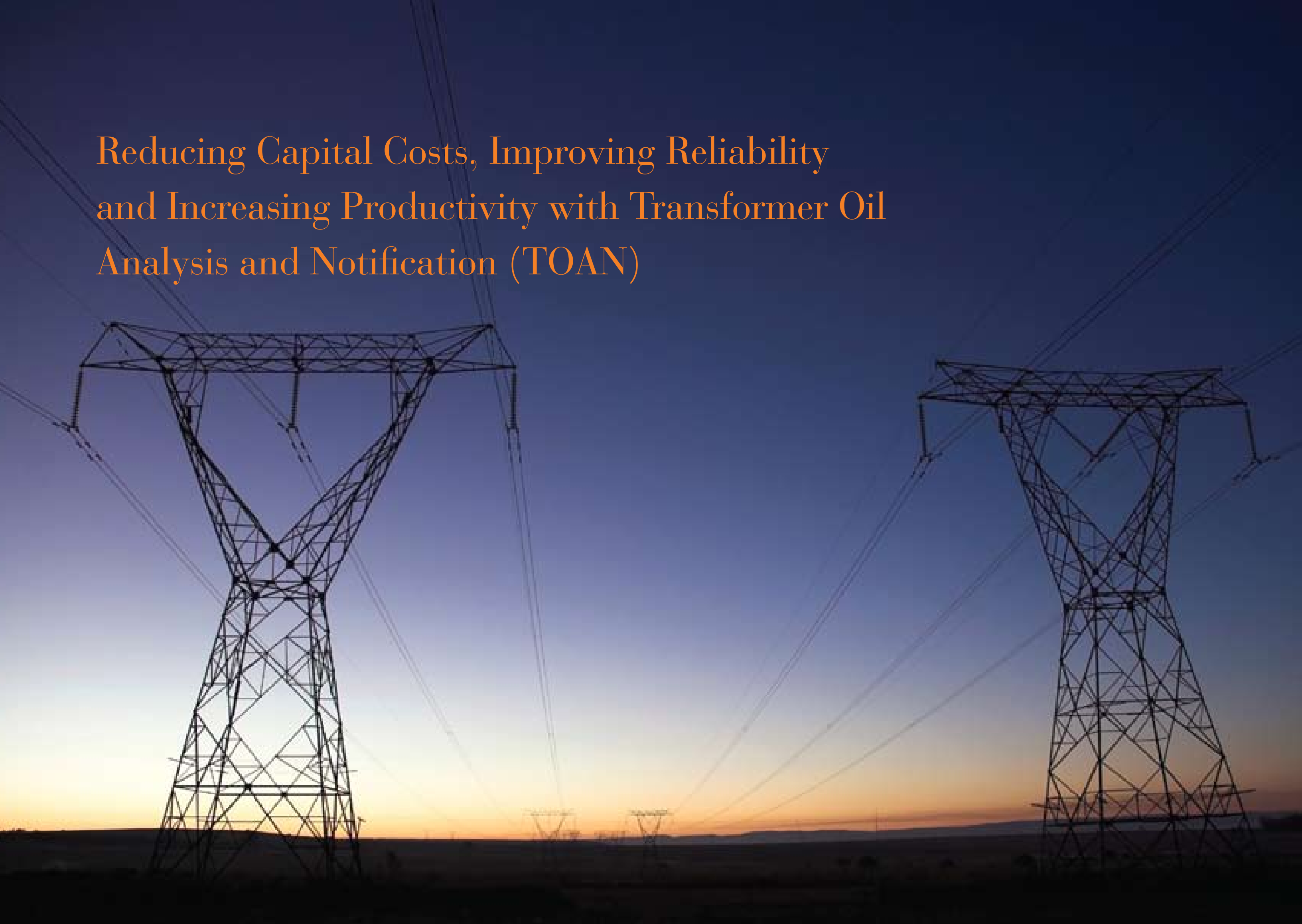
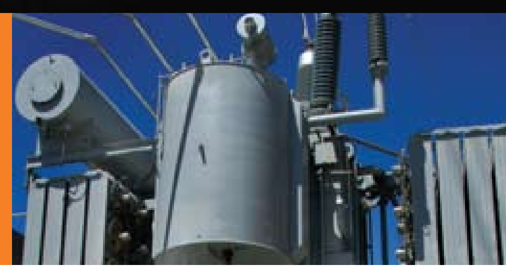


