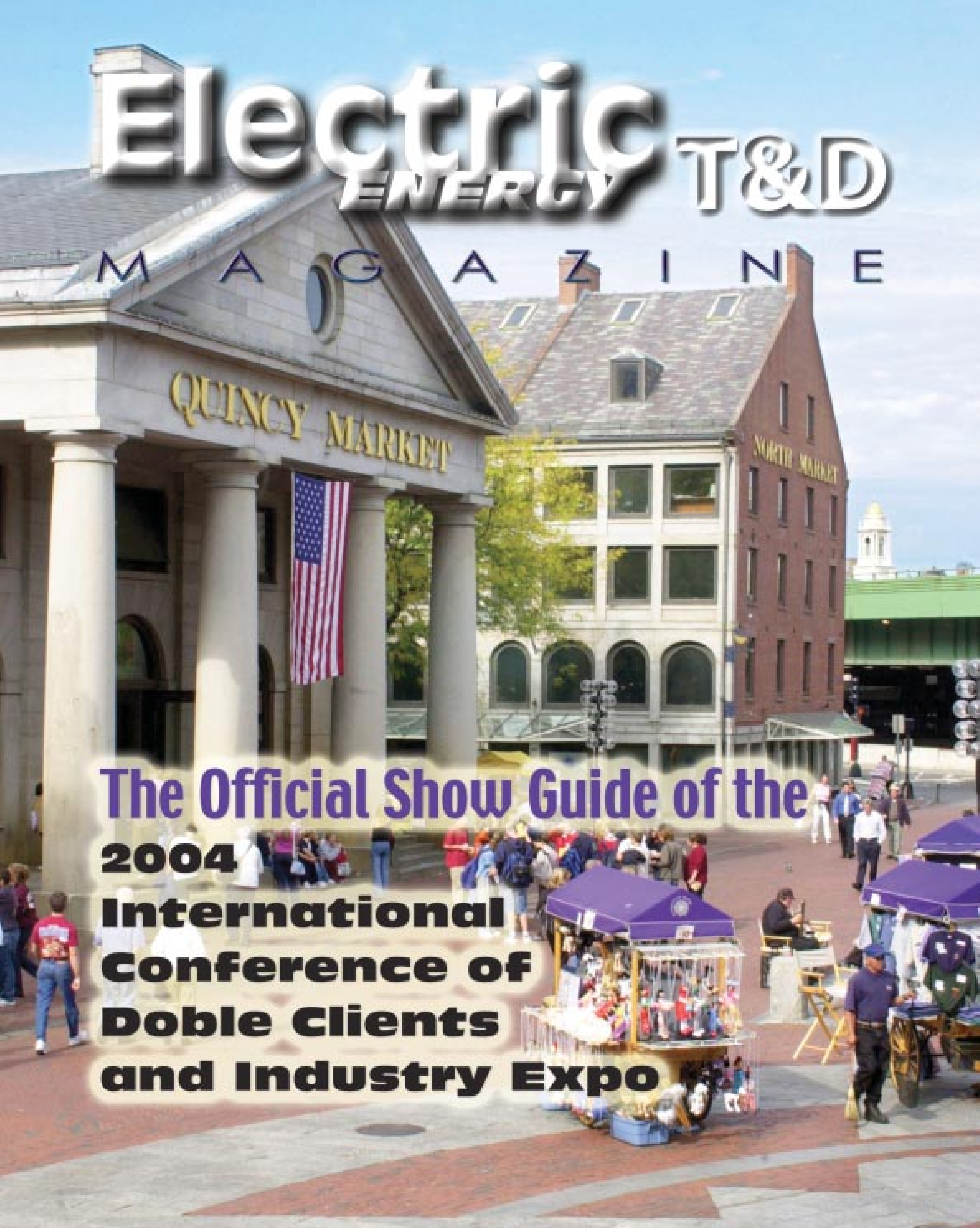
Electric Energy T&D Magazine



The Official Show Guide of the

2004 International Conference of Doble Clients and Industry Expo

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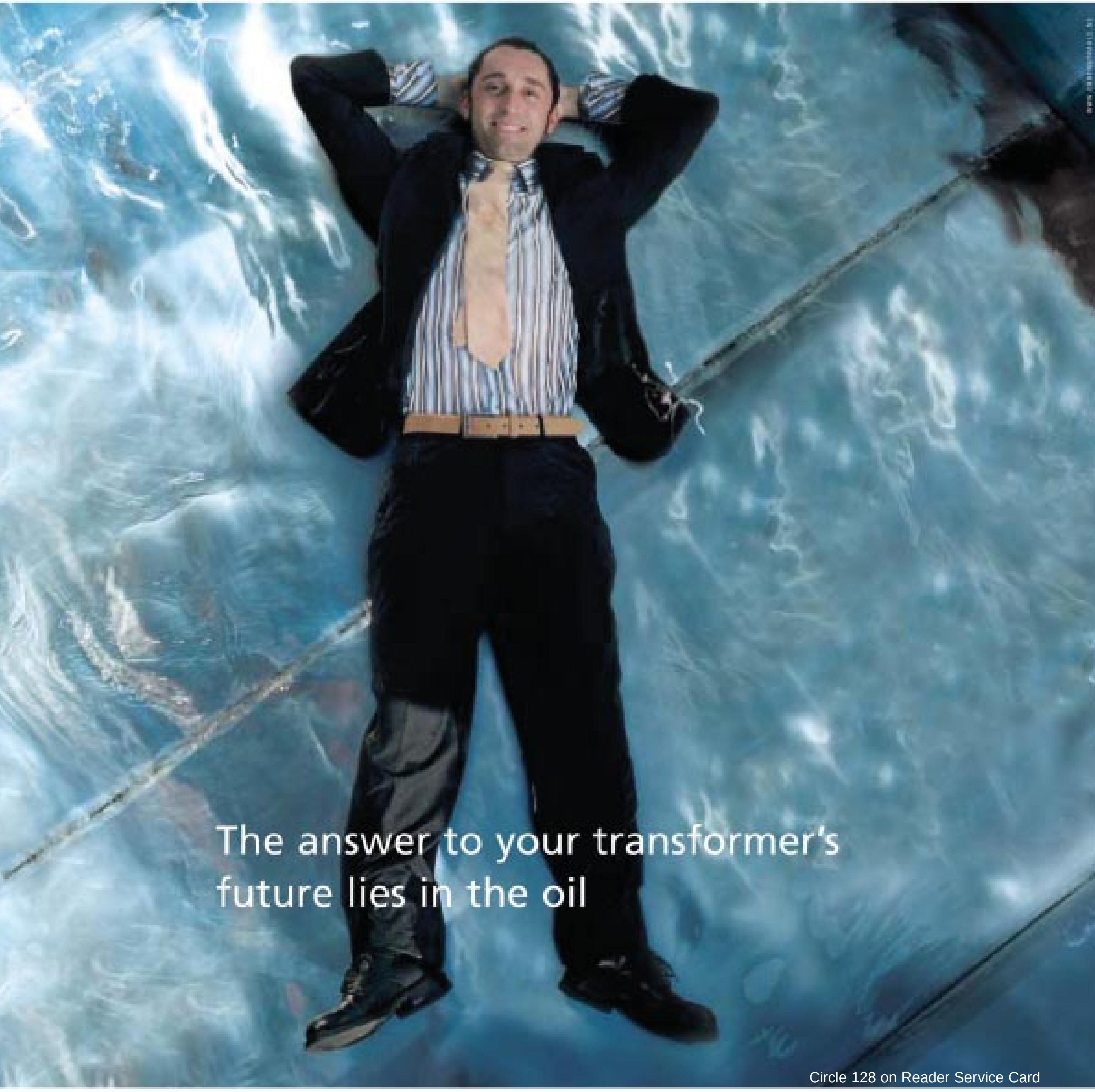

The answer to your transformer's future lies in the oil
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Publisher: Jaguar Media Inc
Editor: Gordon McCormick: gordon@jaguar-media.com
Contributing Editor:
Francis Bradley: bradley@canelect.ca
Publication Manager:
Steven Desrochers: steven@jaguar-media.com
Account Executive:
Joanna Mayoff: joanne@jaguar-media.com
Production Assistant:
Danielle Bernier: danielle@jaguar-media.com
Art Designer: Linda Fleury: jaguar@jaguar-media.com
(MIS) Management Information System:
Frederic Allard: fred@jaguar-media.com

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Electric ENERGY T&D
MAGAZINE

In this Issue

Cover Page Photo: Faneuil Hall, courtesy of the Greater Boston Convention and Visitors Bureau.

MOBILIZE YOUR POWER

The transformation of a "portable"" 50 MVA unit into a truly "mobile" transformer can be a real challenge. Weidmann-ACTI Engineers recently met that challenge by successfully completing an upgrade project for the Vermont Electric Power Company (VELCO). Weight and height restrictions, maneuverability, electrical connections, and cooler relocation were just a few of the major obstacles involved.

VELCO had used this portable transformer throughout the State of Vermont as a spare to back up its inventory of in-service power transformers for 30 years. It was considered "portable" because it could be transported over the road. Unfortunately considerable disassembly and reassembly was required each time it was commissioned, consuming precious time and money. The crew responsible for moving it and putting it into emergency service quite appropriately nicknamed it "The Barely Transportable."

