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.
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. 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 (i.e., 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. 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. 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.
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.
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.

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.

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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.
new transformer – i.e., 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.

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

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].

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 life-time 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 reclamp-

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.

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

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.

References

Further reading