the functional view of the components of the WAM system, combined with a window for the warning and alarm history at the top, and a number of application windows. The application windows appear by selecting the corresponding component in the main view and con-

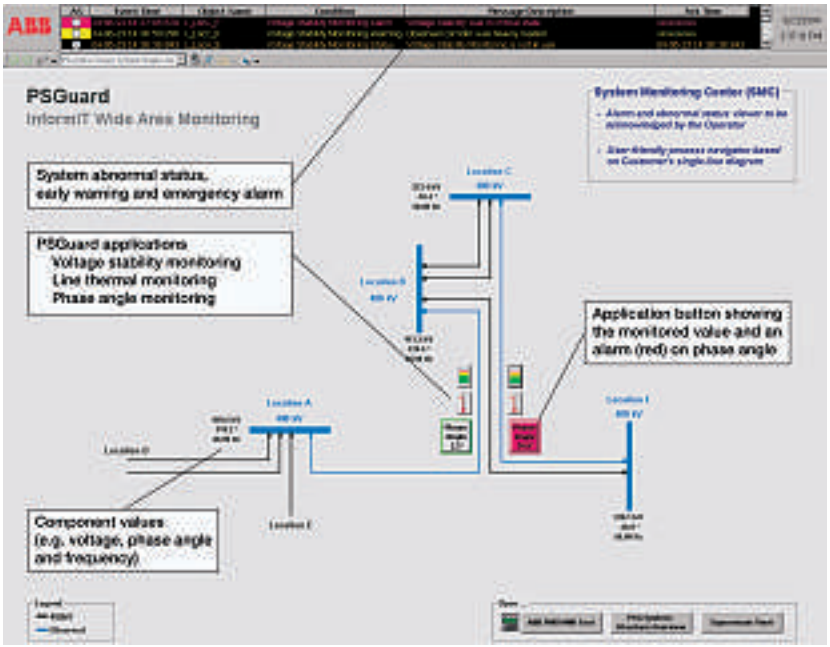
1 PSGuard, a scalable solution.



2 Locations of the PMUs installed in Swiss transmission network.



3 Main view of the user-friendly graphical user interface with application components.



tain trend displays, algorithm outputs, etc.

Dual purpose data

The data collection period, which started with the installation of the WAM system before the winter peak of 2003, is still ongoing. The identified usage of the data from the existing configuration is divided into two categories – power system operation and power system planning.

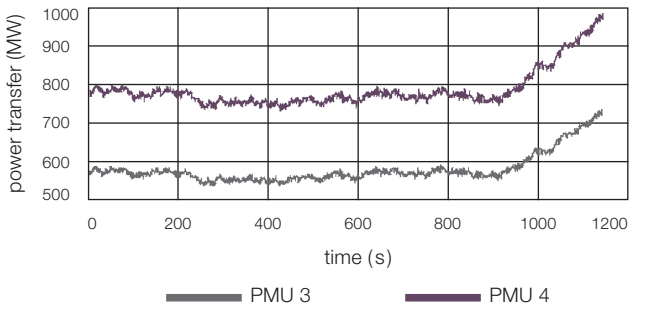
Power System Operation

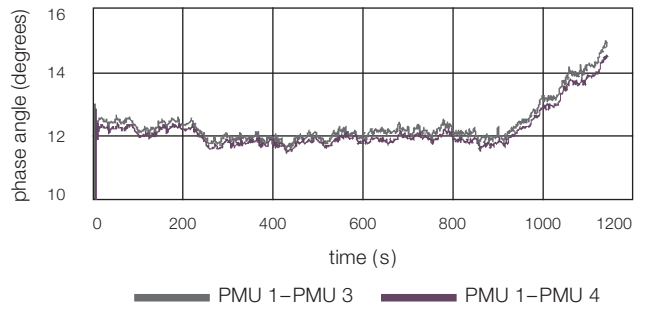
The difference in voltage phase angles across the Swiss network is proven to be a very good indication of the network stress caused by the power export to the South. An almost linear relationship between the transferred power and the voltage phase angle difference is observed. An active power transfer via two monitored lines and its relation to the voltage phase angle difference across the Swiss transmission system is shown in 4. Operators can more readily observe the stress in the Swiss grid caused by energy transfer from France to Italy.

The difference in voltage phase angles across the network is proven to be a very good indication of the network stress caused by the power export to the South.

By monitoring the phase angle difference the operator can detect early signs of line stress and apply mitigating actions prior to serious difficulties arising. The phase angle shift seen in 4 is too small to be of any concern. However, if it increases beyond 20–30 degrees serious consequences can occur, since the line cannot be re-closed if tripped.

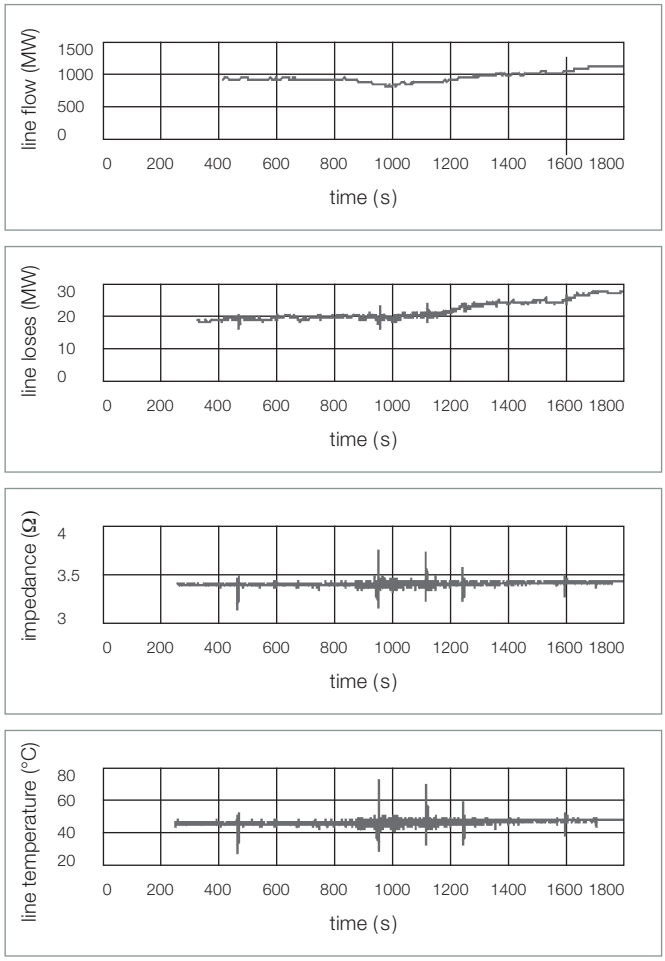
4 Results of phase angle monitoring.





With both ends of a line supervised by such accurate devices as PMUs, the line losses and impedance can be computed very precisely. From these computations an average line temperature can be derived 5. This is usually referred to as a dynamic thermal rating. In this example from the Swiss transmission system the average temperature increases from 46 to 49 °C as a consequence of the 200 MW increase in power transfer within a time span of 30 minutes. The temperature rise leads to an expansion of the conductor, which can lead to short circuits being developed by the cable touching trees or other tall grounded objects. By observing the temperature development, the operator can take actions before any significant damage occurs. The PSGuard system for the Swiss transmission lines was installed after the Italian blackout in 2003; hence so far no data indicating larger temperature changes have been collected.

5 Results of line thermal monitoring.



The two applications mentioned serve as powerful decision support tools both during normal operating conditions and in emergency situations.

Power System Planning

Recordings of phasor measurements can also be used for off-line processing. The data serves as an input for calibration and verification of the implementation of dynamic models of different network components. Of particular interest are the response curves of the power plant controllers. The ability to capture the dynamics of the wide area network can be utilized for the analysis of its behaviour and the identification of specific network properties when planning network reinforcements and extensions. For these purposes, data can be exported from the platform in easily adaptable formats.

Monitoring network stability

The presented installation can be further extended to address more system-wide stability issues. There are on-going research and development activities related to stability monitoring based on phasor measurements by both the utility and the WAM system supplier.

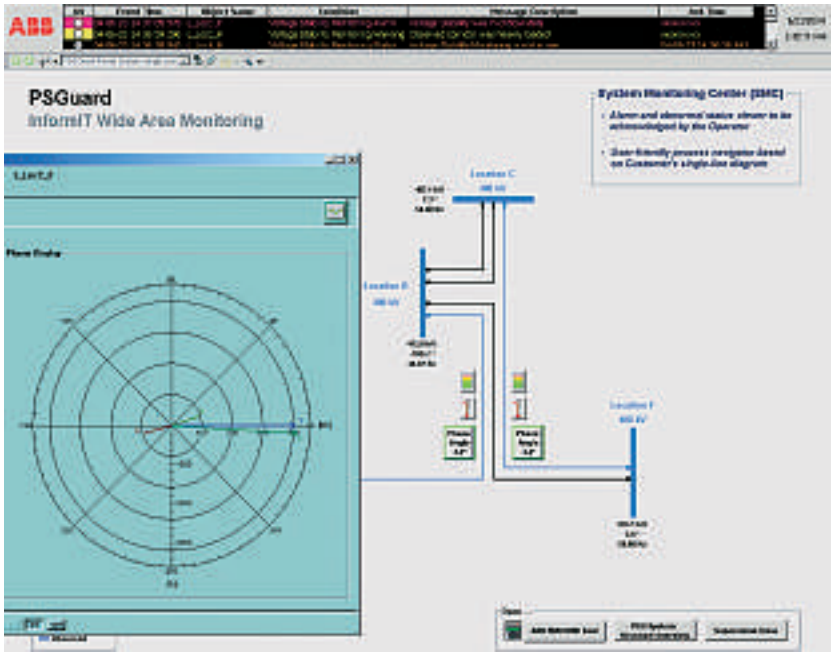
The ability to capture the dynamics of the wide area network can be utilized for the analysis of its behaviour and the identification of specific network properties when planning network reinforcements and extensions.

As already mentioned, phasor measurements can be used for the state estimation procedure, which offers a number of advantages over traditional approaches. Since the measured quantities are voltage and current phasors, linear expressions can be formulated, thus avoiding numerical convergence problems. In addition, PMUs can be placed in the network in such a way that their data serves as a basis for topology identification (ie, status of the lines etc.).

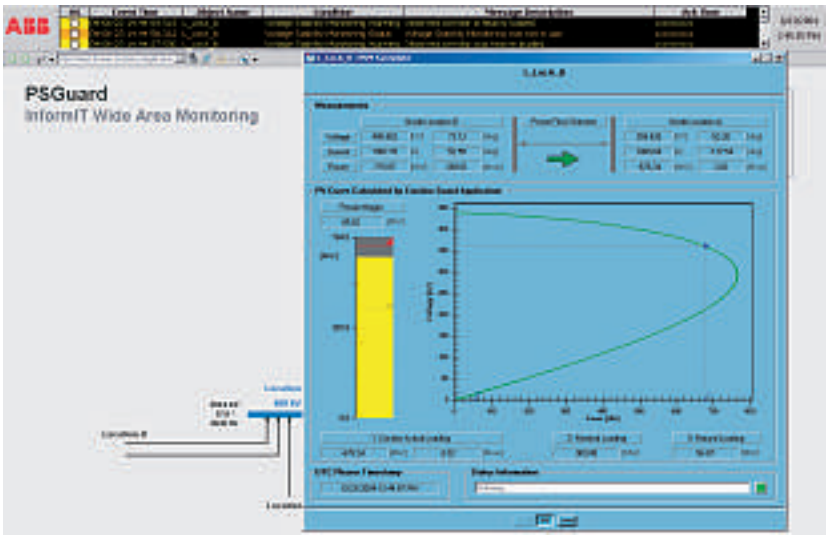
As a first step, a WAM system can be used to monitor conditions related to network stability. The alarms and indicators help an operator to execute corrective actions as depicted in 6. A line-monitoring window overlaps the main view containing the single line diagram. The black area at the top of the page is used to list issued alarms as also shown in 3.

Voltage instability caused by a gradual load increase can be identified early by employing a PV-curve visualisation as shown in 7. However, some phenomena are too fast for human involvement. To handle such events, advanced control features are becoming increasingly important. Today these features are dedicated to Special Protection Schemes (SPS) only. These are sets of local protection relays coordinated via simple rules that are defined in off-line prestudies. An obvious deficiency of this approach is its attempt to cover a vast range of actual operating conditions with a limited set of fixed rules. All current network conditions must be ade-

6	Graphical user interface example of the wide area monitoring system, PSGuard.



7	Graphical user interface example of the voltage stability-monitoring algorithm. A PV-curve is used to express the distance of the actual load to the point of maximal loadability.



quately reflected during both the monitoring stage and during the selection process of optimal control actions in order for the system to react to a dangerous situation most effectively. Therefore on-line or real-time procedures should be employed.

Voltage instability driven by a contingency can be mitigated using a method

> Network security, is an extremely important issue because of its importance for society and the economy.

that focuses on the emergency condition aspects. Phasor measurements appear to be the most suitable signals containing necessary information for the identification of power oscillation modes in power systems.

Conclusion

The experience with the installation of the PSGuard system in the Swiss transmission network has been summarized. WAM systems based on phasor measurement technology have significant quantifiable benefits when applied to various fields of power system operation. The main focus here has been network security, which is an extremely important issue because of the frequently varying stress patterns of power systems. The tools applied for fast and effective operator actions will continuously be enhanced as further results from the Swiss monitoring installation become available.