The goal of this project was to be able to have the unit ready for service within hours of a failure at any location in the area by increasing its mobility without decreasing performance.

To eliminate the need for long waiting periods for permits, the transformer on its new trailer had to be within truck shipping weight and height limitations for the VELCO service area.

The trailer was required to be as short as possible for maneuverability and a 115 kV bus was required to extend the connection from the H bushings and arresters to the rear of the trailer.

Since the coolers are located on the rear bridge, apart from the transformer on the main deck, it was necessary to design flexibility into the piping connections. A shipping location at the rear of the trailer was provided for the conservator tank. While remounting of the tank is still required, it is no longer necessary to provide separate trucking for this component.

To enhance the portability of the transformer and reduce the cycle time for emergency restoration, the mobile transformer was equipped with on-board station service designed according to specific VELCO requirements. The cooling equipment is permanently connected and the transformer is no longer vulnerable to contamination inherent with the removal of the cooling equipment during each transport.

It is a true "mobile" transformer now, and capable of being pressed into service at a moments notice. VELCO estimates the installation time now to be less than twelve hours plus travel time…and all for less than one third the cost of new mobile transformer. ■

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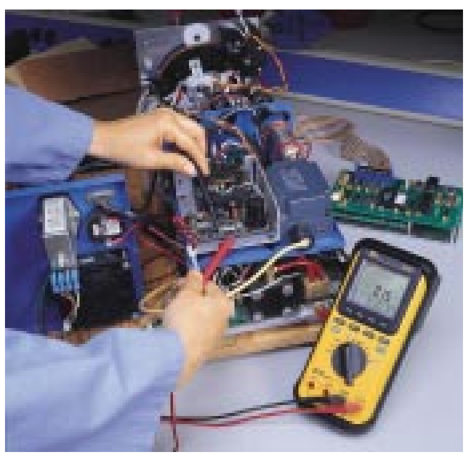

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For more information contact
Dan O'Connell
dan@oconnell-com.com

HINDLEPOWER, INC. RECEIVES NEW PATENT ALLOWANCE

Shown above is a section of the AT10 Group 2 battery charger with the Safety Enclosure added

SAFETY ENCLOSURE — A new addition to it's already outstanding AT10 & AT30 cabinet designs.