Reducing Capital Costs, Improving Reliability and Increasing Productivity with Transformer Oil Analysis and Notification (TOAN)

2008 Edison Award Nomination

Arizona Public Service



APS

Executive Summary

Transformers comprise one of the most capital-intensive investments made by electric utilities. One study estimates there are 100,000 extra high-voltage transformers valued at $200 billion in the U.S. alone. Because of their high and increasing costs, monitoring, protecting and extending the life of transmission transformers is an increasingly crucial activity. The APS Transformer Oil Analysis and Notification (TOAN) system — an automated method of monitoring transformer "health" in near-real time — can make a significant contribution to electric utility reliability and productivity while reducing overall electric utility infrastructure costs by billions of dollars within a decade.

In the past APS, like many utilities, has relied on manual sampling of transformer oil at intervals of one to several months. Employee time, cost and data constraints seriously limit the frequency and accuracy of oil sampling and analysis. The old techniques are simply too slow, too labor intensive and, given workforce changes, too impractical to protect APS' large and crucial investment in transmission infrastructure.

The TOAN project created the first automated system in the nation to combine online monitoring of transformer dissolved gases with analysis and notification of abnormal conditions. Faults are detected with high confidence using artificial intelligence-based software. TOAN is twice as accurate (greater than 93 percent) as industry-standard diagnostic techniques. APS has applied for two patents for the TOAN system.

With TOAN, APS has demonstrated (1) innovation by making a quantum leap in the accuracy standard for monitoring and protecting transformers, (2) leadership by being the first utility to adopt these novel technologies and procedures, and (3) a significant contribution to the electric utility industry's future by improving reliability, increasing productivity and protecting huge capital assets with unprecedented confidence.

Overview: The APS Growth and Reliability Challenge

As Arizona's largest and longest serving electric company, APS is committed to a reliable, sustainable and affordable future. In the last decade, APS has added 300,000 customers while our employee numbers have remained virtually unchanged. This has been accomplished through the use of smarter technologies and improved processes.

APS faces the same cost pressures that confront other utilities, but with the added component of rapid growth. As our customer base grows, so does the need for new transmission and distribution systems. We've added 7,600 miles of new wire and 65 substations in the past 10 years. Improvements to the system have resulted in 38 percent fewer outages, and the outages that do occur are 44 percent shorter in duration than a decade ago.[1] To continue this trend we will likely need to add even more transmission and distribution equipment over the next decade than we did in the previous 10 years.

Our commitment is to remain in the top 25 percent of U.S. utilities in customer service and reliability. The TOAN project is essential to meeting that commitment.

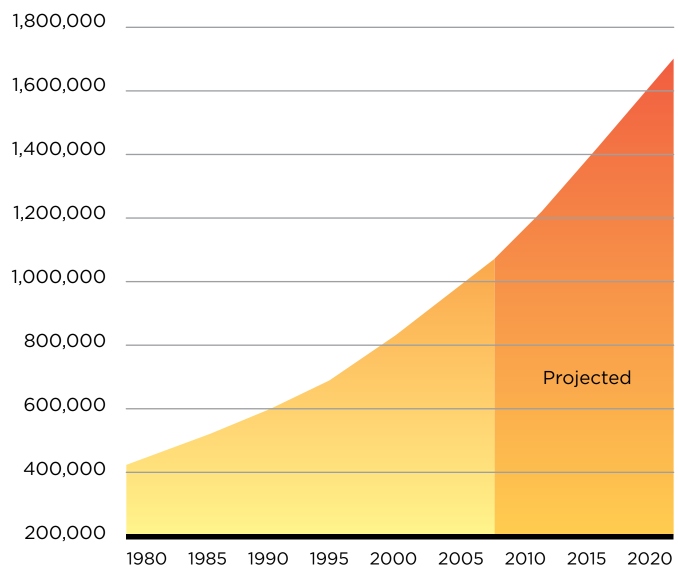
There is a strong but inaccurate public perception that electric utilities are an outmoded industry with aging infrastructure and an aging workforce. Meanwhile, our customers want better service, more control over costs and the latest technology.