Cédric Carnal
Joachim Bertsch
Marek Zima
Utility Automation Systems
Baden, Switzerland
cedric.carnal@ch.abb.com
joachim.bertsch@ch.abb.com
marek.zima@ch.abb.com

Approaching decisions

The complementary solution to the maintenance planning problem

Zhenyuan Wang, Le Tang, George Frimpong, Pedro Tong Lee

Maintenance strategies and asset management are about making decisions: Should equipment be replaced? Should it be refurbished? Or do minor repairs suffice? How much maintenance is needed, when and how? Such decisions must be based on the condition of the equipment, but also on its importance and the cost of a failure. Spending too much money on maintenance is wasteful; not spending enough is asking for trouble. Good asset management is about optimizing this balance and finding the best return on investment. Asset decision-making is now supported by software from ABB. With CALPOS®-Main and Asset Sentry, equipment condition is monitored, available data is analyzed and asset managers receive powerful support in getting their decisions right.

Some of the issues currently facing service providers to the utility industry, whether internal or external, are pressures to reduce costs, increase returns on assets and improve equipment reliability. In addition, a large percentage of the installed infrastructure base is near the end or even past its designed lifespan. To compound the problem, these organizations are losing knowledge through the attrition of personnel.

In the face of these challenges, utilities are wrestling to meet expectations with the planning of their maintenance activities and the associated budgets. One solution has been to build a patchwork of 'home grown' solutions. Another, to turn to a computerized maintenance management system (CMMS) to aid in managing asset maintenance. However, CMMS usually only helps manage crews, materials, schedules and costs. Such systems often do not have or only have limited functionality in maintenance planning. As a result, there is a growing trend in utilities to outsource this activity or to adopt new software solutions to support the maintenance planning process.

Maintenance planning for electric utilities has two aspects: Strategic planning and operational planning. Strategic planning activities include short-term (annual) and long-term (several years) budgeting, major project screening, and maintenance policy revisiting. Operational planning deals with subjects requiring daily attention, such as equipment condition assessment, inspection scheduling and the determination of maintenance action.

These two aspects are equally important because they both affect the financial performance of utilities in the following ways:

1) Over-budgeting is not a viable option, while under budgeting may decrease the reliability of the network, resulting in financial losses due to unexpected outages.
2) Taking the right maintenance action at the right time for the right equipment not only saves money but also reduces the risk of unexpected failures, which are typically more expensive to repair.

Therefore, it is important for utilities to have a good handle on their strategic and operational planning activities. ABB has developed a complementary solution to help utilities master both these activities.

The complementary solution

On the strategic level, ABB has developed an Internet based service-portal called CALPOS®-Main 1, which supports the following maintenance planning activities:

- Iterative maintenance budgeting studies – what-if analysis to find the right replacement and maintenance budgets for the next five years.
- Maintenance strategy formulation – given the annual budget, compare the costs of preventive maintenance (PM), condition based maintenance (CBM) and reliability-centered maintenance (RCM) in the next five years to select the best strategy.
- Equipment maintenance/replacement screening – set the priorities of equipment maintenance/replacement under the selected maintenance strategy in the next five years.
- Decision on equipment repair/replacement – condition/importance based judgment on whether to repair or replace a piece of equipment.

On the daily operational level, ABB has developed another Internet based service portal called Asset Sentry 2, which is backed by an intelligent decision engine, the maintenance decision support system (MDSS).

The Asset Sentry/MDSS combination supports the following maintenance planning activities:

- Set the time interval and grace period of a PM activity or a group of PM activities (called a route).
- Set the recipients of equipment condition alerts.
- Failure mode and root cause analysis for a particular group of equipment.
- Analysis of effectiveness for a particular diagnosis/maintenance technology.
- Aggregated maintenance/repair cost analysis at equipment/substation/region/system levels.
- Detailed equipment condition assessment.
- Ranked diagnosis/maintenance action recommendations.

The CALPOS®-Main based strategic maintenance planning

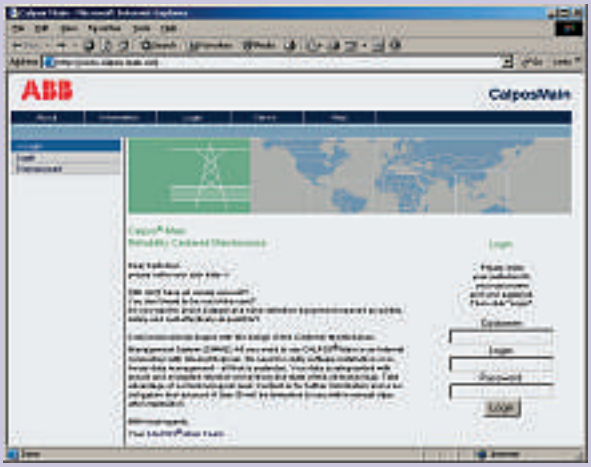
The CALPOS®-Main based strategic maintenance planning is dependent on the survey of the condition and importance of each piece of equipment 3. ABB has developed IT infrastructure to log the survey results. This IT infrastructure consists of: 1) the CALPOS®-Main service portal 1; 2) a database; 3) hand-held data entry devices (running the electronic Palm Acquisition Tool – ePAT). The service portal and database can be hosted by ABB or by the utility customer.

The CALPOS®-Main service portal is supported with intelligent engine modules, including the equipment assessment module and the maintenance strategy evaluation module. Both these modules can be fine-tuned for a particular utility installation. ABB has extensive experience and knowledge of selecting the parameters during the system settings and customization stage of the installation.

After ABB has conducted a training workshop on the survey process steps, the utility field engineers, technicians and specialists can perform an excellent job of surveying and logging data into the CALPOS®-Main database via ePAT or similar tools. Once the survey data is collected, the utility asset manager can optimize the maintenance strategy for the entire network. The selected strategy, represented as lists of equipment in descending order of their replacement and maintenance priorities, may be exported as an XML file to any CMMS as maintenance scheduling references.

The equipment assessment module implements a special algorithm which evaluates a piece of equipment in comparison to its peers. Input to the algorithm consists of so-called condition aspects and importance aspects of the equipment. The output is an overall indicator of whether the equipment needs to be replaced, serviced, or just monitored 4. This module is the basis for the mainte-

1	The CALPOS®-Main service portal.



2	The Asset Sentry service portal.

nance strategy evaluation module and merits a more detailed explanation:

Condition assessment

The condition assessment of the equipment is based on evaluation of, among others, the following items:

- Operating experience: general experience with a particular type, supply of replacement parts, service etc.
- Visual observations: flashover, corrosion, dirt, ground connections etc.
- Measurement results (monitoring): gas and oil analyses, switching times (deviation from required times), pole synchronism etc.

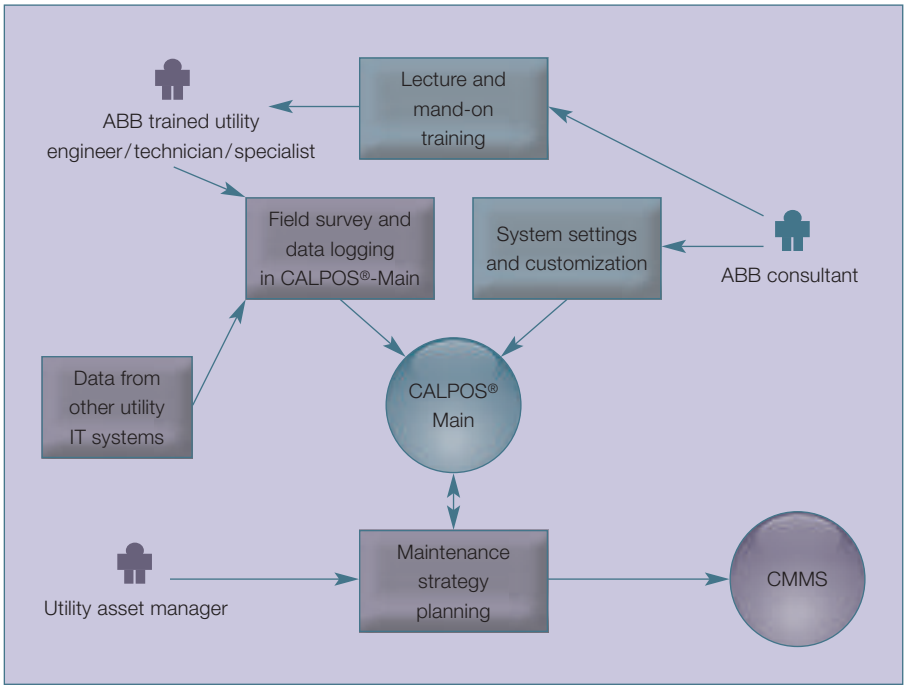
The individual evaluations are multiplied by a weighting factor to reach a condition factor (c), which is standardized to a value between 0 and 100. For each piece of equipment, the higher the value (c) is, the worse is its condition.

Importance assessment

Importance assessment of a piece of equipment depends mainly on the consequences of its failure, as well as on other subjective, company-specific and objective aspects, such as:

- The voltage level.
- The location (nuclear power plant, conventional power plant, substation etc.).
- The value of the component.
- Travel times to the fault location and hence the duration of the down-time.
- The network topology (radial network, meshed network).
- Delayed supply of power after failure of equipment.
- Social aspects of non-availability (for example, hospital).
- Financial aspects of non-availability (loss of revenue, penalties).
- Environmental influences (damage through explosion, contamination).
- Damage to the company's image due to a fault.

3	Use CALPOS®-Main for strategic maintenance planning.

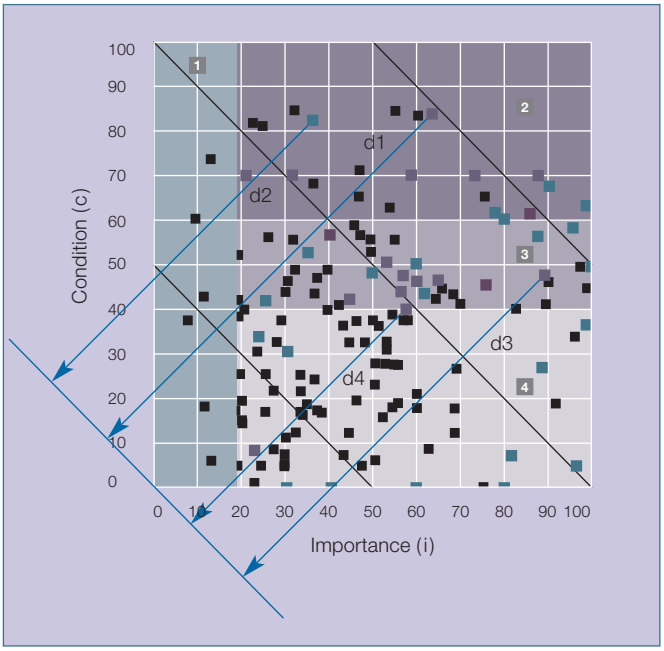


These aspects are evaluated to obtain an importance factor (i), which, like (c), is standardized to a value between 0 and 100, with 0 reflecting an unimportant piece of equipment and 100 representing the most important one.

Decision diagram

The decision diagram in CALPOS®-Main 4 has two axes: the condition-factor (c) and the importance (i). The dots represent the entire population of a particular type of equipment, and each axis represents a decision weight. A dot in the upper-left corner indicates that a piece of equipment is in very poor condition while the consequences of its failure are negligible. A dot in the lower-right corner, on the other hand, indicates that piece of equipment is in very good condition but its failure is associated with considerable consequences.

4 The equipment evaluation concept of CALPOS®-Main.



1 corrective maintenance
2 replacement
3 maintenance (preventive, scheduled, conditionbased, predictive
4 inspection, monitoring

The two decision weights determine a line through the origin of the axes. This line is used to calculate the overall assessment scores of a class of equipment. Each such overall score is computed based on the distance (d) from its corresponding dot to the line. The theoretical ranking of the maintenance measures is then obtained by comparing the overall assessment scores. In practice, however, experience has shown that the following decision categories are suitable:

- c<cw No special action necessary, because the equipment is in good condition
- cw<c<ce Maintenance
- c>ce Replacement

Where cw and ce are threshold values. They correspond to two lines in parallel with the importance factor axis in 4. Inside each category, the measures to be taken are ranked in accordance with the overall assessment score (d).

Customer benefits

The CALPOS®-Main based strategic maintenance planning has been shown to be beneficial to utility customers. Since the market introduction of CALPOS®-Main, several utilities have applied its methodology in their strategic planning process. A Romanian utility has used CALPOS®-Main to achieve an estimated 35% savings on actual maintenance costs. A utility in Germany has integrated CALPOS®-Main into their ERP and CMMS applications. The results produced by CALPOS®-Main are compiled into priority lists for replacement and overhauling according to the strategies defined by asset management. The values of this prioritization are then transferred to the CMMS for the operational maintenance planning activities.

