Fit at 50

THOMAS WESTMAN, PIERRE LORIN, PAUL A. AMMANN – Keeping fit and "staying young" are goals for many – including power transformers. Many of the world's transformers are reaching an age where these goals are becoming critical for their survival, and for the survival of the operating companies. The consequences of a transformer failure can be catastrophic. This is why operators demand high availability and a rapid recovery time after an outage. With an aging fleet of transformers and tight maintenance budgets, transformers remain in service well past their optimal life spans. The assumption that all are fit for an extended working life can be a dangerous gamble. When it comes to transformer asset management, an operator's main objectives are to reduce the risk of a failure and minimize the impact if a failure does occur. ABB's TrafoAsset Management™ provides just the support operators need to make intelligent maintenance decisions to face these challenges.

Keeping aging transformers healthy for longer with ABB TrafoAsset Management™ – Proactive Services

1 A nearly catastrophic failure damaged a transformer

2 The transformer in (1) has been remanufactured to a fully functional state

3 Cost estimates of an unplanned replacement of a typical generator step-up transformer

Environmental cleanup	$500,000
Lost revenue ($500,000/day)	$10 million
Installation labor and processing	$100,000 – $300,000
Additional modifications and site work	$300,000
New transformer unit	$2 million – $4 million

Transformer failures can cost up to $15 million, in addition to an operator's reputation. Source: Doble Life of a Transformer Seminar. Clearwater, FL, United States

Power transformers, which are often the most valuable asset in a substation or plant, are indispensable components of high-voltage equipment for power generation plants, transmission systems and large industrial plants. Unexpected failures cause major disturbances to operating systems, resulting in unscheduled outages and power delivery problems. Such failures can be the result of poor maintenance, poor operation, poor protection, undetected faults, or even severe lightning or short circuits ➔ 1,2. Outages affect revenue, incur penalties and can cost a company its reputation and its customers.

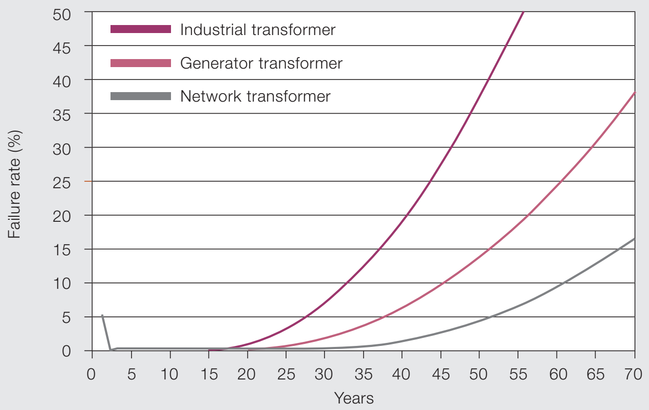
The Institute of Nuclear Power Operations stated in 2002 that more than 70 events had been associated with large, main auxiliary or step-up power transformers (since 1996) [1]. Significant station impact occurred during several events and in addition over 30 reactor scrams (ie, emergency reactor shutdowns) as well as plant shutdowns and reductions in power delivery were associated with transformer events. The result: in many cases, lost production and expensive repairs.

The enormous costs of power transformer failures provide ample incentive for electric companies to ensure reliability and availability throughout the life cycle of these key assets. Transformers cost anywhere from $2 million to $4 million, and on the rare occasions they do fail, the financial impact can be even more significant – in extreme cases, they can leave a company facing financial ruin ➔ 3. In addition, as most countries have strict laws in place that control and regulate power supply, non-delivery penalties can be as high as 100 times the price of the energy itself.