While there is an element of truth about the challenges facing electric utilities, the future holds great promise: the electric industry is in transition, rapidly adopting new techniques to improve reliability, productivity and sustainability. The APS TOAN project, a finalist for the 2008 Edison Award, is a stellar example of efforts by the utility industry to use technology to mitigate the effects of growth and aging infrastructure while improving reliability, increasing productivity and holding down costs.

[1] Reliability as measured by System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI).

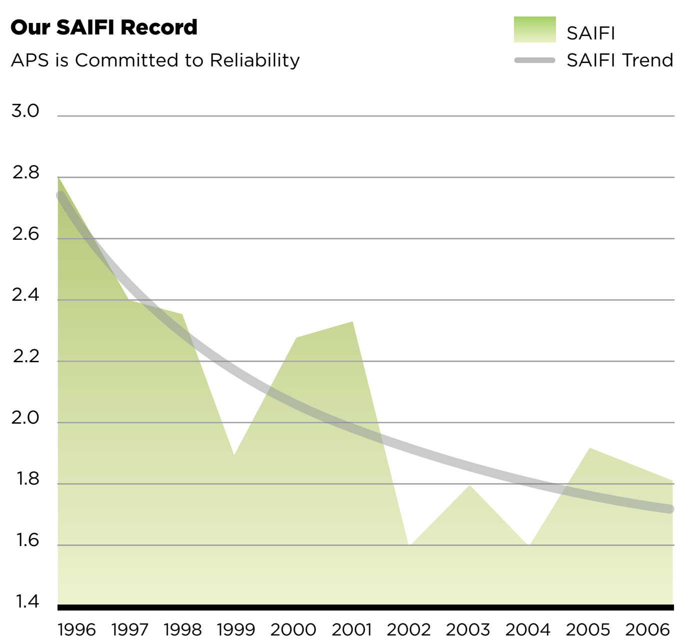
The Growth Challenge

Number of APS Customers Doubles Every 20 Years



Our SAIFI Record

APS is Committed to Reliability



The System Average Interruption Frequency Index (SAIFI) is the average number of interruptions of one minute or longer that a customer might experience, calculated by dividing the total number of service interruptions over the course of a year by the number of customers served.

APS currently has more than 100 online dissolved gas analysis (DGA) monitors on transformers, like this one at the company's Westwing substation, producing more than 200,000 samples per year. As the cost of transformers continues to rise, the need to protect this investment — and ensure customer reliability — becomes more critical.

The Electric Utility Infrastructure Challenge

APS faces tremendous demands for capital investment simply to keep up with growth. In the next decade, we expect to spend nearly $15 billion to maintain reliability, boost our use of renewable energy and increase environmental performance. These infrastructure improvements must be accomplished at a time of rising energy and capital costs. Like other utilities across the country, APS also is confronted with the substantial and increasing cost of replacing aging infrastructure. *Any technology or innovation that can defer, delay or decrease the cost of adding or replacing infrastructure has great value.*

A key element of the electric infrastructure is transformers, and the most important and expensive are the large transmission-system transformers. These transformers perform the initial voltage reduction as electricity gets distributed to homes and businesses, and they play a key role in the overall reliability of the transmission and distribution system. Because they can affect service to a large number of customers, the loss of a single transformer can result in substantial disruption of electric service with large economic impacts — both to the utility and to customers. The failure of a single transformer can cascade into multiple transformer failures depending on the type of failure and the degree of protection. Also, other expensive substation equipment can be damaged or destroyed by a catastrophic failure of a single transformer.