The Asset Sentry/MDSS based operational maintenance planning

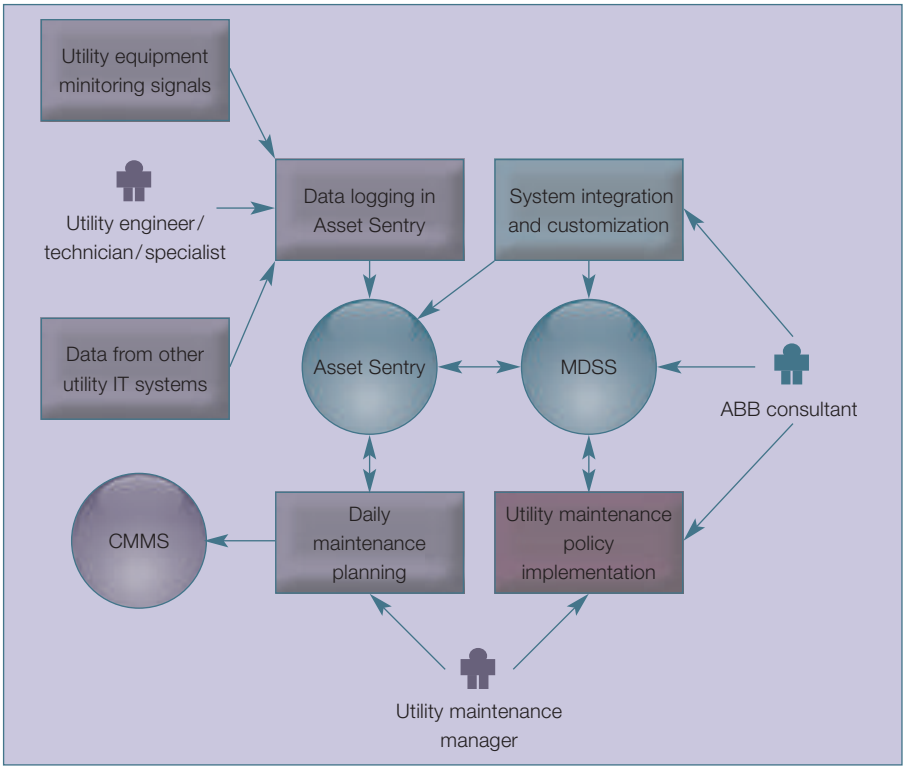
The advantage of Asset Sentry/MDSS based operational maintenance planning is accurate equipment condition assessment and detailed diagnosis/maintenance action recommendation. The basis for this advantage is the ABB equipment data warehousing application, Asset Sentry, and the configurable intelligent decision engine, MDSS 5.

Asset Sentry is an Internet-based data warehousing application. Utility engineers, technicians and specialists can use any Internet browser to enter data. They can also use barcode readers and hand-held devices to speed up the data entering process. Careful 'route' design in Asset Sentry can even provide them with real-time help on what sequence of tasks to perform, so that a single field visit can bring in all the necessary inspection data of, for example, a substation. In addition, Asset Sentry can be configured to receive signals from utility equipment monitoring systems and other IT systems. Data from these systems may be recorded and analyzed in Asset Sentry[1)].

The distinct power of Asset Sentry lies in its integration with the intelligent decision engine – MDSS, which was developed by ABB Corporate Research to provide decision support to data warehousing applications. It consists of a RuleBase Configurator, a Data Mapper, a Reasoning Engine, and a web-enabled human machine interface (HMI) for displaying results. The RuleBase Configurator is used to formulate the data interpretation rules and maintenance suggestions. The Data Mapper is used to match relationships between data points in a data warehousing application and in MDSS. This allows multiple data

[1)] A more detailed description of Asset Sentry can be found in the article 'Informed planning: A web-based solution for integrating electric utility asset information' on pp 52–58 of this ABB Review Special Report.

5 Using Asset Sentry/MDSS for daily maintenance planning.



6 Exceptions in Asset Sentry can help on daily maintenance planning.

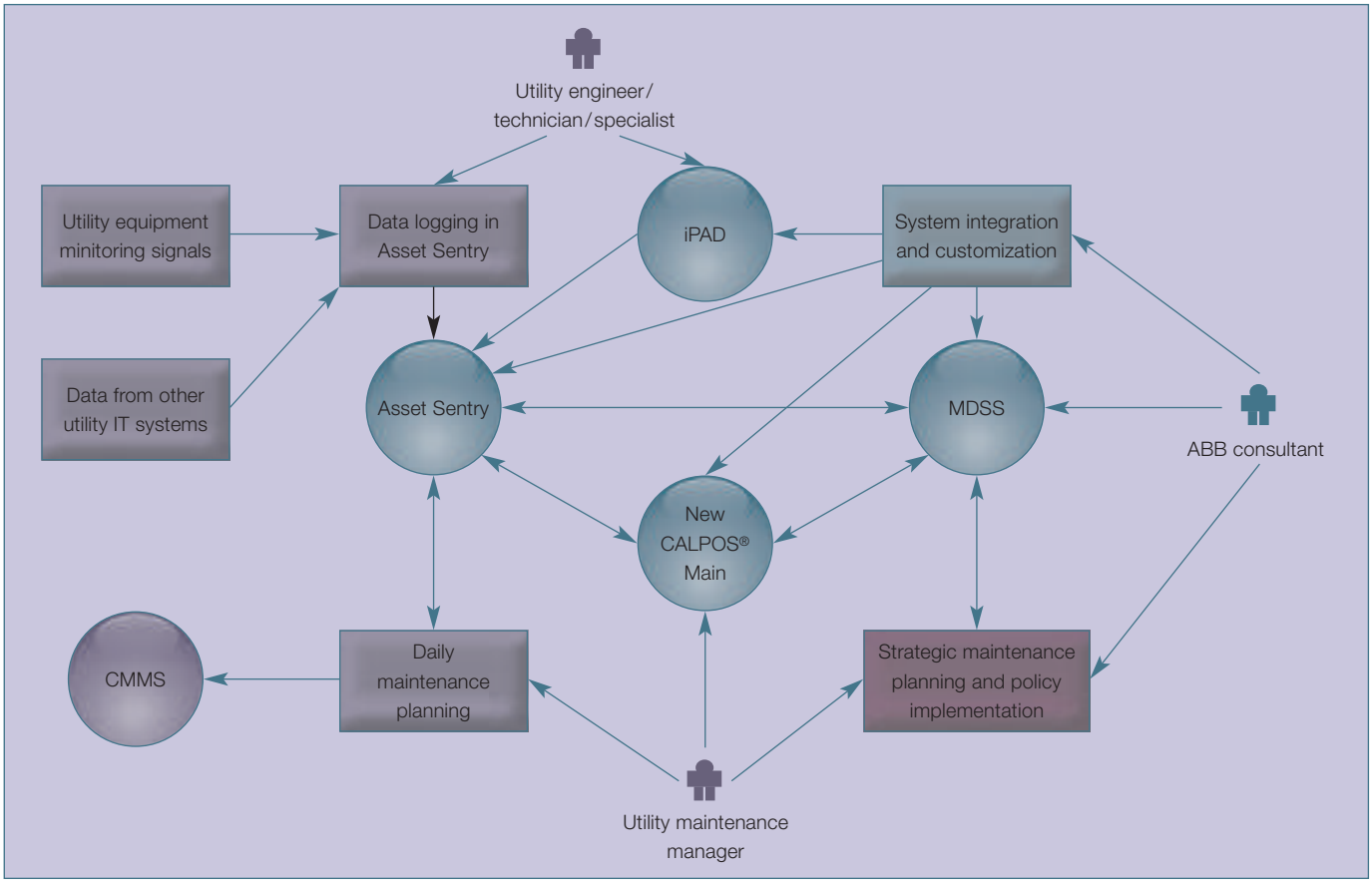
warehousing applications to share the same MDSS RuleBase. The Reasoning Engine applies the rules to a given equipment dataset. The web HMI enables advanced maintenance planning decision support – drilling down to the rational of a MDSS diagnosis/maintenance action recommendation.

A software interface has been developed between MDSS and Asset Sentry. When new equipment condition data is logged into Asset Sentry, all pertinent information about the equipment and the data set are passed to MDSS for processing. The Reasoning Engine within MDSS determines and applies the appropriate rule set to the data. The resulting condition assessments and maintenance and diagnostic actions are passed on to Asset Sentry. When the results contain abnormal equipment conditions and/or recommendations, an exception is generated in Asset Sentry and email notifications are sent to appropriate recipients within the utility organization.

A typical exception generated by the process is shown in 6. The exception contains a problem description, a description of interim conditions that had to be met to arrive at the final problem condition, and suggested maintenance or diagnostics actions for rectifying the condition. A rank score is associated with each condition in the problem description and maintenance/diagnostic action. This score is a measure of the confidence in the assessed condition or the suggested action. If the analysis is

7 Drill down to the rational of a problem description in MDSS Web HMI.

8 The complete maintenance planning solution for the future.



performed in the MDSS web HMI, the utility maintenance manager has options to review the rules that triggered the resulting condition and to request further analysis of the condition by 'asking' an ABB expert 7.

Rule sets in MDSS can be updated and applied instantly after the initial configuration, giving utilities the flexibility to change their data interpretation logics and maintenance practices if deemed necessary. Beyond data reporting and maintenance planning, the real power of Asset Sentry resides in its capability to incorporate expert rules to guide maintenance decision-making.

Looking into the future

ABB foresees the need for utilities to have an integrated solution for asset maintenance planning. This solution must consider network dynamics, financial impact and life cycle costs of equipment. To be complete, such a solution should also include a network analysis module. Future refinement will include tighter integration between the two main tools – the CALPOS®-Main and the Asset Sentry. In addition, maintenance cost information captured in Asset Sentry can be used to evaluate the cost to benefit ratio of maintenance actions suggested by MDSS and passed along to Asset Sentry 8.

Zhenyuan Wang, Le Tang
ABB Corporate Research
Raleigh, North Carolina, USA
zhenyuan.wang@us.abb.com
le.tang@us.abb.com

George K. Frimpong
ABB Consulting
Raleigh, North Carolina, USA
george.k.frimpong@us.abb.com

Pedro Tong Lee
ABB Utilities GmbH, Power System Services
Mannheim, Germany
pedro.tong@de.abb.com

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[2] **D. Tates, J. Smith, G. Frimpong and T. Taylo:** 'Implementation of an Asset Information System at Michigan Electric Transmission Company (METC)', Paper AMM-1, 2004 Doble Engineering Client Conference, Boston, MA, March 21–26 2004

Illuminating experience

Keeping Staffordshire lit up

Paul Northwood

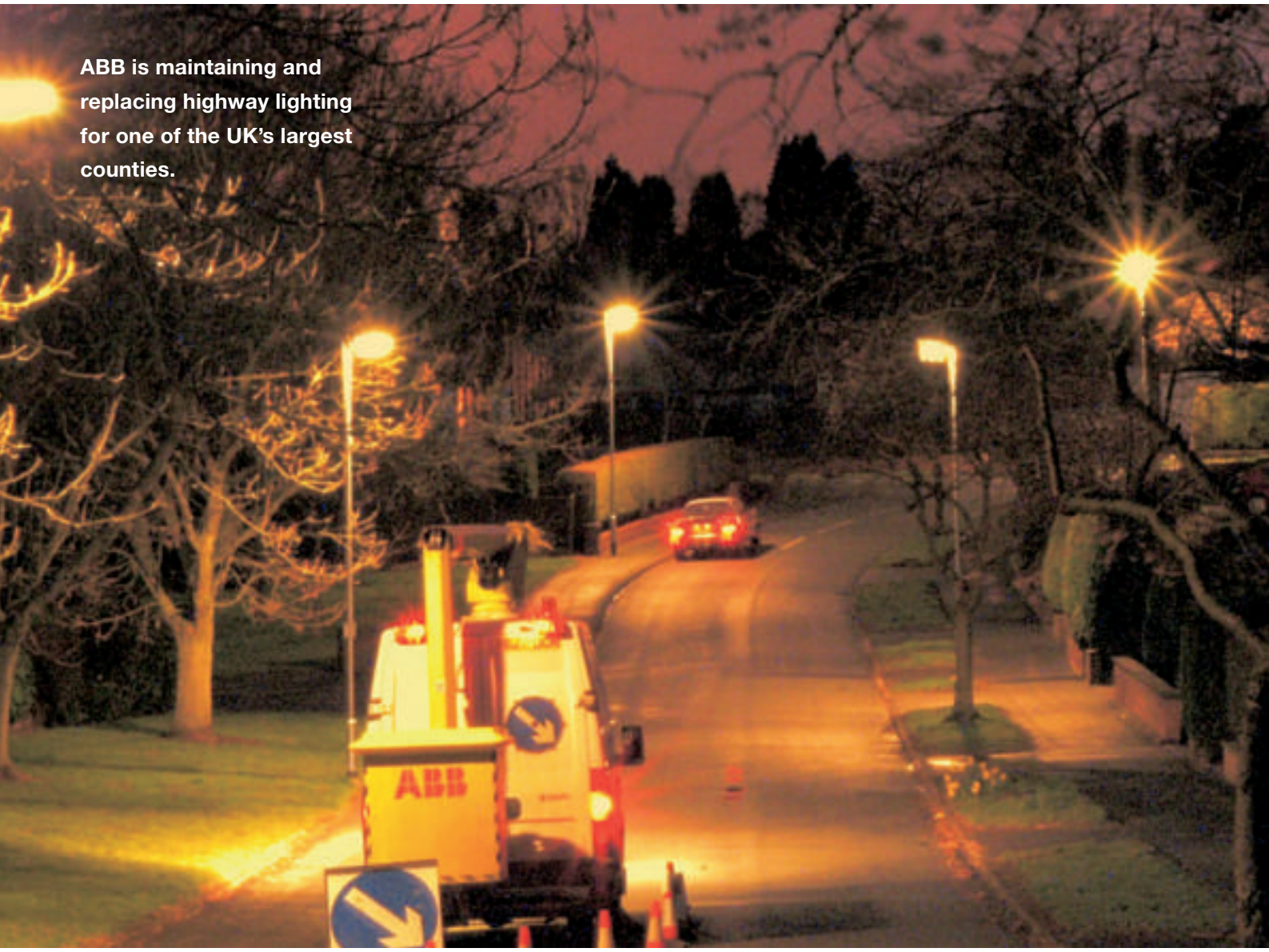


ABB is maintaining and replacing highway lighting for one of the UK's largest counties.