EASTON, PA- HindlePower, Incorporated, one of the leading manufacturers of battery chargers and specialty power supplies, announces the patent approval of a Safety Enclosure already housed in their line of AT10 Group 2 and there latest addition to their line-up of battery chargers the AT30.

This specially designed transparent material allows for safe viewing of the entire electrical devise. Built of 1/8" clear plexi glass, it prevents the exposure of live voltage. This safety enclosure provides an added measure of safety to the operator. The installation of this safety enclosure protects the operator by providing limited access to the battery charger, thus, protecting the operator from harm.

The plexi-glass safety enclosure is imprinted with a Component Layout and a Connection Diagram, allowing for easy installation. A Quick Operation Guide is included to allow for a fast setup and ease of operation. Safety Instructions and a complete set of Self-Diagnostics Error Codes complete the information provided.

Each safety enclosure provides limited localized access to the interior panel and to the electrical devices positioned within the housing. The plexi has a cutaway allowing for easy access to the AC Input Breaker and the DC Output Breaker. The new design qualifies the HindlePower Chargers for the CE labeling which continues to enhance the world class status of battery chargers manufactured by HindlePower, Inc.

Headquartered in Easton, Pennsylvania, HindlePower manufactures and distributes products primarily to end users in stationary and utility markets, throughout the United States, Canada and Europe. The company's products are an excellent choice for utility, power generation, oil and gas, transportation, mining, chemical plant, shipboard and platform applications. HindlePower products are certified worldwide, meeting the Industry's highest standards for quality and safety.■

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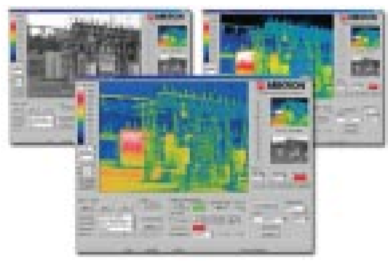
Art Salander/VP, Sales & Marketing
HindlePower, Inc.
Email: batchgr@aol.com

New DualVision Remote Substation Monitoring System is First to Combine Infrared-Enhanced Visual Surveillance with Thermographic Maintenance Monitoring



Intranet/Internet-enabled system offers 32 user-defined IR regions of interest per camera to trigger screen alarms or outputs to SCADA systems

Intruders can't hide and remote equipment inspections are made easier with Mikron Infrared's new DualVision 724 Remote Monitoring System for substations. The system is the first to combine visual and infrared cameras to produce optimized, blended images for simple quick analysis – all in a single intranet/internet-enabled package. Utilized with Mikron's MikroSpec™ R/T software, the system produces a composite IR and visual image, as well as separate images of each. The resulting composite can be viewed in an infinitely blended percentage of visual/IR, simply by moving a slider bar in the software screen. Up to 32 regions of interest (ROI's) can be defined on the thermal image in any complex shape, enabling the system to trigger alarms at the approach of intruders or from temperature excursions on substation hardware.

Visual surveillance enhanced with IR imaging makes it easy to spot intruders 24/7, without supplementary lighting.

"The declining cost of IR imaging technology now makes it economical to provide both security and maintenance monitoring in a single package, on one line, to any computer," said Jon Chynoweth, Vice President of Sales of Mikron Infrared. "From a security standpoint, an intruder cannot hide from the IR camera at night. And each IR camera effectively does 32 jobs by monitoring that many user-defined zones, whether it be a fence perimeter for security or a transformer for impending failure, triggering alarms at the master control when high/low setpoints are exceeded. Up to 14 cameras can be monitored at one time from a PC, and this system can easily be used as a component for an enterprise-wide SCADA system."

The DualVision 724 system consists of separate thermal imaging and video cameras in an environmentally sealed, temperature-controlled enclosure. Both cameras have Internet IP addresses and password protection, allowing control from any computer using wired or wireless Ethernet.

MikroSpec Real-Time Thermal Data Acquisition and Analysis software blends the thermal and IR camera feeds into a single DualVision image with correct aspect ratio and spatial area.

By applying an isotherm color pallet to the IR image, hot spots are easily identified while viewing the scene as a visual image. The composite image can be adjusted to show any percentage of the IR and visual. ROI's in the image can be defined using 10 different shapes, including freehand.

The MikroSpec R/T software can record up to 75 minutes of blended visual and IR video to a hard drive when capturing every frame from a camera set at a frame rate of 30 Hz. Total record time can be greatly extended by capturing images at intervals, rather than continuously. Video capture can be triggered by a temperature alarm from one of the ROI's or by direct signal from the PC. A user-selectable prebuffer of video allows the operator to also capture what happened in a scene before an event trigger.

The IR and visual cameras are housed in a single enclosure that has a hinged back section containing all the interface connections, including RJ45 Ethernet, RS170 video, connection for a high-resolution LCD, and a power termination strip. The front section holds the cameras and has a slanted IR-transparent window to resist snow/dirt buildup. Cameras are supported on an internal shelf, with space underneath for power supplies, wiring, etc. A remote-controlled panand-tilt head is also available.