Not only are transmission transformers extremely important to reliability, they are expensive (from $1.5 million to more than $6 million each depending on size) and their costs have increased rapidly, doubling and even tripling over the last five years. Further, the lead time for purchasing and obtaining large transformers has increased over the same period from about a year to nearly three years. Therefore protecting and extending the life of transformers is an increasingly crucial activity.

A large percentage of this country's transmission and distribution equipment — such as transformers — is approaching 40 years of age and may need to be replaced over the next decade. For example, one large Midwestern utility reported in early 2005 that 72 percent of its 345-kilovolt transformers were in the 21 to 40 year range and 73 percent of its 161-kilovolt transformers were in the 21 to 50 year range. Meanwhile, at APS, 79 percent of the company's 345-kilovolt transformers are between 28 to 46 years old and 66 percent of its 525-kilovolt transformers are between 21 to 38 years old.

As transformers age and replacing them becomes more costly, monitoring their condition and having confidence in their "health" will become increasingly important. In the past, APS, like many utilities, has relied on manual sampling of transformer oil at intervals of one to several months. Employee time, cost and data constraints seriously limit the frequency and accuracy of oil sampling and analysis. The old techniques are simply too slow, too labor intensive and, given workforce changes, too impractical to protect APS' large and crucial investment in transmission infrastructure. As if the cost and reliability impact of an unplanned transformer loss were not enough, workforce concerns added yet another reason for APS to seek a more sustainable, long-term solution to protecting transformer and substation assets.

"This is cutting edge when you think of the implications from a cost standpoint and a reliability standpoint."

APS President and CEO Don Brandt at a March 2008 gathering of company leaders

The TOAN Project Solution

The Transformer Oil Analysis and Notification (TOAN) system allows APS to automate the monitoring of transformer oil data, receive notification of abnormalities in near-real time, and take actions necessary to prevent outages or more serious forms of transformer failure such as explosions and fires.

Catastrophic transformer failures occur when fast developing arcing faults inside a transformer build up enough pressure to rupture the transformer tank and spill burning oil over large areas. These faults can progress from undetectable levels to failure within days or even hours. Online monitors are used to detect these fast developing faults and hopefully prevent catastrophic failures.

Beyond Online Monitoring. As in previous manual oil sampling techniques, TOAN uses dissolved gas analysis (DGA) of insulating oil to determine the "health" of a transformer. Somewhat like a human blood test can warn of potential problems, DGA can detect overheating and arcing conditions in transformers and assist in determining when to remove transformers for repair or replacement. The process is completely automated and does not require employee intervention unless an abnormality is detected and reported. This allows substation maintenance employees to focus intensively on more time-critical work.

In the TOAN system, online DGA monitors take samples every four hours to track the condition of transformers, and the frequency of sampling can be increased if conditions warrant. Currently at APS, there are more than 100 online DGA monitors on transformers producing more than 200,000 samples per year. While useful, the traditional online monitoring process creates massive amounts of data that had to be analyzed and turned into organized, actionable information. APS plans eventually to monitor about 170 to 200 transformers, which will result in even more data to analyze.

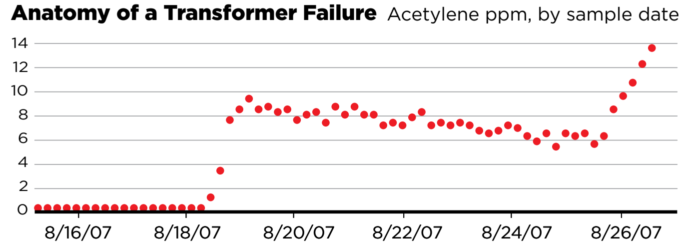
Under the old system, analyzing the generated data required extensive training and was extremely time consuming. Not only was this very costly, it diverted employee time away from other important activities. Further, with a workforce made up of many knowledgeable and experienced employees approaching retirement, the future availability of a workforce with enough expertise to analyze the mounds of data will be increasingly problematic.