An aging fleet

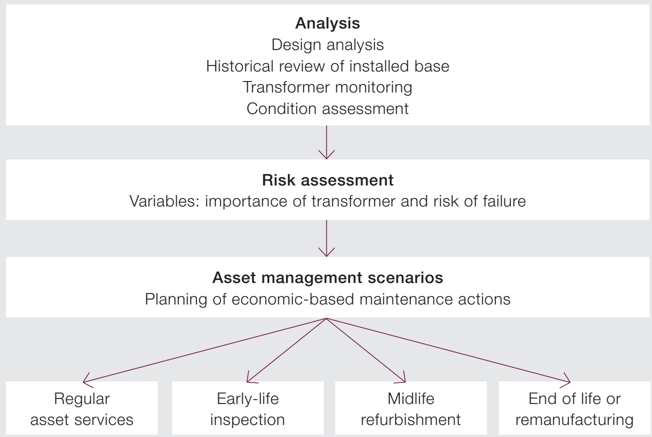
Although transformers are regarded as highly dependable equipment, the world's current transformer fleet is quite old. The average age for those in industrial plants is 30 years, and 40 years for those used by utilities. While aging transformers are generally not "ticking time bombs," their failure rates as well as their replacement and repair costs are steadily – albeit slowly – increasing. ➔ 4 shows the development of the failure rate of transformers installed in industrial plants (dark orange), generation plants (light orange) and transmission networks (gray). The risk development curves are steeper for industrial and power generation plants as the transformers in these installations tend to be used more intensively. While age alone does not increase the risk of unexpected failures, it generally is an indication of this risk. Risk of failure is heightened by other factors, including type of application and the tendency to load

4 Development of the transformer failure rate in three different applications

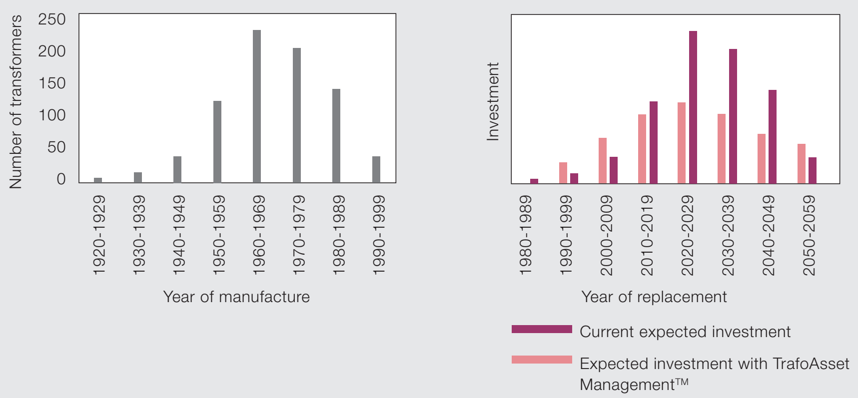


Source: CIGRE WG 12-05. (1983). An international survey on failures in large power transformers. ELECTRA, 88, 21-48.

6 Overview of ABB TrafoAsset Management – Proactive Services



5 Transformer investment then and now



5a The investment in new transformers peaked in the 1960s and 70s. Without optimized maintenance strategies and extended lifetimes, there will be another investment peak some 50 years later.

5b Implementing ABB's TrafoAsset Management program can help smooth the potential investment peak.

The world's current transformer fleet is quite old, and the cost of replacement has forced many companies to keep transformers operating beyond their recommended life span.

transformers to their maximum to meet the economic needs of the deregulated environment and competitive markets.

➔ 5 shows the investment peak in the 1960s and 70s for many companies in Europe and the United States. The cost burden when replacing aging equipment has forced many companies to keep transformers operating beyond their recommended life span in order to smooth the investment peak. This is only possible by optimizing the maintenance of the transformers and by implementing measures that extend their use.

At the same time, financial constraints demand an increased return on investment under reduced maintenance budgets and spending. The maintenance budgets are under increased pressure due to liberalization and deregulation, which have created a more finance-based focus. As a result, operators can no longer follow a simple time-based maintenance strategy that mitigates risks by doing everything, every year, for all transformers. Instead, they must implement a more sophisticated condition-based maintenance strategy: doing more maintenance for high-risk transformers than for low-risk transformers.[1] This requires reliable information about the status of the transformers.