The visual camera can be color or b/w. Cameras can be fixed focus or have auto iris and remote focus. The MikroScan IR camera uses state-of-the-art uncooled UFPA microbolometer technology, providing measurement accuracy of ±2% or 2°C. It can be set manually or automatically for three different temperature ranges. Two image update rates (30Hz/60Hz) are selectable. Standard field of view is 28.9°(H) x 21.9°(V), with autofocus from 30 cm to infinity. Telephoto and wide-angle lenses are available. All DualVision systems are fully integrated by Mikron Infrared and provided on a turnkey basis to ensure customer satisfaction. ■

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Contact Jon Chynoweth at
jon@mikroninfrared.com

By:
Stanley R. Lindgren
Director of Product Strategy
Serveron Corporation

By:
Paul Fischer
Product Marketing Manager
Serveron Corporation

Correlating DGA Results to Transformer Load

On-line DGA

Causal Relationships

There are approximately 100,000 power transformers in use in North America today. Worldwide the count is close to 500,000. Power transformers are an expensive asset that generally cost between $100K and $4M each, depending on their size and application, among other factors. In the realm of transmission and distribution they typically represent the highest valued assets of the system. There is no doubt that power transformers are critical components of the electrical grid and the power generation system.

The demand placed on these critical components continues to increase. Deregulation has led to large increases in generation capacity with little consideration given to transmission capacity. This has led to a decrease in the reliability of power delivery and an increase in the likelihood of major blackouts as safety margins disappear and the age of these key assets continue to increase.

The direct cost of failure includes the cost of replacement equipment, environmental cleanup, and replacement power purchased on the spot market; in areas with many industrial and large commercial customers costs can also include penalties for the unplanned outage. At the highest level of the electrical infrastructure, reliability has been achieved through redundancy. However, even when redundancy exists there are impacts due to failure. The financial impact may be much greater to the consumer than to the utility. Even with redundancy, switching interruptions resulting from a failure can have a major impact on many customers. Industries based on process controls may lose data or be forced to shutdown as a result of such transients. The costs to industrial and financial customers, when long outages occur, are dramatic. Such costs are now beginning to be discussed in terms of tariffs and associated penalties for utilities not delivering reliable power.

Monitoring the state of health of power transformers, a key component in the path of reliable power, has traditionally been performed using routine Dissolved Gas Analysis (DGA) tests performed at annual or semi-annual intervals. Measuring the level and rate of change of combustible gases in transformer insulating oil is an accepted industry practice based on the fact that the presence of combustible gases is a reliable diagnostic tool which is used as indicator of undesirable events in the transformer, such as hot-spots and electrical arcing; events which may portend a future of unreliable performance by the transformer.

By closely monitoring dissolved gas levels many transformer failures can be prevented. Prevention, however, is only possible if the reason for the presence of gases is understood and can be either controlled or corrected by means of repairs or prescribed usage profiles. Relating transformer gassing events to load, temperature, and external system events can be a difficult or even impossible task when only one or two DGA samples per year are available to perform such analysis. Daily on-line monitoring of key gases provides the level of detail required to show causal relationships between gassing and external events in a way that traditional infrequent laboratory sampling cannot.

Can You Trust Your DGA Results?

A 40 year old 500 kV transformer, with a history of accumulated high levels of methane and ethylene, was selected to evaluate on-line continuous DGA monitoring by comparing on-line measurements to laboratory DGA measurements. Because the on-line analyzer provides six gas-in-oil measurements daily it was also possible to use the on-line data to determine if and to what extent gassing of the transformer was load dependent.

Internal examination of the transformer identified carbon deposits between the core frame and the tank wall due to deteriorated insulating material. Repairs were made at that time but gassing continued, leading to a second inspection and degassing. The transformer was returned to service in June 2003 with a Serveron® TrueGas™ analyzer monitoring eight gases every four hours (six samples per day, seven days per week).

Simultaneously, weekly oil samples were submitted to three laboratories over a three month period. Although absolute measurements of gas levels varied between labs and the on-line analyzer, the general trending of the gases were consistent between all measurement sources.

Figure 1 directly compares the on-line DGA measurements with the laboratory measurements. Since the on-line measurements occur at a frequency that is 50x that of the weekly laboratory measurements they appear as continuous lines on this chart. Each color on the chart represents a different gas, as indicated by the legend at the bottom of the chart.

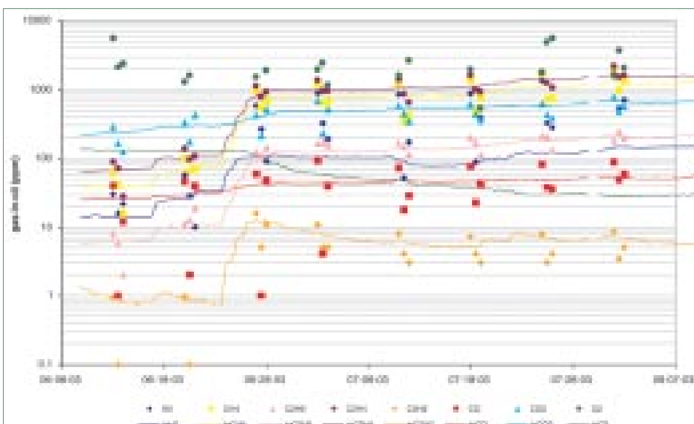

figure 1: weekly DGA results from three different laboratories compared with TrueGas results

The weekly laboratory measurements are plotted in groups of three (slightly offset from each other on the horizontal axis for clarity). In general, the on-line results intersect or track very closely with the laboratory results. Oxygen (in green) shows the least correlation due to the fact that the laboratory samples are easily contaminated by the atmosphere either during the oil sampling (extraction) process, during transport, or during injection into the laboratory gas chromatograph apparatus.