Artificial Intelligence. TOAN uses artificial intelligence programming to analyze the data produced by online oil sampling, to categorize the severity of any fault conditions and to generate a notification about a problem. TOAN was designed as an "exception-based" system of dissolved gas analysis.

To rapidly analyze and classify transformer faults, APS enhanced existing artificial neural networks (ANN) and an expert system originally developed by Virginia Tech University. This existing system was developed to work in an off line environment and was not suited for processing on-line DGA samples. APS enhanced this system in a number of ways to produce better analysis of samples and more accurate predictions of transformer issues.

Since a highly accurate analysis algorithm was needed to separate normal and abnormal samples for the TOAN project, APS first tested the software to assure it met the company's accuracy requirements. The software correctly identified a fault condition nearly 93 percent of the time, but it needed further changes for online monitoring.

Anatomy of a Transformer Failure Acetylene ppm, by sample date



There is only a brief amount of time to make a decision that can prevent a transformer failure. In the example depicted above, the transformer failed 15 minutes after the last sample was taken. In February 2008, TOAN was able prevent a transformer that exhibited similar behavior from failing.

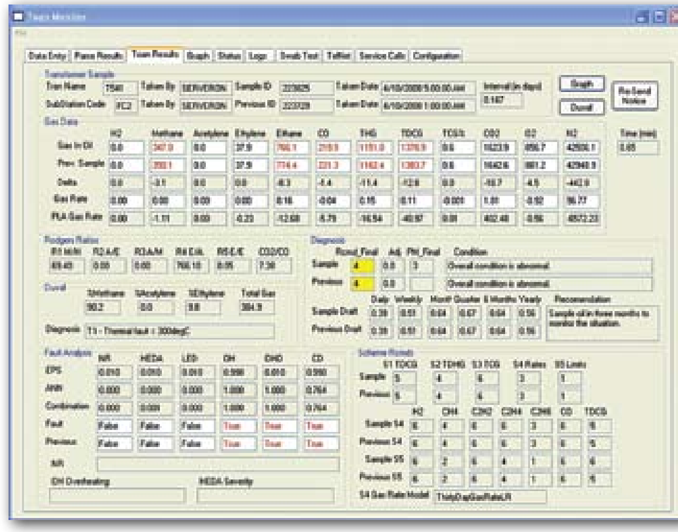
Adapting the artificial intelligence software for online monitoring proved to be challenging. For example, APS had to create a communication system to obtain the data from the online monitors and store it in a single data base. This solution included cellular modems and wireless data transfer as well as hard-wired approaches to collect data online from APS substations in remote locations. The sheer size and diversity of the APS service territory — comprising about 35,000 square miles, and traversing every terrain and climate imaginable — added to the difficulty.

Harmonic Regression Analysis and Piecewise Linear Approximation. To successfully work in an online environment, the TOAN team also adapted the use of Harmonic Regression Analysis to stabilize the measured gassing rates and Piecewise Linear Approximation to quickly determine and report changes to the measured gassing rates. Patents have been filed for both of these innovative algorithms.

Harmonic Regression Analysis was incorporated to cancel out the harmonic effects of temperature and load and only display the steady state gassing rate. Among the eight gasses being measured, carbon dioxide and carbon monoxide behave differently than the other six. The carbon gases exhibit a cyclic behavior (like a sine wave) that is caused by the rising and falling of ambient temperature and load. The gases are generated when temperature and load are high and then reabsorbed into the transformer's insulation when temperature and load decline. In addition, Harmonic Regression Analysis can be used to accurately predict future carbon gas levels. This information is valuable to asset managers trying to predict a transformer's effective age and remaining life.