In May 2003, operating under the banner of 'Lighting For Staffordshire', ABB commenced a 25-year PFI (Private Finance Initiative) contract for the asset management of around 106,000 items of apparatus owned by Staffordshire County Council, including highway lighting and illuminated traffic sign equipment. The contract, which should result in fewer accidents and less crime, is estimated to be worth around $11.5 million a year, making it the UK's largest privately funded highway lighting programme.

The contract is estimated to be worth around $11.5 million a year, making it the UK's largest privately funded road lighting programme.

Under the terms of the contract, ABB is renewing all items of apparatus which are in poor condition or which exceed their anticipated lifespan. The renewal programme is being planned in five-year phases and ABB expects to replace around 25,000 items of apparatus in the first five years. Initially, the contract focused on the North of the County, and then as the replacement programme gathers momentum it is being extended across all of the County of Staffordshire. To date ABB has replaced 2542 items of county owned illuminated apparatus.

White light

In some areas of the county ABB is taking the opportunity to replace traditional sodium or mercury street lighting with new technology fluorescent lights. These provide a 'white light' which offers the following advantages:

- Improved colour rendering (for Police identification).
- They make a reduction in residents 'fear of crime'.
- Encouraging and aiding mobility of pedestrians during the hours of darkness.
- Increasing driver reaction time by up to 50 percent, which improves road safety.
- Improving the night time street scene and the overall quality of life for residents.
- Residents prefer the 'brighter' white light as it makes them feel safer.

There is also a problem with older type luminaires in that the optics do not properly control the direction of light. This leads to light being directed into areas other than the road and pavement and a substantial proportion goes up into the sky causing unnecessary light pollution (sky glow). However, the new technology luminaires have advanced optical performance, enabling light to be directed more precisely and making more efficient use of light on the area to be lit and minimising sky glow.

So far, well over 100 streets in the county of Staffordshire are already seeing the advantages of white light.

Asset management

The asset management of Staffordshire's existing lighting stock is a key element in the PFI project. ABB is inspecting every single item of apparatus at least once a year to ensure that its electrical safety, optical performance and structural condition are acceptable. A lighting column has a life expectancy of 40 to 45 years, while the average modern lamp, in use from dusk to dawn, will last for around three years. Anything which does not meet ABB's standards is being repaired or replaced. Lamps are

What is PFI?

The Private Finance Initiative (PFI) was announced by the UK government in 1992 with the aim of achieving closer partnerships between the public and private sectors. It provides a framework in which the public sector can contract to purchase services from the private sector on a long-term basis so as to take advantage of private sector management skills incentivised by having private finance at risk.

With PFI, the public sector defines what is needed to meet the public needs and ensures, by contract, delivery of the output it sets. Consequently, with PFI the public sector can harness the private sector to deliver investment in better quality public services while maintaining frontline services in the public sector.

The UK government only uses PFI where it is appropriate and where it expects to deliver value for money based on an assessment of the lifetime costs of both providing and maintaining the underlying asset and of the running costs of delivering the required level of service.

To date over 300 PFI projects, each with a capital value of over $27 million and a combined capital value over $69 billion have been signed. In 2003-2004 PFI is projected to make up 11 percent of total investment in UK public services.

also being renewed on a regular basis to maintain lighting standards.

ABB has been set a target of ensuring that a minimum of 98 percent of all highway lighting in the County is working correctly at any one time. To help achieve this, ABB patrollers are scheduled to visit each item at night once a month in the summer and twice a month in the winter. Any faults identified by the patrollers are recorded and repaired. Currently, ABB is exceeding this target by keeping over 99 percent of the lighting stock in full working order.

About Staffordshire

Staffordshire, located between Manchester and Birmingham, is at the heart of the UK's geographical and industrial heartland. With a population of over 800,000, Staffordshire is the seventh largest county in the UK. It comprises eight districts, several large towns and two cities set amongst 260,000 hectares of unspoiled countryside.

Faults and emergencies

In addition to ABB's own monitoring, around 200 fault reports a week are received from the public, either by telephone to a dedicated call centre or via a special website[1]. ABB aims to repair most faults within five working days. ABB also receives around 40 emergency calls a week, where there is a risk to life or property. For these cases a two-hour response is provided – at any time of day or night – and out of the first 1200 emergency reports, ABB was late just once, and then by just one hour.

A two-hour response is provided – at any time of day or night.

Primarily, ABB sees its role for Staffordshire County Council as an asset management service. So as well as making sure that the county's road lighting stays lit, ABB is working to ensure the longevity and reliability of the lighting stock to maximise the return on both ABB's and the council's investment in the maintenance and renewal programme. The feedback ABB has received from the Staffordshire County Council is that it is delighted with progress on the PFI project, and this is also opening up opportunities to undertake additional work, both for the council and for private developers, such as providing lighting schemes for new housing developments.

[1] www.lightingforstaffordshire.net

Paul Northwood
ABB Power Technologies
Stone, UK
paul.northwood@gb.abb.com

Informed planning

A web-based solution for integrating electric utility asset information

Robert Glickman, George Frimpong, Tim Taylor

The customers of an electricity utility company expect the power to be there every time they switch on a light. Any failure to meet this expectation can affect the productivity of industries and damage the regional economy.

However, the utility provider is also limited in its means, as it is required to produce economically.

Are the twin goals of reliability and productivity incompatible? Not if a good asset management program is used. Reliable knowledge of the status of equipment permits better anticipation of maintenance and effective deployment of resources.

ABB's Asset Sentry software breaks through this Gordian knot. Asset Sentry collects and processes data from all components. Instant access to the status of, and information on equipment is provided to asset managers. Condition data, operational parameters and costs can be evaluated and maintenance planned.

Introduction

The impacts of recent blackouts around the world have enhanced awareness to the need for new technologies in the energy industry. Such technologies include improving performance in grid reliability while minimizing operating, maintenance and capital investment costs. Utility companies are also increasingly recognizing the link between asset management and grid reliability.

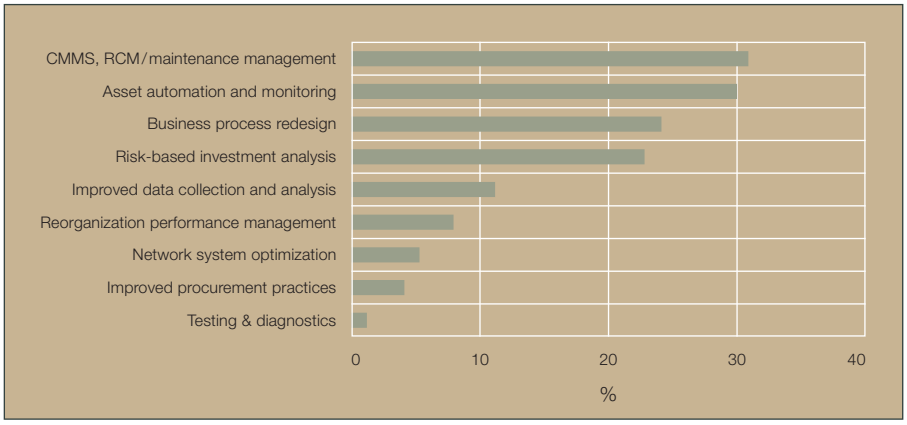
Corporate strategy is crucial in an organization's commitment to change. Interviews with top executives have found that the two highest topics of immediate concern are maintenance management and asset automation and monitoring 1.

For the future, these executives see automation and sophisticated financial planning tools as highest concern 2.

Doubtlessly, these priorities require sophisticated new technologies to support management decisions. Such decisions can range from simple direct actions responding to power grid events (eg, transformer de-rating due to gassing) to strategic investments and process changes required to remain competitive in today's energy industry (eg, restructuring of human and IT resources). One such technology is Asset Sentry. This was introduced by ABB to offer customers better asset management information. Furthermore, Asset Sentry supplies asset managers with database monitoring capabilities to help them understand budget impacts and operations for future automation requirements.

In this article, the challenges faced by asset managers in the energy industry are laid out. The fundamentals of evaluating a business' asset management strategies and processes are introduced. Basic functionality and implementation of Asset Sentry is explained, and information and reports available from Asset Sentry are exemplified. Some benefits from real implementations for those attempting to fundamentally change their own asset management strategies and processes are outlined.

1 Current asset management priorities.
Source: ABB Study: Executive Interviews

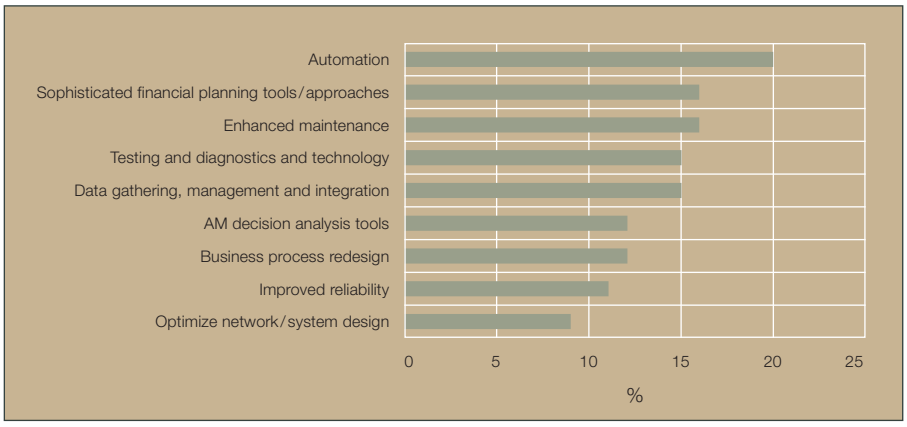


Asset information management challenges

Issues that have been expressed as important by owners, managers and service providers in selecting new technologies for managing their assets include the following:

- Expert technical knowledge with industry best maintenance practices and knowledge of equipment characteristics. This ensures that only the most important and useful information is captured in restructuring the maintenance program. This ultimately impacts the capital budget.
- Knowing with certainty what equipment is actually installed in the field. This is perhaps the biggest challenge to equipment owners. Asset information is typically stored in various database formats in several locations across an organization. When databases are kept independent, this can lead to discrepancies in the data and nomenclature used to identify assets. The ability to have all equipment information in one place will ensure certitude concerning installed assets and improve the integrity of the data. (3 shows the types of information that ABB's Asset Sentry implementation can assemble).
- Gaining control over the operation and maintenance of these assets. Having all maintenance processes in one place is a key driver in the deci-

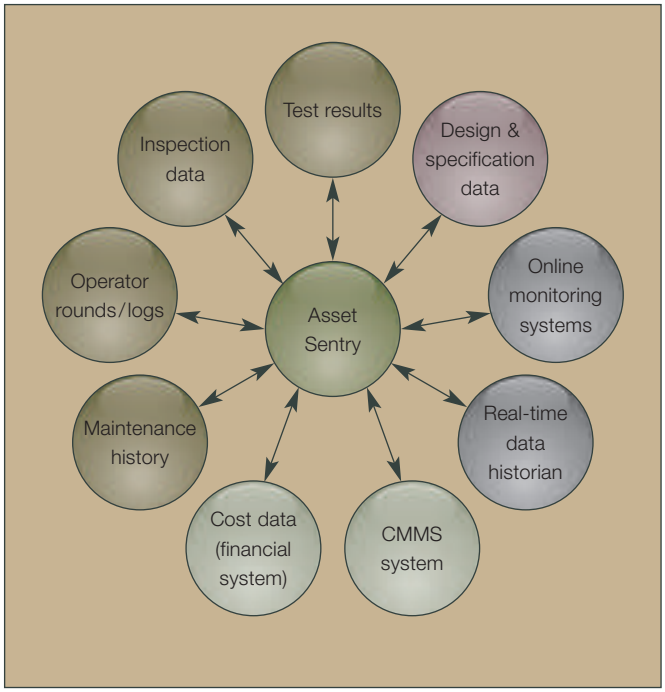
2 Future asset management priorities.
Source: ABB Study: Executive Interviews



sion making process. This includes access to equipment information, maintenance data and maintenance history and activity reports. It is also important to be able to prioritize the corrective maintenance work, the cost and hours required for repairs, the ability to maintain a searchable history of actual work performed and the capturing of root causes and failure modes. (4 shows a typical group of maintenance processes that can be implemented in Asset Sentry).

- The goal is to be able to easily evaluate and analyze maintenance expenditures and address which region, substation, line, equipment or maintenance activity is costing the most.

3 Integrating islands of information.



gether into DGA technology. Further, all DGA analyses for transformers in a substation can be grouped into a *route*, which contains the DGA technology points for all the transformers. Each monitoring point can be set up with two alarm limits that can be triggered based on the value of the measured reading.