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Can you trust your laboratory DGA results? Yes, other than oxygen (and nitrogen) which can be easily skewed by atmospheric contamination, these three labs and the on-line analyzer provided substantially similar DGA measurements. The absolute values (levels) of the on-line analyzer and laboratory measurements varied, but the trends and direction of the results are consistent.

Transformer Background

The 500 kV transformer which was monitored as a part of this study has shown hot-metal gassing (C_2H_4, CH_4, C_2H_6, and traces of C_2H_2) since its initial placement into service just over 40 years ago. The unit has been degassed a number of times during its history of operation. The internal inspection identified the gassing to be associated with deteriorated insulating material used to electrically isolate the core and coil assembly from the tank wall. Attempts were made by the manufacturer to minimize circulating currents, however the problem continued, leading to a second internal inspection and degassing and was returned to service in June of 2003 with a Serveron TrueGas analyzer installed.

Transformer Gassing Problem

The core and coil assembly is held in place with brackets between the core-frame and tank-wall at the four corners, top and bottom, with insulating gaskets to provide electrical isolation. An over-heated spot was found during the initial inspection at one of the lower brackets; indicated by carbon deposits and thermo-vision. Repairs consisted of removing the core-frame to tank-wall grounding strap and reinstalling it to bridge the damaged gasket.

Unfortunately, this did not eliminate the gassing. So a second internal inspection of this transformer was performed and revealed the following:

- It was impossible to determine whether another frame ground is providing a path for circulating currents.
- The core was meggered (after lifting the core-to-frame ground) and measured above 1000 megohms, indicating that the core is not grounded and is isolated from the frame.
- Windings and clamping appeared to be tight.
- No carbon deposits were found.

Service Decision

Following the second inspection it was decided to return the transformer to service on the basis that gassing is probably being caused by circulating currents involving the core frames or another grounding structure. Most importantly, gassing did not appear to involve the windings.

Electrical tests indicated that the transformer was okay. Lifting the core and coil assembly inside the tank or untanking the transformer to attempt to isolate the core-frame ground was considered not worthwhile.

The risk of not finding the problem, not being repairable if found, or of causing further damage to the transformer outweighed the risk of the existing gassing problem. It was decided that on-line DGA monitoring and periodic degassing should enable the transformer to remain in service.

Daily DGA Measurements

The daily sampling associated with on-line monitoring provides a level of detail that is simply not possible using traditional laboratory measurements. With such detail it is possible to correlate DGA results with SCADA measurements and significant events associated with the transformer, such as loading, winding temperature, and LTC adjustments.

The logarithmic chart of on-line DGA measurements shown in figure 2 includes plots of the eight gases which are automatically measured every four hours by the on-line analyzer and one "summation gas" (TDCG, total dissolved combustible gas). The tenth plot, the light green and somewhat softer line near the bottom of the chart, is drawn on a linear scale (its corresponding y-axis scale is not present on the chart) and is a relative indication of the load on the transformer. In addition to the DGA measurements, this data is also automatically collected by the on-line analyzer via its LoadGuide™ input six times each day.

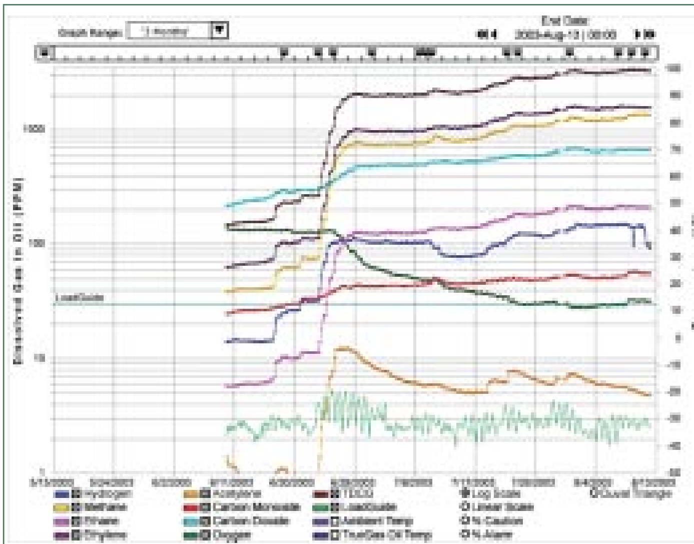


figure 2: 3-month on-line results (log scale) with LoadGuide indicated in light green (linear scale)

Correlation With Load

By comparing the LoadGuide fluctuations with actual SCADA data one can "calibrate" this relative load line with the true load on the transformer. A plot of the SCADA data representing the load through the transformer bank is shown in figure 3.