ABB TrafoAsset Management – Proactive Services

Operational managers require special tools to support their strategic and day-to-day decisions, which address the above challenges and result in the right maintenance actions at the right time. Here, a clear trend has emerged: Managers are moving from using time-based

Footnote

1 High risk means high probability of failing and/or high impact of a failure on business results.

maintenance to implementing condition-based maintenance, where decisions are no longer driven by an average timeframe defined by past experience and observations, but instead take into account the actual condition of the equipment and the level of reliability required to fulfill its function. TrafoAsset Management supports this trend by focusing on three elements: analysis, risk assessment, and planning of maintenance actions based on asset management scenarios → 6.

Analysis

The design data, the information in the installed base system, the results of the condition assessment and the maintenance history provide ABB with a 360-degree view of a transformer fleet. This data plays a pivotal role for ABB in the assessment management process. Not only is it important for minimizing the risk of failure, but it also provides valuable information for initiating maintenance work should a problem occur – that means quick maintenance and short downtimes.

Design analysis

ABB has access to original designs for more than 30 legacy brands and design knowledge of nearly 75 percent of the installed base of large power transformers in North America – including those from Westinghouse, GE, ASEA and BBC – and other predecessor technologies. All new ABB transformers are built using the same design concept, which incorporates standardized, service-proven components and modules, ensuring flexible, dependable and adaptable transformer designs.

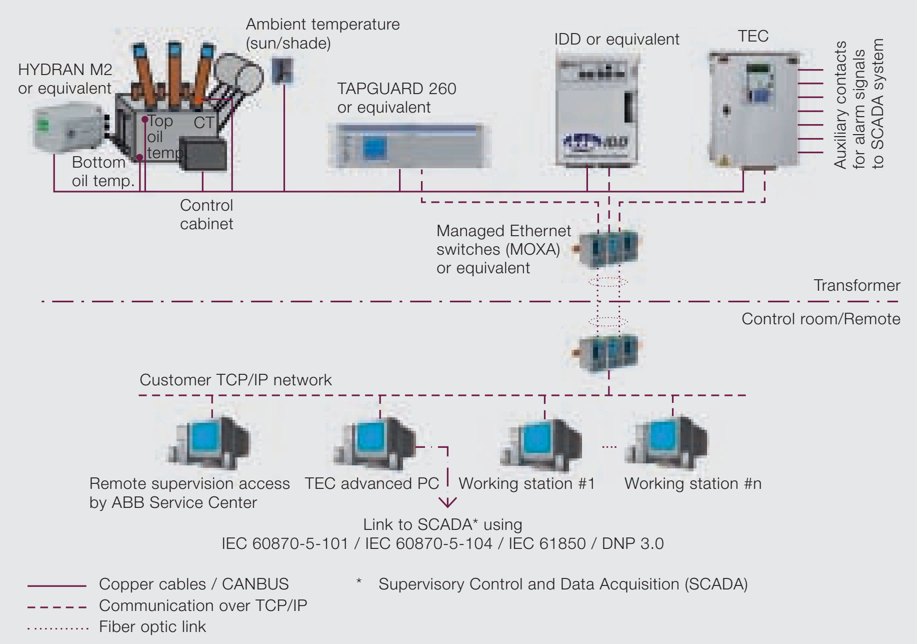
Historical review

ABB's installed data system monitors a wide range of the company's products. A plethora of data on transformers is available and is continuously updated, eg, current owner details and history. The system provides an important basis for the proactive detection of problems. For example, an analysis revealed about 700 potential cooler problems in the installed base of transformers. The search focused on 10 to 600 MVA transformers that were over 20 years old and had oil- and water-type coolers. Many failed completely due to leakages in these cooling systems, and one such failure resulted in a three-month production shutdown and lost revenue for the operator. Using the information in the installed base system, operators were contacted proactively and the systems could then be checked regularly.