Readings that are outside the alarm limits trigger alert notifications that are automatically sent to assigned individuals via email or pager. The emails contain basic information to allow the receiver to identify the problem that triggered the alert; equipment description, location and a description of the alarm condition. The user can then follow a database link to obtain more details on the Asset Sentry website.

Basic functionality of Asset Sentry

Data repository

The pre-requisite for any asset management system is to have a repository for all equipment information. This information may include but is not limited to:

1. Basic equipment information: Description, location and responsible individual or sub-organization, manufacturer, serial number, model number, installation date and design specifications/documents.
2. Equipment specifications: Ratings, basic nameplate information, types and model numbers of accessories.
3. Grid criticality of equipment (the impact of the loss of an item on the total productivity).
4. Historical monitoring activities and measurement data.

Planning and scheduling of maintenance

The second basic functionality of Asset Sentry is to provide the ability to automatically plan and schedule routine and Preventative Maintenance (PM) activities. This allows the entire PM work plan to be automatically tracked. PM activity due dates and PM frequency are entered once for applicable items such as dissolved gas analysis, oil quality, infrared inspection, breaker timing, power factor. Upon completion of every scheduled activity, the system automatically schedules the next due date.

In order to facilitate collection of the appropriate status data during each maintenance activity, monitoring points are setup for each measured parameter. A characteristic of monitoring points is that they can be either numeric or multiple-choice (OK/NOT OK) and are grouped together into measurement technologies defined in Asset Sentry.

For example, all the points collected during a DGA analysis are grouped together into DGA technology. Further, all DGA analyses for transformers in a substation can be grouped into a *route*, which contains the DGA technology points for all the transformers. Each monitoring point can be set up with two alarm limits that can be triggered based on the value of the measured reading.

Asset Sentry has built-in functionality to notify the appropriate people if a scheduled route becomes overdue beyond a certain grace period.

Notification and tracking

Asset Sentry has built-in functionality to notify the appropriate people if a scheduled route becomes overdue beyond a certain grace period. At preset intervals beyond the grace period, a notification can be sent to the appropriate individual until the route is completed.

Alert notifications are automatically generated whenever alarm limits for monitoring points are exceeded. Additionally, an exception report is generated to track the resolution of the problem. Exception notifications can also be generated whenever exceptions are manually entered into the system.

For example, if an oil leak is detected on a transformer while other work is being performed at that substation, it

would be entered against that transformer as a manual exception. The exception would have a general description of the problem, the person who identified it and an evaluation of the severity of the problem using predefined priority classifications.

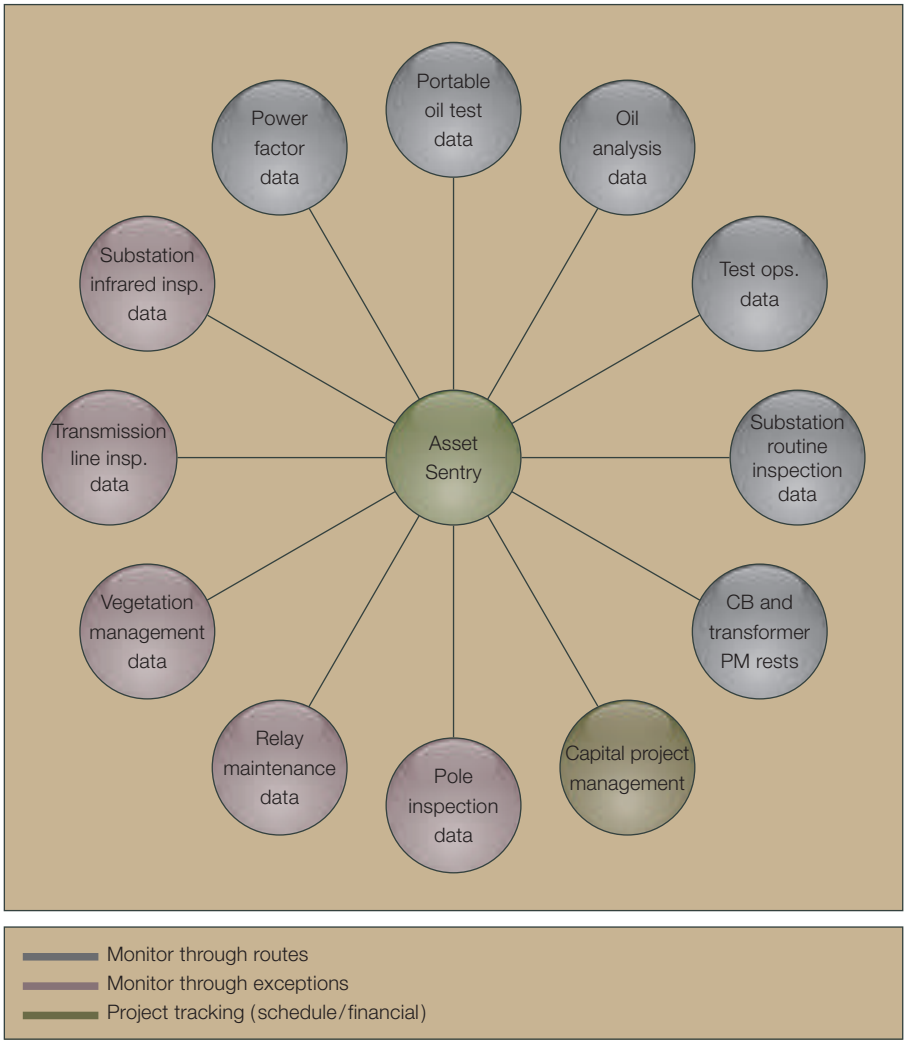
An example process for resolving exceptions is as follows:

1. Notifications are sent to the assigned asset manager and equipment specialist.
2. The equipment specialist reviews the problem, adds analysis comments and recommendations, assigns a failure code, categorizes the condition of the equipment (could be normal, marginal or unacceptable) and provides estimates of time and dollar resources required to rectify the problem.
3. Upon input to the system of item (2) above, a notification is sent to the asset manager for approval.
4. The asset manager's approval triggers a notification to the contractor or service group responsible for correcting the problem.
5. When the work is complete, a notification is sent to the asset manager and a copy to the originator of the problem.
6. All the actual expenditures and labor hours are entered into the system, or are automatically transferred from an accounting system. The exception is then closed, thereby closing the loop in the exception tracking process.

Document management

Asset Sentry allows the storage of all types of electronic documents, including maintenance and testing procedures, equipment specifications, vendor manuals, one-line diagrams, drawings, parts lists, work procedures and maps. In addition, documents specific to an exception (images of hotspots, test reports, etc.) can be loaded and made available within the exception report. These can then be utilized during analysis of the exception. Furthermore, documents can be loaded against a manufacturer and/or model number – this allows service bulletins to be referenced for any particular model of component.

4 Integrating condition monitoring processes



Capital project management

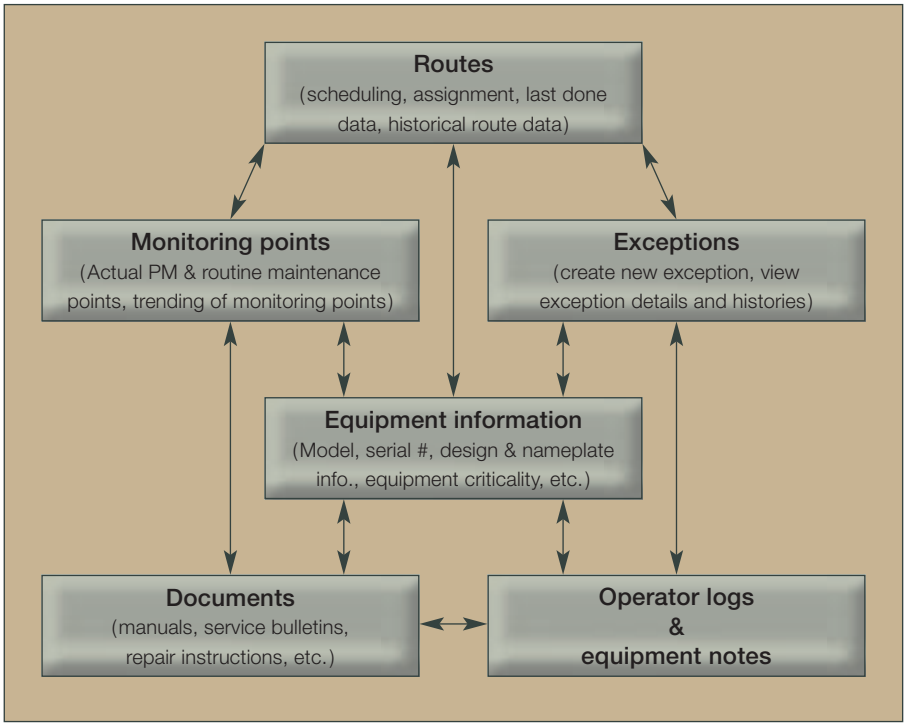
Information on all capital projects can be stored in Asset Sentry, allowing the full scope of project management functions to be performed by the system. An interface to accounting systems also gives the tool access to cash flow data. Project information can be tracked down to the level of individual work orders or in aggregate for the entire project.

Typical implementation

The scope of implementation performed to date for customers ranges between 8'000 and 20'000 assets. For example, transmission implementations may encompass the following substation components: air circuit breakers, air break switches, batteries and chargers, capacitor banks, circuit switchers, air compressors, current transformers, disconnect switches, ground switches, lightning arrestor, LTC transformers, motor operated switches, oil circuit breakers, potential transformers, power transformers, reactors, relays, SF_6 breakers, station power generators and station power transformers. In addition, transmission line segments may be loaded into the system.

Monitoring points for substation inspections and data such as power factor, comprehensive oil analysis, portable oil test and test operation processes can be implemented. These can be used for

5 Condition monitoring in Asset Sentry.



monthly substation inspections, testing, maintenance inspections or predictive maintenance data collection. Infrared inspection, transmission line inspection, relay maintenance, pole inspection and vegetation management processes may also be included and monitored using data collection routes or exceptions within Asset Sentry. The choice will depend on the depth of maintenance details desired by asset managers.

As part of the implementation process, the customer's database must be configured, equipment information tables populated and the overall system hierarchy put in place. For example, data may be setup in a four-tier hierarchy with the following levels: Region (North, South, East, West), Area (City), Substation/Line (Airport Sub) and Equipment (Components – which include substation equipment, all line segments and relays). In addition, all equipment information and specifications are migrated/loaded into the system. In order to access information on any equipment in the system, the user follows the equipment tree from the region down to the specific equipment.

Asset information is displayed through various web pages. There are embedded links on the equipment information page to various pieces of information.

For example, users can link to the exception report to identify all exceptions associated with given equipment, or link to the monitoring tasks to review all monitoring points set up to monitor the condition of that equipment 5. Users can also link to the routes used to collect condition data on equipment. Furthermore, manuals can link to all documentation (service bulletins, manuals, configuration files, etc.) for that equipment, as well as to associated logbook entries and notes or create an exception associated with this equipment.

Asset Sentry provides several custom reports for tracking performance of routes and equipment condition.

Asset Sentry information and reports

Searching for information

Perhaps the most important aspect of asset information management is the ability to find key information quickly. Asset Sentry provides a search engine with various data filters that allow practically any asset information to be sought and displayed. Searches can be performed on either equipment or exception information. For example, answers to the following questions can be readily obtained:

- Where are all the Type U bushings located on the system (or substation, area or region)?
- What are the locations of all the ITE SF_6 circuit breakers that were installed on the system between 1969 and 1980 that have serial numbers containing the string 'BUZ'?
- How many oil circuit breakers of a certain vintage are installed on the system and where are they located?
- How many air compressor leaks have been recorded within the past 6 months and on what components?
- How many open exceptions are on the system (region/area/substation or specific component)?
- Which exceptions have been approved for repair but are still outstanding?

The search engine returns listings of all equipment or exceptions meeting the specified criteria. Each item on the list is a hyperlink either to the equipment information or to an exception report.

Reporting

The usefulness of an asset management system lies in its ability to convert the stored data into report information. Asset Sentry provides several custom reports for tracking performance of routes and equipment condition. Reporting is

accomplished through a Crystal Reports engine. Reports can be customized with filters for key parameters of the data (eg, location, equipment type and subtype, manufacturer, date ranges, technology).

For example, a report can be generated that shows the predominant failure modes for all equipment types on the system or at a specific location 6. This report can be further customized to show the failure modes for just one manufacturer. Here are a few examples of reports that aid the asset management process:

- Tracking how many exceptions are generated by region, station or equipment to date or within any time interval.
- Tracking the effectiveness of analyzing and resolving exceptions identified on the system (show how many exceptions identified, approved vs. closed).
- Tracking the effectiveness of contractors in completing approved work.
- Performing failure and root cause analysis to help identify the most common failure types for components in the system.
- A trend engine can also be activated to review the trend of any of the recorded numeric monitoring points.

In addition to the custom reports in Crystal Reports, the system allows data from every report to be exported to Microsoft Excel. This allows increased flexibility in performing specialized analysis in Excel.