Online monitors use an average of a predetermined number of samples to calculate transformer gassing rates. This approach leads to a delay in reporting a gassing event and underestimates its severity. This methodology is inadequate because when a transformer fault becomes critical, it is usually a fast-acting process. The APS Piecewise Linear Approximation algorithm, on the other hand, matches the gassing rate of each measured gas and does not require the selection of a predetermined interval. As a result, critical changes in a transformer's behavior can be detected immediately and reported.

Accuracy and Action. TOAN is designed to sort through data and categorize the severity of a fault with a high degree of accuracy and provide stable predictions. Users will tend to disregard predictions of severity if the system frequently gives a false cry of "wolf!" If the readings are constantly revised up and down, the system will be less useful.



TOAN is designed to sort through data and categorize the severity of a fault with a high degree of accuracy.

Therefore TOAN sends out notifications only when the dissolved gas samples indicate a problem, a change in problem status or a change in severity. The analysis tool decides to notify responsible individuals based on changes in six different fault types and/or six fault severity levels. If new samples have the same fault type and severity as the previous samples, the system does not send out a notification. This greatly reduces the burden on substation maintenance staff.

Making Innovation Work. There are many bright ideas that never get put to work. At APS, employees are encouraged to assume responsibility and have embraced a sustainability culture. Nevertheless, implementing TOAN required substantial management support and cross-departmental cooperation as well as a considerable amount of team-building and training.

To assure smooth functioning of all the business, construction, engineering and information technology aspects of implementing TOAN, APS created a Process Improvement Team. This team addressed and solved several significant real-world issues such as the proper installation of the oil monitors, which was handled by different departments on new and refurbished transformers; updating of peripheral software and data communications systems; training of maintenance employees; and re-defining the tasks of the relevant departments with the consensus of departmental managers.

The Potential of TOAN

The TOAN system is making a significant contribution to the way APS maintains its critical transmission and distribution infrastructure. TOAN has the potential make a similar revolutionary contribution to electric industry practices. APS believes that TOAN, by protecting and potentially extending the life of transmission substation assets, can significantly reduce utility capital costs, increase productivity and improve reliability.

Reduced Capital Costs. TOAN can reduce electric utility capital costs by practically eliminating the potential for catastrophic failures and the associated fires and equipment damage to substations. Catastrophic transformer fires can disrupt service for hours or days and cost millions of dollars. In 2004, APS experienced a transformer fire at its Westwing substation that destroyed five large transmission transformers and cost APS and its partners in the substation an estimated $28 million. After extensive review of the fire and the company's maintenance procedures, APS and industry experts developed a number of recommendations to avoid future substation fires. The most significant innovation to emerge from this extensive review and improvement process is TOAN.

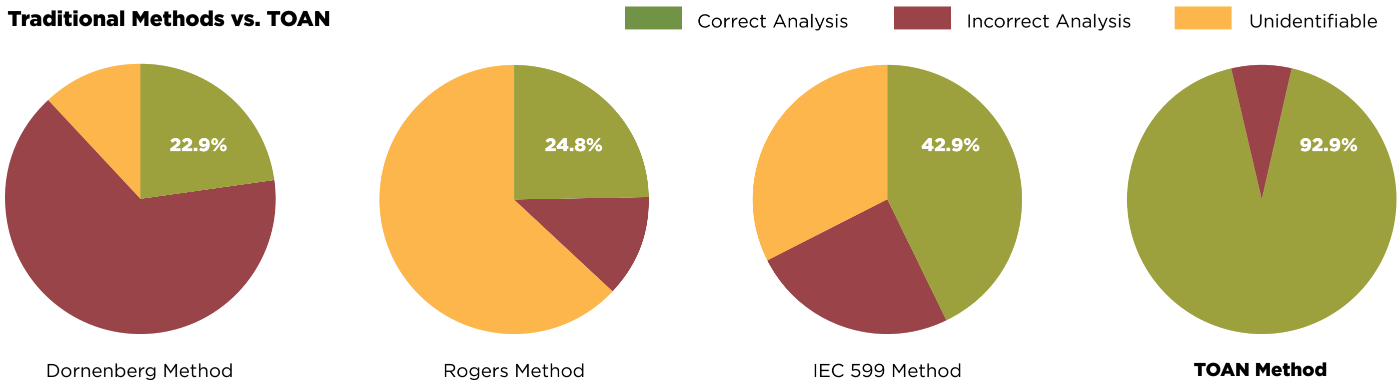
TOAN also has the potential to extend the practical life of transformers by deferring the need for scheduled replacements. TOAN can provide confidence in a transformer's health that would allow utility asset managers to keep older units in service, thereby deferring capital costs.