Transformer monitoring

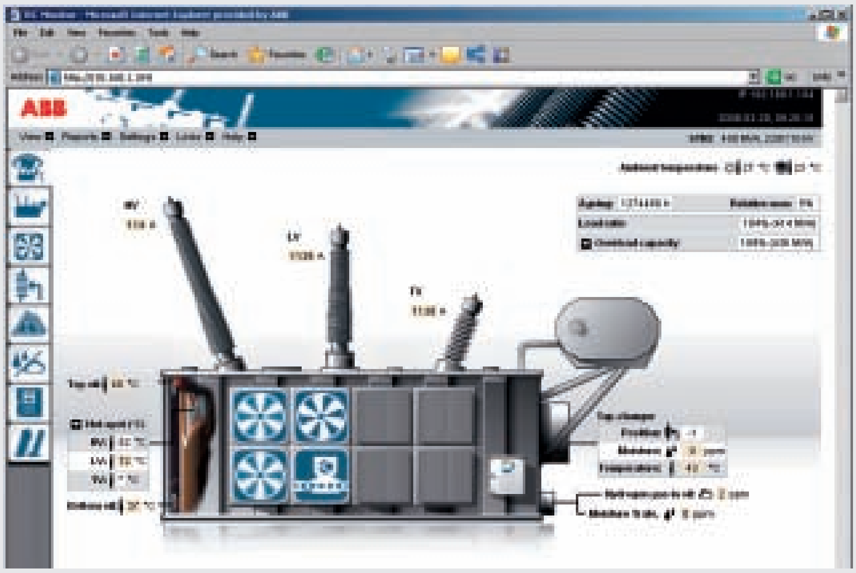
Transformer monitoring is becoming an essential component of transformer management. It serves as an early warning system for any fault developing in the main tank and in the accessories, allowing an operator to evaluate the severity of the situation. Multiple transformers are connected to the operator's network and can be monitored from a local control room or from remote working stations → 7. Sensors measuring dissolved gases, moisture in oil, oil temperature, load current for each unit, and ambient

7 Structure of a transformer monitoring system



Source: Uhlmann O. (2009). ABB Transformer Service Engineering Solutions Portfolio Overview.

8 Transformer monitoring interface showing the status of important parts of the transformer



Source: ABB TEC Monitor. Retrieved January 2010 from http://tec2.vbelnat.se/.

Footnotes

2 The risk of catastrophic failures can be reduced statistically from 0.07 percent to 0.03 percent through transformer monitoring [2].

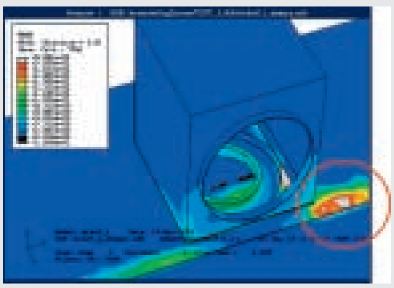
3 First-level maintenance is the first line of problem management where information is gathered and symptoms analyzed to determine the underlying causes. Clear-cut problems are typically handled with first-level maintenance by personnel who have a general understanding of the products.

9 Typical output results of ABB's Mature Transformer Management Program™ (MTMP)

9a Step 1: Transformer fleet screening (of the whole transformer fleet) provides a risk assessment.

Plant 1 – Results of condition assessment and action plan						
	Mechanical	Electrical	Thermal	Accessories	Overall risk	Risk mitigation – 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 top-oil thermometer / online 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

9b Step 2: Transformer design and condition assessment (of a subset of high-risk transformers) suggests concrete actions for each transformer.



9c Step 3: Life assessment/profiling (of a few transformers that had unusual results in steps 1 and 2) uses in-depth analysis to show the status of the transformers. The circled area indicates the need for immediate action.

temperature send data to the system via analog signals. The interface provides exact status information by generating a model of the transformer and its working condition and then comparing the measured parameters with the simulated values → 8. Discrepancies are detected and potential malfunctions and normal wear in the transformer and its ancillaries are indicated. The monitoring system also tracks transformer alarms, recording an actual event as well as the sequence leading up to the alarm to assist operators in determining the root cause. The benefits of monitoring are substantial. A CIGRE study has shown that transformer monitoring can reduce the risk of catastrophic failures by 50 percent[2] [2]. Furthermore, it has been shown that early detection of problems can reduce repair costs by 75 percent and loss of revenue by 60 percent, and that annual cost savings equal to 2 percent of the price of a new transformer – ie, approximately $40,000 to $80,000 – can be achieved [3].