Maintenance decision support

A new module recently developed by ABB provides advanced analysis of the condition data in Asset Sentry. The maintenance decision support system MDSS[1)] is interfaced with Asset Sentry to provide decision support for maintenance actions. With MDSS, users can define advanced rules that govern the diagnosis of various technology measurements (eg, DGA, power factor, breaker timing). These rules can transcend technologies and can be derived from such sources as

- IEEE and IEC guides for interpreting condition data
- Manufacturer technical guides
- Perhaps most significantly, from the intrinsic knowledge of technical experts and consultants

When condition data is entered for any equipment in Asset Sentry, it is automatically analyzed by using the rule sets in MDSS. Where abnormal conditions exist, information on the analysis and recommended actions are entered in Asset Sentry as an exception. This immediately triggers the appropriate notifications for review and action. 7 shows analysis and reporting of dissolved gas data recorded in Asset Sentry.

> In some cases the auxiliary components can be just as critical to operations as the major assets.

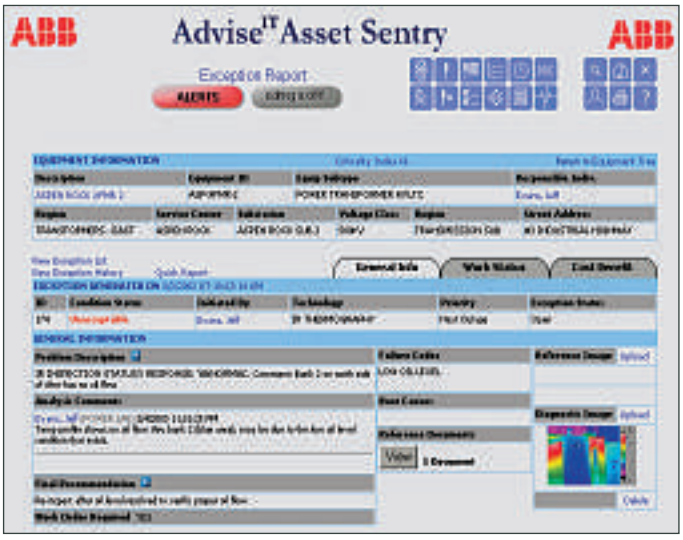
Through using MDSS, the real power of Asset Sentry – analyzing data and providing expert recommendations for maintenance actions – can be realized.

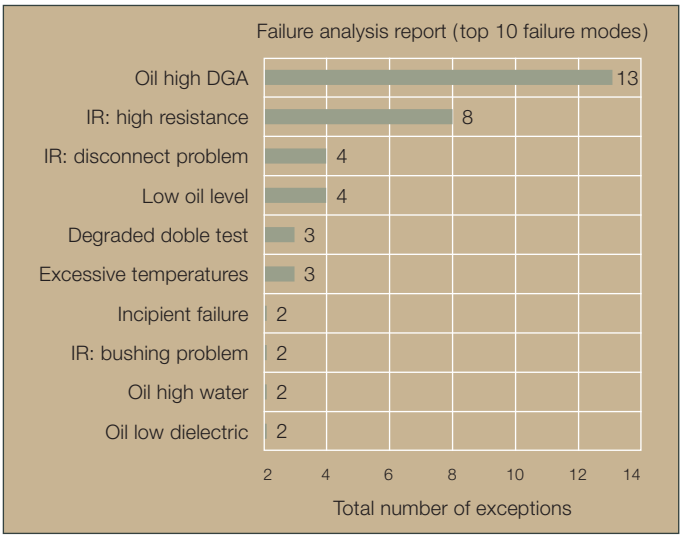
Summary of benefits of Asset Sentry

Perhaps the largest benefit expressed by current users of Asset Sentry is the

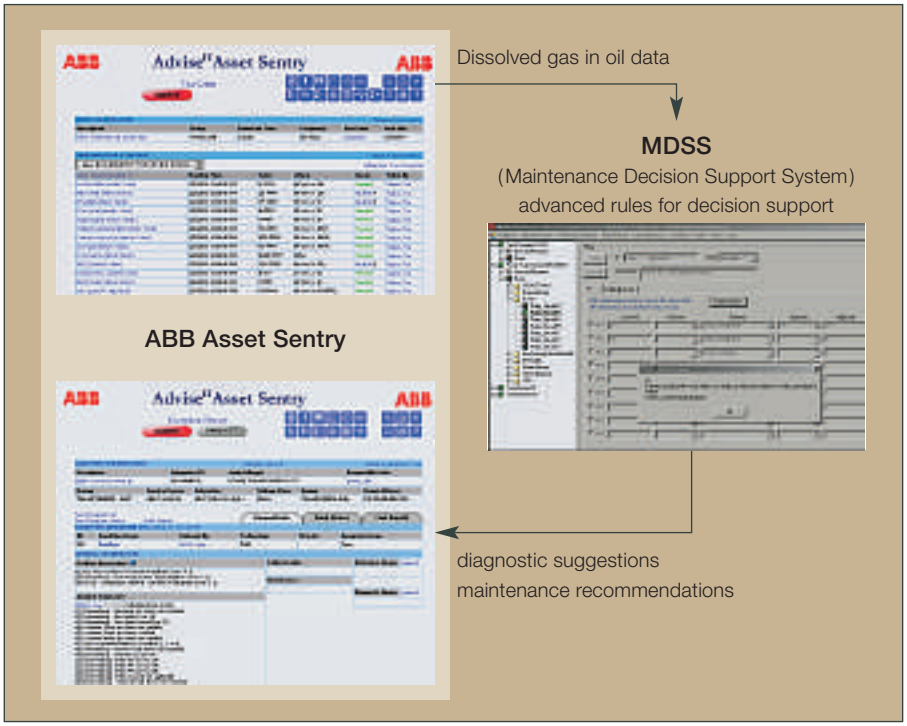
[1)] See article 'Approaching decisions: The complementary solution to the maintenance planning problem' on pp 43–48 of this edition of ABB Review Special Report for a more in-depth discussion on the functionality of MDSS.

6 An exception displayed in Asset Sentry (left) and failure analysis mode (right)





7 Analysis and reporting of dissolved gas in oil data.



ability to have at their finger-tips, a centralized easily accessible information source, without the burden of IT support and software updates. This reduces total ownership cost and makes it easy to include an inventory of major assets (transformers, circuit breakers, etc.) as well as an accounting of auxiliary components. In some cases the auxiliary components can be just as critical to operations as the major assets.

In the setup phase, information on the assets may be received in various database formats. In typical utility settings, databases are kept independent of each other leading to obvious discrepancies in the data and nomenclature used to identify assets. Asset Sentry provides a simple means of warehousing all relevant equipment data in one place to ensure uniformity and data integrity.

As part of the implementation, customers have at their disposal ABB's expert technical knowledge with industry best maintenance practices and knowledge of equipment characteristics. This ensures that only the most important and useful information is captured in restructuring the maintenance program (which ultimately impacts the capital budget). Several information sharing sessions on the assets and brain storming sessions on maintenance processes must be held between the owner, asset manager, service provider and Asset Sentry experts. This is crucial for better understanding of the processes and utilizing the systems to full capability.

Customers have at their disposal ABB's expert technical knowledge with industry best maintenance practices and knowledge of equipment characteristics.

With Asset Sentry, customers have the ability to store all maintenance processes in one place; equipment information, maintenance data and history for all maintenance activities, and reporting on activities. They also have the ability to prioritize the corrective maintenance work, capture the cost and hours required for repairs, maintain a searchable history of actual work performed, and capture root causes and failure modes.

Furthermore, Asset Sentry allows customers to easily evaluate and analyze maintenance expenditures by identifying areas or equipment that are the highest contributors to maintenance expenditures.

The selection of Asset Sentry and the technical expertise provided by ABB has proven to be invaluable to customers and the management of their assets

Robert Glickman
ABB Inc.
robert.glickman@us.abb.com

George Frimpong
ABB Inc.
george.k.frimpong@us.abb.com

Tim Taylor
ABB Inc.
tim.taylor@us.abb.com

Extreme maintenance

No location too challenging for an on-site repair!

Sonia Potsada, Ronaldo Marcondes, Jose Carlos Mendes

When a transformer fails in a plant, it is usually shipped back to the factory for repairs as soon as possible. However, what do you do when the transformer weighs more than 180 tons and the nearest factory is 1200 km away? And additionally, the state of the roads makes transport slow, expensive and increases the risk of damage? This is exactly the situation that confronted ABB when called upon to repair a transformer at the Itaipu power plant on the border of Brazil and Paraguay.

Rather than move the transformer to the factory, a complete factory was taken to the transformer! A fully equipped workshop including clean room was constructed on site. The transformer was taken inside, dismantled, repaired, reassembled and tested locally. This flexible and innovative approach reduced down time,risk and cost for the customer.

Power transformers represent a considerable investment and customers expect to keep them running for as long as possible – optimally and trouble-free. However, the older a transformer gets, the higher the probability that a breakdown will occur. The service and support side of ABB Transformers is there to ensure their continuing performance. Guided by diagnosis and preventive maintenance as well as regular inspections, proper service work can be implemented by their customers, either utility or industrial, to ensure optimum availability of his transformers.

Refurbishment, service and repair as well as on-site work are growing in importance because the average age of power transformers around the globe is approaching the final phase of their lifecycle. A power transformer failure can, and usually does, have serious consequences through the loss of electricity supply. The financial issues related to such a shortfall are significant. Penalties for non-delivery are extremely high for the simple reason that a non-delivery situation directly affects the customers of the utility, who in the worst case have to shut down their own production facilities causing severe economic difficulties. This negative chain reaction also demonstrates the responsibility that power suppliers are faceing and explains why reliability and availability are such important key words within the industry.

Service portfolio and on-site repair solution for a longer life

ABB covers a wide range of service and support activities in order to guarantee that transformers stay on-line. Regular maintenance carried out professionally and proactively contributes towards optimum transformer performance.

The main areas of service and support are:

- On-site preventive maintenance
- Spare parts supply
- Condition assessment including advanced diagnosis and monitoring
- Engineering support
- Workshop repair
- On-site repair or retrofit.

ABB workshops and service centers worldwide provide a complete portfolio of solutions to care for transformers produced by all manufacturers in all phases of their life cycles. Of course, all the work carried out by ABB's experienced and professional staff follows accepted international standards.

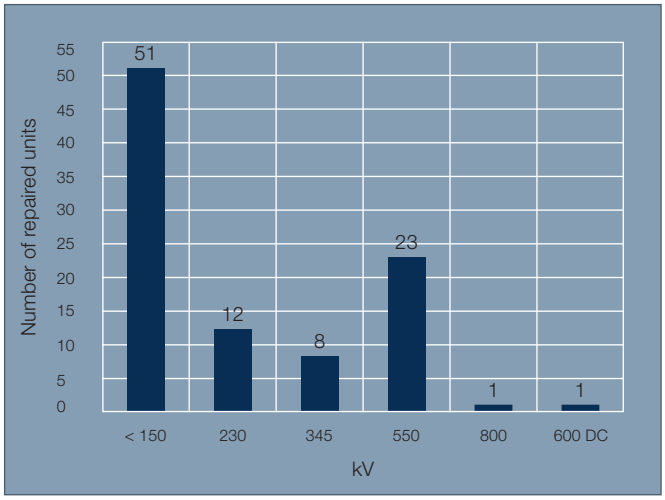
ABB makes efficient use of state of the art tools in its workshops around the world to design, produce and test the transformers repaired in its factories. However, ten years ago, several large utilities in different countries, but especially in Brazil and South America in general 1, asked for new solutions that would allow the repair of large units directly on site.

These requests were driven mainly by transport issues in remote regions or in areas with difficult transportation conditions. The challenges for the transformer owners were to find a way to:

- Reduce repair lead-time of failed units.
- Reduce transportation costs.
- Avoid risks linked to transporting aged units under tough conditions.
- Ensure the same high quality standard was available as for work done in repair shops.

1 Map of South America showing locations of on-site repairs of high voltage power transformers.

2 On-site complete repairs from 1992 to 2003.



Several manufacturers have offered site repairs for many years, but ABB's goal was to set up a professional process to provide a quality and cost effective solution.

An important component of the on-site repair process is the high voltage test capability. High voltage on-site tests for power transformers are one of ABB's important developments. This is of growing interest, either as part of transformer commissioning or as a diagnostic assessment tool after a failure or as a preventive check. This capabilty is also used as an acceptance test after transformer repair or refurbishment.

A detailed on-site repair project

Experience counts

ABB has a global presence, which demands the highest of standards in differing economic and environmental situations. ABB Power Technologies in Brazil has carried out more than 96 on-site repairs of transformers for electric power supply companies as well as industrial plants. Not all of these transformers were ABB transformers, hence the service teams were faced with different technologies.

2 shows the repaired transformers in their various power classes. Since 1992 more than 520 transformers have improved their performance and reliability after on-site repair work was carried out.

Background Situation

This on-site repair study is centered on the Itaipu Power Plant 3. This is the largest hydro power plant in the world and is situated on the Parana River, bordering both Brazil and Paraguay. It has a generation capacity of 12600 MW with an additional 1400 MW coming on-line during year 2004. The power plant is connected via two main transmission links to the heavy industrial load centers of Sao Paulo and Rio de Janeiro. The distance from the power plant to the main centers is more than 900 km. The HVDC transmission system is located near Foz do Iguaçu and has been in operation since 1984.