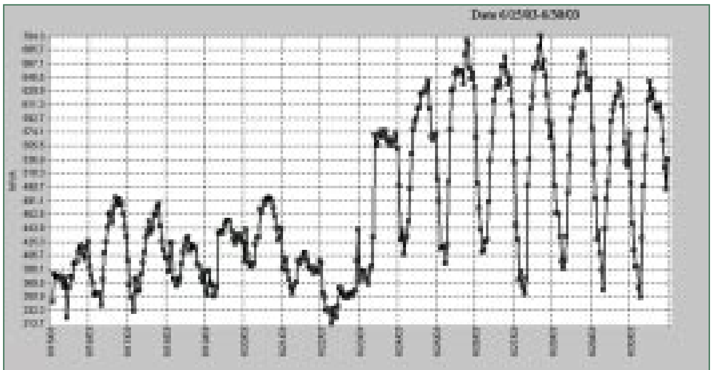
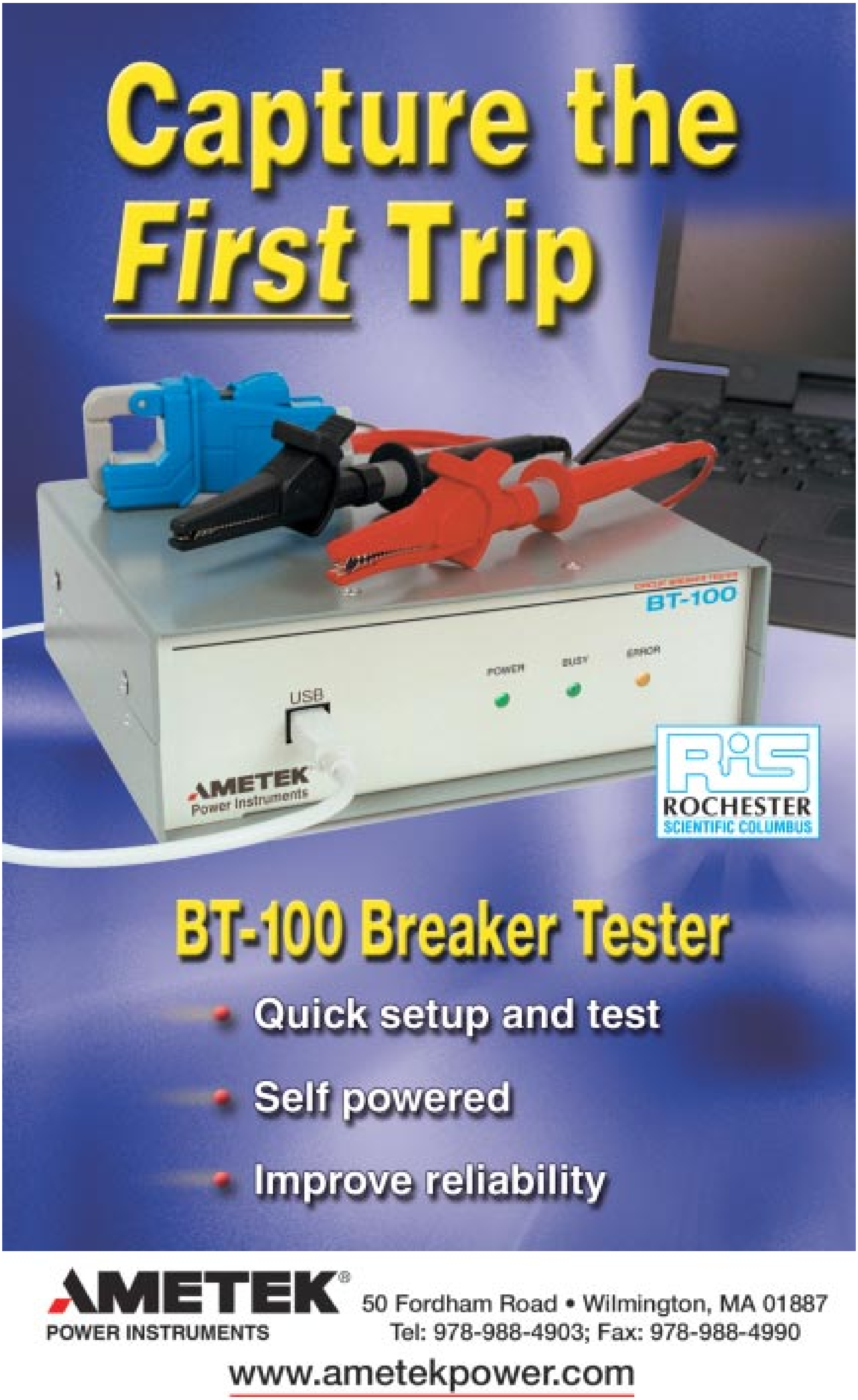


figure 3: SCADA load data through the transformer being monitored

The SCADA load data in figure 3 corresponds to two weeks of on-line DGA data collected near the beginning of the plots of figure 2. Aligning the date information on the x-axis of both charts, one can locate within figure 2 the identical load variations near the beginning of the on-line analyzer's LoadGuide plot (the smooth light green line near the bottom of the chart).

One point that is immediately evident is that continuous on-line monitoring clearly shows combustible gasses being generated by this transformer whenever the transformer load exceeds approximately 50% of nameplate (producing hot-metal gases including acetylene). On-line DGA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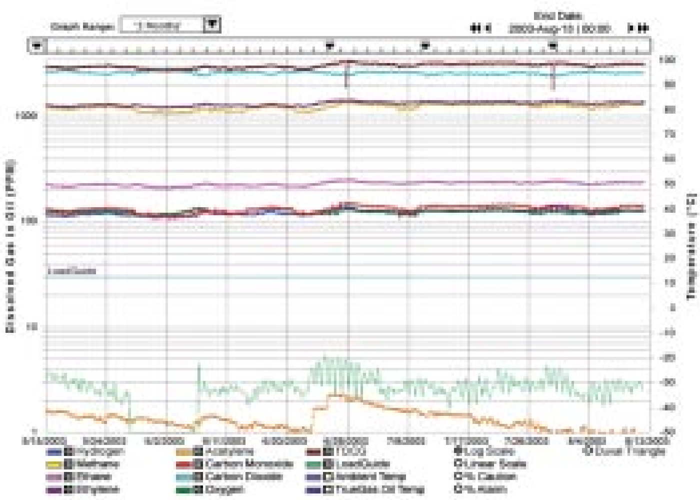

figure 4: sister transformer's on-line results (log scale) with LoadGuide (linear scale)

figure 5: on-line and weekly measurements for one laboratory of acetylene (linear scale)