The strength of ABB's Transformer Electronic Control, or TEC, monitoring system is that it receives all the relevant information from just a few multipurpose sensors. Other necessary parameters are calculated, adding only minimal complexity to the transformer. The end user is no longer forced to spend a lot of time sorting and interpreting data. In addition, the maintenance manager receives important information indicating the necessary actions for first-level maintenance.[3]

Condition assessment

ABB is the pioneer in highly customized condition assessment offerings. Its MTMP (Mature Transformer Management Program) is a state-of-the-art minimally invasive condition assessment process used to evaluate the power transformers in a customer's fleet and to identify which units need to be replaced or refurbished and when.

This process is implemented in three steps → 9. It starts with a high-level fleet assessment based on easily accessible data, such as unit nameplate data, oil and dissolved-gas-in-oil data, load profile and history of the unit (transformer fleet screening) → 9a. Next, a subset of the transformers identified in step one is examined in more detail (transformer design and condition assessment) → 9b. Modern design rules and tools are used to evaluate the original design, and advanced di-

Operators can no longer follow a simple time-based maintenance strategy that mitigates risks by doing everything, every year, for all transformers.

agnostic tests are performed to assess each of the principal properties of the transformer in a structured way. These include mechanical status, thermal status (aging of the insulation), electrical status of the active part and the condition of the accessories, such as tap changers, bushings, overpressure valves, air-dryer system, pumps and relays. The number of units identified for further analysis is typically limited to two or three out of a population of 100. At this stage (life assessment/profiling) ➔ 9c, highly specialized experts analyze the units using simulation tools. Detailed data is then sent to the end users' operational managers, providing concrete information about whether a transformer can be overloaded, its nominal power or voltage rating increased or its lifetime extended [4].

Early detection of problems can reduce repair costs by 75 percent and loss of revenue by 60 percent.

Risk assessment

The risk assessment ➔ 6 is based on two variables. The first, risk of failure, is estimated using the input from the analysis phase, ie, age or time in service, transformer's nameplate data (kV, MVA, etc.), application and loading practices, operational problems or issues, latest field-test data (eg, dissolved gas and oil analyses), availability of a spare transformer and spare parts. The second variable is the importance of a transformer in a network, indicating how much of the operator's system will be out of service if a particular transformer fails. By comparing these two variables, different levels of urgency for maintenance actions can be defined ➔ 9a. The asset manager can then ensure that maintenance of high-risk transformers is prioritized.

Asset management scenarios

The risks for a transformer operator include not only the inherent technical risks but also the economic consequences of a possible fault, eg, the cost of non-delivered energy. With this in mind, ABB and a large operator co-developed an economical model that evaluates the life-cycle costs of a transformer fleet over a given period ➔ 6. The model takes into account four categories of costs related to the cost of ownership over the lifetime: investment, maintenance, operational and consequential costs. Comparative investment scenarios and sensitivity studies can be run by varying the replacement year or maintenance of the unit. For each scenario, the process shows the associated net present value. An optimization routine can also be used to automatically minimize the life-cycle costs of the population. The process outputs a list presenting the optimum time to maintain or replace the individual transformers or transformer groups. The net present value of the whole population of transformers is determined by looking at the condition of each unit and the maintenance actions selected to improve their condition. The operational manager can then evaluate different maintenance scenarios and obtain a summary of the payback of planned maintenance actions. The novel aspect of the method is that not only are maintenance costs considered but economical benefits related to the impact of maintenance on reliability are considered as well [5].

Maintenance packages

ABB provides personalized recommendations and support using available data and state-of-the-art tools and maintenance packages, as shown in ➔ 6. These include regular asset services, early-life inspection, midlife refurbishment and remanufacturing. For many operators midlife refurbishment has become very important as their transformers are aging. Midlife refurbishment is an extensive overhaul of a transformer to extend the remaining lifetime and increase reliability, and is typically performed after half of the expected lifetime. It involves several maintenance steps, including advanced diagnostics to check mechanical, thermal and electrical conditions. New or refurbished accessories such as on-load tap changers, bushings, pumps, temperature sensors, valves, gaskets and water coolers might be used. Refurbishment of the active part through, for example, cleaning, winding reclamping, connection retightening and installation of new parts, is often an aspect of a midlife refurbishment.