Repairs of high voltage power transformers

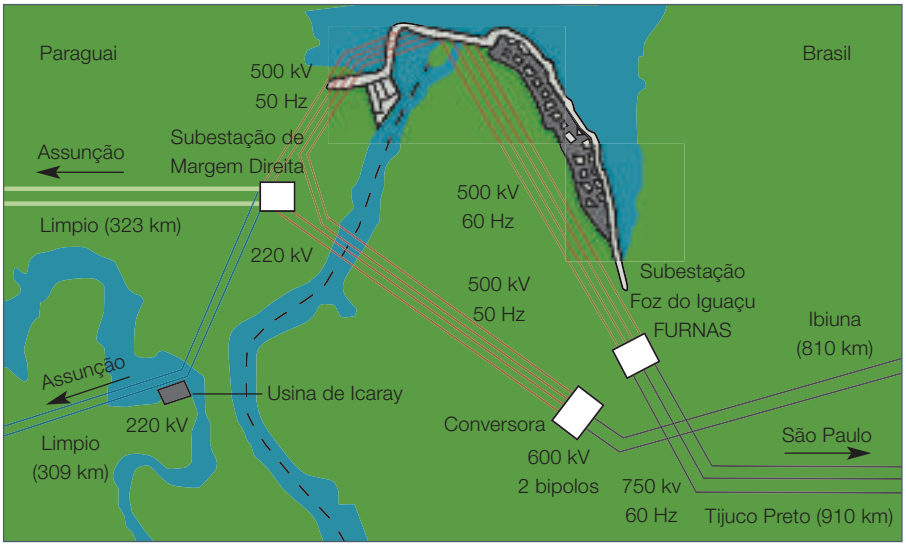
For many parts of the world a large distance between generation and consumption centers is typical. Such geographical difficulties are challenges the ABB service teams often have to face. The importance of the stabilizing effect the Itaipu power system has on the whole Brazilian network and the associated economy must not be underestimated.

Scenario

The story begins in 2002 when an electric failure damaged one of the converter transformers installed at Foz do Iguaçu. The required repair work entailed a complete replacement of the winding blocks.

The larger transformer factories are centered around Sao Paulo. This means that the distance that would have to be covered by large and heavy custom

3 The substation at Foz do Iguaçu and its importance in the transmission system.



trucks is approximately 1200 km (one way). In this particular case the time involved would have been about 60 days as a result of the geographical and infrastructure conditions. The total cost for such a site-factory-site solution would be more than $1 million. In addition the risks of damage as a result of the complex transportation route should not be underestimated.

The decision was made to carry out the operation on-site. This was to become the first on-site repair of such a large HVDC converter transformer in Brazil.

The on-site repair process

An experienced team of transformer specialists are required to perform on-site repair of high voltage transformers. This is where the quality and standards of the experienced ABB service team has its chance to show its competence. First, the site repair facility must be erected and the transformers hauled there. The draining of oil and disassembly of the active part follows. The necessary core repairs are carried out and new parts are installed. Now re-assembly of the active part begins followed by on-site drying. Finally, the on-site routine of high voltage testing takes place to ensure that all is well.

4 The metal house erected for on-site repair at Foz do Iguaçu.

Erection of the site repair facility

In order to carry out such an on-site repair it is necessary to erect a repair facility with a solid foundation. In this case the metallic housing had an area of 500 m² and was 20 m high 4. It was erected on a spare transformer base. Environmental circumstances had to be taken into account: The repair facility was built to be able to withstand winds of 150 km/h and to remain watertight under heavy rainfall. Within the metal exterior, there was an internal extra-clean room. This provided a controlled environment for assembling the active part. The weight of the transformer's active part was approximately 180 tons and the lifting equipment used had a capacity of 400 tons 5.

Additionally, dry air generation stations (air dew point of < –30°C and air outflow above 400 m/h) were installed to guarantee that the transformer's active part as well as the extra-clean room was under a continuous and controlled dry airflow with a positive pressure. A mobile station with vacuum, drying and oil treatment equipment was brought on-site. The necessary mobile lifting devices (mobile cranes) and the lifting devices needed for the assembly and pressing of the active part were also erected.

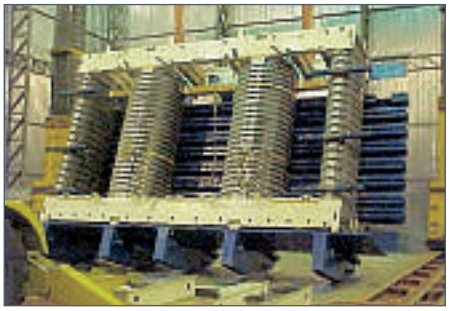
The project step-by-step

After the draining of oil from the active part, the upper core frame was opened and the upper core yoke disassembled. The opening of all internal lead connections and the disassembly of the HV winding connections and the pressboard lead structure followed. The next step was the disassembly of the windings, main insulation and core-winding insulation. Special lifting devices driven by the mobile auxiliary crane were used to remove the windings from the core limbs.

The repair was carried out including the replacement of the complete pressboard core insulation by fiberglass material. In order to retighten the core it had to be placed in a horizontal position. For this purpose a mobile core stack table capable of supporting 180 tons was constructed 6.

5 Lifting equipment inside the metal house.

6 Repairing the core. Assembled mass: 173 tons.



All parts delivered from the factory, such as windings and main insulation, had already undergone intensive in-factory tests. Measurements such as winding ohmic resistance, voltage ratio (with auxiliary test core), measurements of leakage magnetic flux and applied voltage between parallel conductors had been recorded.

The next step in the process was the on-site assembly of the active part and its tank, final pressing and the external assembly.

The on-site drying process is carried out after the assembly and tanking of the transformer's active part. It is made up of a series of successive cycles of vacuum and hot oil circulation. After each drying cycle, the control parameters are checked. These are vacuum time, vacuum pressure, core temperature and insulation and oil temperature. The quality of the on-site repair process, with its drying, low final moisture and high quality insulation of the transformer, is comparable to an advanced in-factory drying process.

Quality control is, of course, a very important aspect. Every phase of the process is recorded according to internal procedures certified in compliance with ISO 9001 and ISO 14001.

After re-assembly the final electric tests were carried out.

On-site electric tests

A complete set of mobile testing equipment was shipped to the repair facility. This included the following components:

- Variable frequency 60–240 Hz motor-generator group. There are three motor-generator groups available: 300 kVA, 850 kVA and 2MVA. The proper group is selected according to power and voltage rating of the transformer.
- Step-up and regulating transformers.
- Reactive power compensating capacitors and reactors.
- No-load and load measuring system.
- Partial discharge measuring and monitoring system as per IEC60076-3 and IEC60270.

7 depicts a general single-line connection diagram of the test setup normally used for HV power transformer on-site testing.

The following on-site tests were carried out:

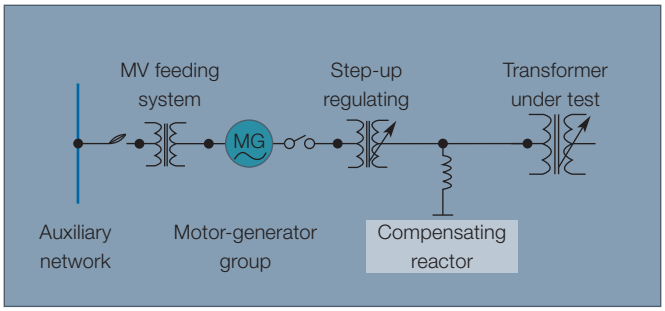
- Routine tests: Insulation resistance (core and structure-core); polarity, phase angle displacement and phase sequence; voltage ratio; measurements of winding ohmic resistance; insulation resistance measurements (Megger), insulation power factor measurements (Doble) and insulation capacitances of windings and condensing bushings; verification of accessories, functional tests and thermometer calibration.
- Loss measurements: no-load losses and excitation current at 90%, 100% and 110% of rated voltage; load losses with reduced current and short-circuit impedances.
- Dielectric tests: applied voltage, long-term induced voltage (1 hour) with monitoring of partial discharges and voltage level up to 150 percent of rated voltage; no-load energization with rated voltage during 24 hours with monitoring of partial discharges.
- Special tests: frequency response (FRA), in some cases.

Project conclusion

The successful conclusion of the project demonstrates the value of on-site repair work as a solution in areas that present geographical and infrastructural challenges with regard to transportation.

The whole project was a cost effective and reliable solution, which reduced the mean time to repair, increased transformer availability and avoided transportation risks. ABB's dedication to service has provided the operators with a reliable and long-lasting solution providing benefits at all stages.

7 Test setup: single-line-diagram.



Sonia Potsada
ABB Transformatoren GmbH
Mannheim, Germany
sonia.potsada@de.abb.com

Ronaldo Marcondes
Jose Carlos Mendes
ABB Ltda.
Brazil
ronaldo.marcondes@br.abb.com
jose-carlos.mendes@br.abb.com

Powering innovation

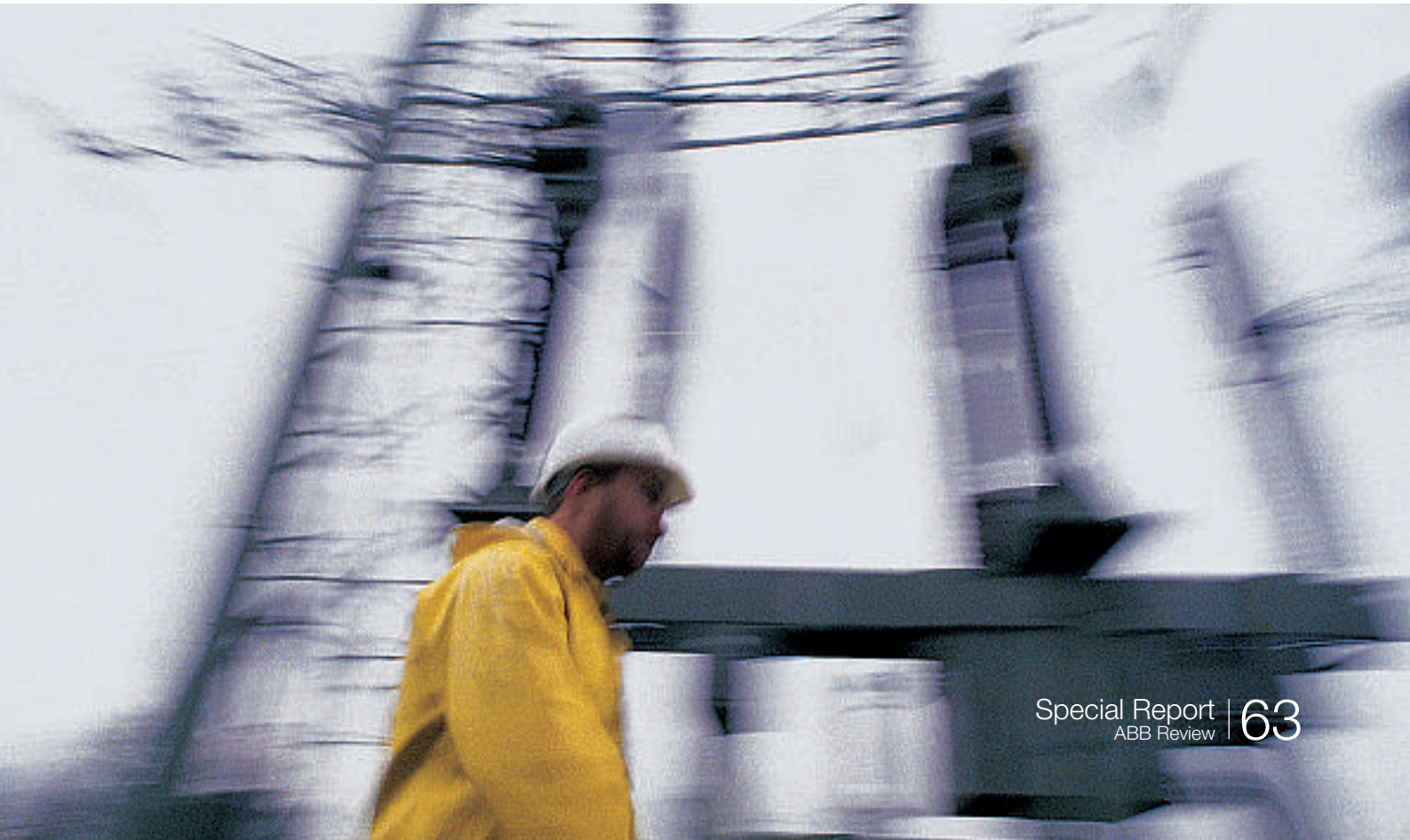
Innovative service solutions for power generation

Hans-Peter Heil, Rolf Klare

Due to the liberalization of energy markets, competition in the worldwide supplying industry has toughened. The final consumer demands stable prices, whereas energy suppliers face pressure to reduce costs in such sectors as fuel, personnel, assets, maintenance and modernization.

As little as fifteen years ago, the emphasis of control technology support for power stations was on hardware maintenance of customized mainframe computers. Today this is radically different: As before, service contracts are the backbone of the link between equipment operators and ABB. Today, however, service concentrates on supporting power-plant-specific software. Furthermore, the reduction of customer maintenance personnel leads to additional demands on the flexibility of ABB service.