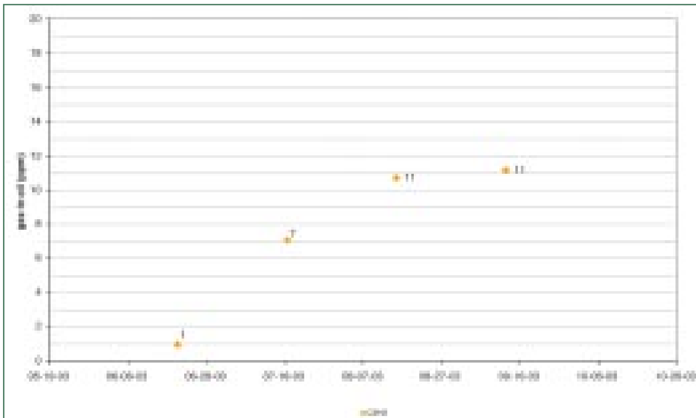

figure 6: laboratory measurements of acetylene at one month intervals (linear scale)

data acquired from a second identical (sister) transformer in the same bank indicates this load-dependent behavior might be an inherent weakness in the transformer (see figure 4).

If there is a concern that operating at or above a load level that generates gas might pose too great a risk, a simple solution to the problem would be to limit the transformer to operating below the gas generating load level, 50% in this example. When this tactic is not practical, monitoring the generation of gases closely and in real-time whenever the transformer is above the gas generating load level is another approach, with the strategy of diverting load if gassing proves excessive.

Given the well-known history of use and prior gassing levels associated with this transformer the decision to continue to operate at or near the gassing level, while simultaneously collecting daily DGAs using the on-line analyzer, is a prudent choice. As is the case in this example, when it is impossible or impractical to eliminate the source of combustible gases in a transformer, a continuous on-line DGA analyzer can be used to closely monitor the combustible gas generation whenever the transformer must be used at or above the gas generating load level.

Infrequent Sampling Results in Aliasing

Of additional interest is the fact that some of the gases generated as a result of the "excess" load actually dissipate over time. When gasses dissipate timing of the DGA test relative to the events of interest becomes even more important. Sampling too long after an event may result in finding no trace of the gas which was generated, because the gases are no longer present in the oil for measurement by traditional means.

The conventional DGA samples that were taken alongside the on-line analyzer were performed at one week intervals. In any normal scenario this would be considered a very high rate of sampling. If we compare the results of the conventional results with the on-line results, for just acetylene and one of the three laboratories, we see very good correlation (see figure 5).

Without the continuous on-line results plotted alongside the manual results it can be difficult to actually detect the real trend of the acetylene. Certainly it would be hard to make a strong case for correlation of transformer load to acetylene production.

At a more typical (but still aggressive) laboratory sampling rate of one per month the bias associated with the rate and timing of the sample can further affect observations so that correlating gassing events to external events can be impossible to determine. If there is a causal relationship between the two it may in fact be missed due to aliasing of the data resulting from too low a sampling rate. See figure 6 for an example of how sample timing and rate can adversely affect one's observation of the events.

Conclusions

The high rate of sampling associated with on-line DGA monitoring of both combustible and non-combustible gases can be used to identify causal relationships between transformer gassing and significant events associated with the transformer, such as operating conditions, loading, winding temperature, and LTC adjustments; whereas testing laboratory samples cannot — due to variations in sampling techniques, testing methods, and the aliasing effect that results from low sampling rates. Transformers can escalate beyond their normal gassing level, to unacceptable levels, very quickly (within hours). Such key events can only be tracked with high DGA sampling rates.

When it is impossible or impractical to eliminate the cause of gases in a transformer, continuous on-line DGA data can be used to help define acceptable transformer operation profiles. But use of on-line DGA monitoring need not be limited to "problem" transformers. Transformers that consistently show "no gassing" when operating at nameplate may, in fact, be candidates for safe operation above nameplate ratings. In either case, continuous on-line DGA provides the additional significant information that can be used to extend or safely limit a transformer's range of operation.

Today, decisions to repair or replace power transformer equipment are based on historical experience, not on real-time data, because much of the information relating to the real-time operating condition of the equipment simply does not exist or is not easily obtained. Continuous on-line DGA data provides significant and useful real-time information regarding the operational characteristics of expensive and critical transformer assets that, when combined with their performance history, allow utilities to prudently operate gassing or overloaded transformers and extend their projected service life. ●

About the Authors

Stanley R. Lindgren, Director of Product Strategy
stan.lindgren@serveron.com

Stan Lindgren is Director of Product Strategy for Serveron Corporation, Hillsboro, Oregon. Before joining Serveron in February of 2001 Mr. Lindgren was Manager of Power Transformers at EPRI in Palo Alto, California, since 1986. From 1979 to 1986 he was with the Paragon Electric Co. Inc. in Two Rivers, Wisconsin, a subsidiary of AMF Inc., where he was Manager of Strategic Planning and Product Acquisition. At RTE Corporation, Waukesha, Wisconsin, Mr. Lindgren was Product Marketing Manager for RTE's Small Power Transformer Division from 1971-1978. Products were three-phase pad-mounted, secondary-unit-substation and power transformers, 5000 KVA and below. At Allis Chalmers in Milwaukee, Wisconsin, he held various positions in product application and technical marketing for the Power Transformer Division 1952-1971, involving all types of medium, large, and EHV power transformers. He obtained his Bachelor of Science in Electrical Engineering (Power) from Kansas State University.