The benefits

Not knowing the risk structure of its fleet, a company tends to overspend on the maintenance of its low-risk transformers and underspend on the high-risk transformer ➔ 10. Overspending on low-risk transformers is a "high-risk activity," as approximately 30 to 50 percent of maintenance actions are unnecessary [6]. But needless maintenance work can be avoided by implementing regular fleet assessments. The use of preventive or predictive maintenance is improving the transformer economy, which has been challenged by the limited maintenance resources associated with utility deregulation. Focusing the personnel and capital resources to the prioritized needs – with the priority based on the condition assessment ranking – can provide improved reliability at a fraction of the cost of traditional time-based maintenance programs.

It is estimated that life extension of five to 15 years can be achieved with properly focused preventive maintenance programs. The economic advantage related to preventive maintenance work and corrective actions can also be expressed in terms of extended life of the transformer assets – this is achieved by eliminating failures that might have occurred due to the lack of timely critical maintenance.

A proactive approach

ABB TrafoAsset Management provides operators with the information, expertise and maintenance tools they need to face the challenge of managing their transformer fleets. The result is improved asset management and lower risk of unexpected failures. In addition, the comprehensive range of data collected, from design to condition assessment, helps reduce the impact of a failure by enabling the transformer to quickly return to normal operating con-

ABB's TrafoAsset Management focuses on analysis, risk assessment, and planning of maintenance actions.

One of ABB's customers, a major transformer operator, had been using a time-based maintenance strategy, which meant that it did not know whether the maintenance done on each transformer was adequate for its risk profile. In addition, the maintenance budget was under pressure due to market liberalization and it was unclear whether it would be sufficient for the risk structure of the transformer fleet.

ABB thus undertook a fleet assessment study of 128 individual transformers at 54 different substations to determine the risk of failure of each of the transformers in the entire fleet. The result was a prioritization of the fleet based on corrective measures, such as detailed design or condition assessment, diagnostic evaluation, inspection, repair, or replacement. With this information, the customer could then reallocate its resources to the high-risk transformers and reduce costs in the process.

The benefit of a condition-based maintenance approach is shown clearly in this example. The customer benefits from an optimized use of time and resources, which results in increased fleet reliability. Much more of the maintenance budget is now concentrated on the transformers that show a high risk of failure or are of high importance in the network. These transformers are maintained proactively in order to lower the risk of an unexpected failure.

Unit	Budget prior to fleet assessment	Budget after fleet assessment
11 high-risk transformers	$110,000 (9% of budget)	$245,500 (25% of budget)
47 medium-risk transformers	$470,000 (37% of budget)	$434,000 (45% of budget)
70 low-risk transformers	$700,000 (54% of budget)	$294,500 (30% of budget)
Total: 128 transformers	**$1.28 million maintenance budget**	**$974,000 maintenance budget**

Distribution of maintenance budget before and after ABB fleet assessment. The result of the optimized maintenance solution is a savings of 24 percent of the customer's maintenance budget ($306,000 annually) as well as having better maintained high-risk transformers.

ABB's asset-management approach provides a clear picture of the risk structure and the maintenance required to deliver needed asset reliability and availability.

ditions. By performing proactive maintenance based on the TrafoAsset Management method, operators benefit from a lower risk of unexpected failures as well as fewer penalties (for utilities) and loss of revenue (for industry) → 10.

The importance of asset management and proactive services based on condition assessments of transformers is paramount due to the increasing average age of the worldwide transformer fleet and the more demanding conditions regarding quality of uninterrupted energy delivery. ABB's integrated modular asset-management approach provides a clear picture of the risk structure and the maintenance required to deliver needed asset reliability and availability. This allows operation managers to make the best use of maintenance and replacement budgets, allocating funds to high-risk units.

By reducing the risk of failure within given financial constraints and by minimizing the impact of a failure when it does occur, ABB's TrafoAsset Management is providing a powerful service.

For more information on ABB's transformer offerings, please visit www.abb.com/transformers.

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