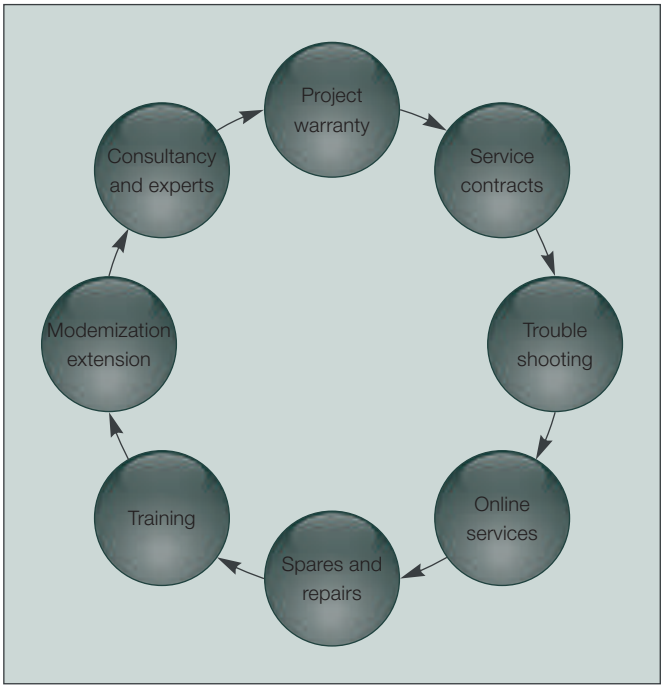
The broader service portfolio includes measures for increasing the operational efficiency of power plants. Tried and tested methods are provided for optimizing equipment, boiler and turbine start-up and load operation. The upgrading of control technology to meet modified market conditions or operating patterns is also included in the portfolio. Every service solution is a blend between protecting the customer's investment, drawing advantage from modern technology and cutting operating costs.



Service contracts

ABB has service contracts with many customers across the globe 1. This arrangement presents several advantages to the customer: they can model service packages according to their precise needs and have calculable annual service costs. Besides reducing technical liability, this also lessens the financial risk for the customer. Furthermore, even for services going beyond this for which ABB must charge, there are financial advantages. Moreover, response times are fast and predictable. This type of long-term cooperation between ABB and customers leads to reduction of failures, shortening of down-times and so to an improvement of equipment availability.

1 ABB supports customer equipment throughout its lifespan.



Typical performance related components of a service agreement are:

- Fault correction
  - Hotline service
  - Remote service
  - On-site service
- Preventive maintenance / condition oriented maintenance
- Spare part pooling
- Software service

Hotline / expert service

A hotline guarantees customer access to the service organization around the clock, every day of the year, ensuring a fast response when a fast response is needed. Familiar partners and dependable communication are there to help when a fault occurs – initial support is provided by telephone. The customer receives speedy and professional assistance in identifying and correcting the problem.

The hotline also provides advice on everyday problems. The customer talks directly to qualified service technicians with the latest technology at their fingertips. ABB service centers around the globe have access to knowledge and product data banks. Furthermore, service technicians are prepared to intervene within an agreed time-frame.

2 ABB service centers permit remote service via a direct data link.

Remote service

Remote service connects the ABB service center 2 to the customer's control infrastructure via a direct data link. Here too, ABB assures the rapid reaction of the service organization. The direct link (for example using an ISDN line) enables the highest possible quality of support through the best possible quality of information. Verbal communication and complex instructions are bypassed because ABB can look directly into the control system and perform a qualified diagnosis from the service center. If the problem can be solved without a technician traveling to the site, the customer saves time and money. ABB support provides the following benefits:

- Support when problems occur through remote access
- Analysis and diagnosis of the control technology
- Analysis and diagnosis of computer systems and networks
- Analysis and diagnosis of process and archive data

An advanced security strategy protects the equipment from unauthorized access.

On-site service

If the customer has an 'on-site' agreement with ABB and requires assistance, ABB will be on-location very quickly. Through the preceding hotline contact and remote service, ABB's technicians are already familiar with the problem and have the necessary specialized tools with them. ABB guarantees reaction times for on-site intervention. Such intervention includes not only analysis, diagnosis, remedy and recording of results, but also the identification of vulnerabilities and systematic suggestions for improvement. If the customer has a spare part pooling agreement with ABB, the tech-

3	Final check before restarting a power plant.

nicians will also bring original spare parts.

The on-site service does not only cover control technology: Other components, eg, analysis technology, measurement technology and electro-technical affected by the fault are also included in the diagnosis and repair.

Preventive / condition oriented maintenance

The surest protection against failure is scheduled and requirement-focused preventive maintenance. Together with the customer, ABB draws up a systematic maintenance plan. A suitable task-sharing agreement is laid down. This includes:

- Maintaining control and electro-technical components according to individual maintenance schedules.
- Identification and replacement of components at risk.
- Maintenance reports with recommendations for the further planning of maintenance.
- Regular inspections to verify the functional efficiency of, eg, turbine, boiler and block protection.

Spare part pooling

Within the scope of a spare part pooling agreement, ABB delivers parts within an agreed response time – enabled by modern logistics. This reduces risks as well as investment and warehousing costs for the equipment operator. Whether replacements are sought for defective equipment or spares stores are to be optimized, ABB helps with advice as well as with the parts.

Spare parts can be single original items or substantial packages for the parts store. Based on the spectrum of equipment on-site, ABB advises on the optimal compilation of spares packages.

Advice and optimization

What must be done to boost productivity and cut operating costs? To systematically ascertain the necessary measures, ABB offers equipment audits. Besides a tailor-made suggestion for a maintenance contract, this audit can suggest measures to:

- Minimize fuel consumption
- Maximize production
- Cut emissions
- Boost availability
- Lower planned and unplanned down times
- Increase productivity of operating personnel deployment

Optimizing the start-up of boiler and turbine

ABB's Boiler Start up Optimization is primarily focused on identifying an optimal steam generator start-up strategy. A prediction of steam temperature and pressure development permits an optimal starting and loading of the turbine (as the thickest walled element of the entire steam power plant).

Optimizing load operation

The control method for optimized load operation relies primarily on the use of process-models in all significant areas of the power station process (feed water, air and load regulation). The main task of the superposed load regulation is coordinating the operating modes of the steam-generator and turbine. ABB uses model-based unit control, MODAN and MODAKOND, for fast reactions in frequency support. These methods are universally designed for almost any type of fossil fuel power station. Through the improvement of control performance and fuller use of material capability, equipment efficiency is boosted with a very short amortization period.

> The surest protection against failure is scheduled and requirement-focused preventive maintenance.

ABB's Turbine Stress Calculator: universal thermal load calculator

On older steam turbines without load calculator, ABB's Turbine Stress Calculator enables shorter heat-up and load delays. Such time-savings have direct economical benefits.

Turbine Stress Calculator is a new software application that calculates the total thermal load of steam turbine rotors. It uses available measurement data such as steam pressure, temperature and turbine speed without requiring additional measurements (or even drilling into the turbine). Almost all steam turbines can be equipped with this modern load calculator.

4	Service is teamwork.

Industrial^{IT} for power plant management

Inform^{IT} Information Management collects, archives and consolidates data from the power station process, control technology and accountancy. It performs remote diagnosis of different components, feeds data to other application (eg, performance monitoring and schedule optimization), enables Excel reports and serves data to accountancy.

Another program, Advise IT Performance Monitoring measures real-time performance of individual components such as heat-exchangers, pumps, motors, but also the entire power station complex. Elaborate analysis functions expose the causes of power drops, identify the components at fault and suggest suitable measures to achieve the necessary efficiency improvements.

Optimize^{IT} Simulation & Validation predicts the efficiency of the power plant under different operating conditions. This model-based tool simulates the thermodynamic behaviour under differing ambient and equipment conditions and permits 'what if' scenarios for developing optimal operating strategies and so cut operating and maintenance costs.

Industrial IT for Asset Management

This package includes tools with which utilities can optimize the lifetime and value of their assets. Optimize IT Lifecycle Optimizer optimizes power revenue considering production costs and equipment depreciation. Another tool from this family is Support IT CMMS Interface for SAP and Maximo: This permits vertically integrated solutions such as condition-oriented maintenance, maintenance history and spare parts management.

Industrial IT for combustion optimization

Combustion optimization is about improving efficiency and reducing NO_x and CO values. The parameters with the greatest influence on efficiency are excess air and exhaust temperature. NO_x concentration is influenced primarily by the combustion temperature. CO output varies strongly with the stocheometry of the burner.

> Good service needs highly qualified staff. They must be familiar with both the technology in question and the newest products and systems.

The customer is free to choose his own optimization targets, eg:

- Reduction of primary energy consumption (CO_2)
- Lowering of emissions
- Maximizing power output

Highly qualified personnel

Good service needs highly qualified staff 3. They must be familiar with both the technology in question and the newest products and systems. A typical example from the service team is Kurt Thiele. The graduated electrical engineer has commissioned numerous electrical and control technology installations in power plants around the globe – and so accumulated an immeasurable experience. *"As service staff I have to be aware of far more than just the purely technical aspects"*, he explains, *"in the many deployments which I complete every year, I must always find the right approach to the customer's personnel. Moreover, evening and night shifts are often required, because the punctual restarting of a power plant often depends on my successful contribution"* . Solutions must often be based on different available techniques. *"In service, plan X is rarely the right way to get things done. A lot of creativity is required to find economic solutions. But I can always count on the support of my colleagues in the service team* 4*, and if necessary, on the R&D department"*.

Summary

Cooperation between equipment suppliers, service providers and power plant owners have considerable potential for creating a competitive advantage in the market. The significance of such value creating partnerships will continue to rise. ABB, with its broad international experience is well prepared to support customers in all their service needs.

Hans-Peter Heil, Rolf Klare
ABB Utilities GmbH
Mannheim, Germany
hans-peter.heil@de.abb.com,
rolf.klare@de.abb.com

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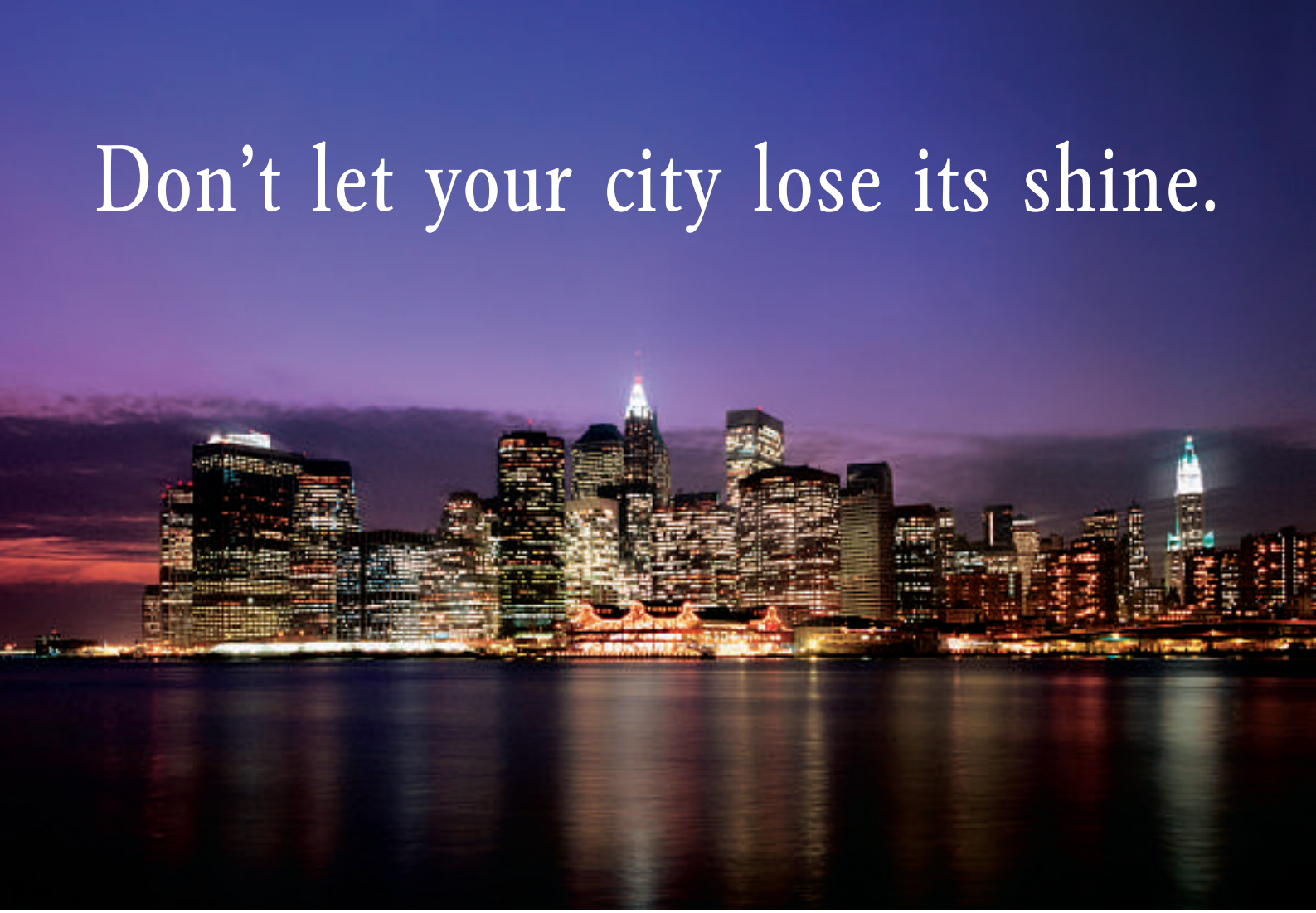

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