Currently the TOAN online monitoring system is installed in about 100 APS transmission substations and eventually will monitor 170 to 200 of APS' most critical system transformers (230 kilovolts and above). In addition to the online monitoring capabilities, TOAN analyzes all manual DGA samples from all other APS transformers.

Obviously the largest potential for property protection, reliability and productivity gains resides with the large, expensive transmission transformers that provide power to large numbers of customers. The largest of these transformers

Catastrophic transformer fires like the one that destroyed five transformers at the company's Westwing substation in 2004 may one day be a thing of the past — not only for APS, but for the entire electric industry.

Monitoring Accuracy
Traditional Methods vs. TOAN



costs more than $6 million and can require significant lead time (up to three years) even to purchase. The $40,000 cost of TOAN per transformer is an insignificant cost compared to the potential benefit when installed on a multimillion dollar investment whose health is essential to reliability.

Nearly every electric utility employs extra high-voltage transformers. One study estimates there are 100,000 transmission transformers valued at $200 billion in the U.S. electric grid. The same study found the failure rate on these transformers to be about 1.5 percent, and the failure rate on APS transmission transformers is about one percent per year. Within the industry, catastrophic failure rates are much lower — perhaps 30 per year — but despite the low risk, the consequences can be very severe. With such large numbers involved, clearly a system like TOAN can avoid huge capital expenses by only preventing a few failures. And by extending the useful life of existing transformers, the potential impact could quickly mount into the billions within a decade.

Increased Productivity. The TOAN system can increase productivity because the system automatically samples and analyzes transformer oil and sends notices of anomalies. Manual sampling is very costly and time consuming. At APS, for example, manual sampling can require an employee to drive for hours to test transformers at a remote substation.

Perhaps more significant, TOAN also automates the data analysis process, which would require countless hours of highly paid, skilled employees pouring over huge amounts of data. With automated sampling and analysis, trained, experienced employees use their time in more urgent tasks or on projects that require human expertise.

Improved Reliability. The TOAN system or a similar process can also make a significant contribution to reliability. When APS experienced its Westwing Substation fire, miraculously there were no customer outages. But for several months afterward, capacity margins on the transmission system were very thin and were threatened by unrelated but widespread wildfires. Other utilities have not always been as fortunate. Avoiding catastrophic failures can clearly avoid large and lengthy outages. TOAN has the potential to eliminate such failures.

Conclusion

By creating and implementing the TOAN system, APS clearly embodies characteristics of innovation and leadership and offers a significant contribution to the electric utility industry.

- TOAN is innovative in the way it combines and improves existing technologies. It transcends current methods of monitoring and protecting transformers, making a quantum leap in accuracy.
- APS demonstrated leadership by not only creating TOAN, but by being the first utility to implement the system. Implementing TOAN required considerable intra-company leadership to abandon comfortable old methods and to accommodate new technologies and procedures.
- Finally, TOAN can make a lasting and important contribution to the electric utility industry. It offers every utility the ability to improve reliability, increase productivity and reduce capital costs. It will allow utility asset managers to monitor the health of transmission transformers — one of the industry's largest cumulative investments and most expensive and critical individual items — with unprecedented confidence.

A Better Tomorrow Starts Today