Paul Fischer, Product Marketing Manager
paul.fischer@serveron.com

Paul Fischer is Product Marketing Manager for Serveron Corporation in Hillsboro, OR, since 2001. Prior to joining Serveron Mr. Fischer was employed in engineering and marketing roles for companies involved in the embedded computer and application markets, designing and selling equipment primarily for industrial applications. Mr. Fischer has a Bachelors of Science in Engineering from the University of Minnesota, Minneapolis and a Masters of Science in Engineering from the University of California, Berkeley.

2004 International Conference of Doble Clients and Industry Expo.

Welcome to Boston, Massachusetts and the 2004 International Conference of Doble Clients and Industry Expo.

This marks the 71st year of the Doble Conference and we are pleased to have you be a part of this event.Thank you for joining us at the 4th Annual Doble Industry Expo. We are pleased to have assembled some of the leading players in the electric power industry for this year's event. Doble's Industry Expo focuses not only on the newest leading-edge products and solutions, but also on educating attendees on how to enhance and upgrade existing equipment for maximum power delivery and efficiency.

The demonstrations given at this year's Expo serves as the perfect compliment to the conference program. Our Conference schedule has been developed to offer you maximum flexibility and convenience to compare the products you discuss in the sessions, with real-life settings in the exhibit hall. This way, you have the opportunity to acquire information on industry-wide product development and services both in and out of the meetings.

As always, Doble's Industry Expo offers you extraordinary access to the industry's top suppliers and manufacturers of electric power apparatus. We urge you to take advantage of the many opportunities available to share you questions, ideas and concerns with all exhibitors.

Again, we're delighted to welcome you to Boston and to the 2004 International Conference of Doble Clients and Industry Expo. Please take some time to walk around, enjoy the refreshments and don't forget to enter into the Industry Expo Contest! Have a great week!

Preliminary Schedule of Events

2004 International Conference of Doble Clients

Updated 3/03/04 lc

Sunday March 21

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info							Registration & Information Desk									
Committee Meetings																
Industry Expo		Exhibitor Set Up									Expo Open 5 - 7 pm					
Social											Welcome Reception 5 - 7 pm		Hospitality Suites open at 7pm			

Monday March 22

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info	Registration & Info Desk															
Committee Meetings									RM 3:30 - 5:00							
NewComers Orientation & Activities	Newcomers Orientation						Basic Power Factor 1:30 - 4									
Keynote Address & Opening		Keynote														
User Group												DTA User Group 6-7:30 pm				
Asset & Maintenance Mngmnt				AMM 10:00 - 12:00			AMM 1:30 - 5:00									
Circuit Breakers				CB 10:00 - 12:00			CB 1:30 - 5:00									
Industry Expo					Expo Open 11 am - 1:30						Expo Open 5 - 7 pm					
Social													Hospitality Suites Open at 7 pm			

Tuesday March 23

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info	Registration & Info Desk															
Committee Meetings	BIT 7:30 - 9:30 AMM 7:30-9:30								ACCA 3:30 - 5 PAT 3:30 - 5							
User Group												Breaker Timing User Group 6-7:30 pm				
Bushings, Insulators, Instr. Tx			BIT Session 9:30 - 12				BIT Session 1:30 - 5:00									
Rotating Machinery		RM session 8:00 am - 12 pm					RM session 1:30 - 5:00									
Industry Expo					Expo Open 11 am - 1:30				Exhibitor Mtg 3 - 4		Expo Open 5 - 7 pm					
Oil Committee Mtg & Dinner												Oil Committee Meeting & Dinner				
Social													Hospitality Suites Open at 7 pm			

Wednesday March 24

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info	Registration & Info Desk															
Committee Meetings	IM 7:30-9:30am								CB 3:00 - 5:00pm		Transfrs 5 - 7 pm					
Arresters, Capacitors, Cables & Access.		ACCA 8:00 - 12:00pm														
Insulating Materials, Transformer-related Topics Session			IM Tx Session 9:30- 12 pm				IM Tx Session 1:30 -5:00pm									
Rotating Machinery & Protection Apparatus Test Joint Session		RM/PAT Generator Protection Session					RM/PAT Session									
Tutorials							Tutorials 1:00 - 5:00pm (Transformer Cooling 1 - 4, Safety 4 - 5)									
Industry Expo		Expo breakdown														
User Group	SFRA User Group 7:30 - 10															
Social													Hospitality Suites Open			

Thursday March 25

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info	Registration & Info Desk															
Committee Meetings																
Transformers	Transformers Session 7:30 -12 pm						Transformers 1:30 - 5:00									
Insulating Materials, General Session		IM General Session 8:00 - 12:00pm														
Social												Reception &	Group Dinner at Hotel			

Friday March 26

	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
Registration/Info	Registration & Info Desk															
Committee Meetings					Advisory Committee											
Transformers	Transformers Session 7:30 -11															

2004 Hospitality Suite Holder Company Descriptions

Please see the Suite Map for Company Suite Locations and Times

ABB Inc.
940 Main Campus Drive, Suite 500
Raleigh, NC 27606
Beverly Jenkins; 919-856-2360
beverly.a.jenkins@us.abb.com
www.abb.com
- ABB Inc. serves electric, gas and water utilities, as well as industrial and commercial customers with a broad range of products, systems and services for power transmission, distribution and automation.

AREVA T&D Inc.
1510 Chester Pike, Suite 110
Eddystone, PA 19022
Customer Care; 888-AREVA-TD
customer.care.usa@areva-td.com
www.areva-td.com
- AREVA T&D offers a complete range of reliable T&D solutions to address the different needs of every stage in the equipment life cycle, including high voltage switchgear, large power transformers, power quality solutions (e.g. SVC, STATCOM, HVDC), and T&D services (e.g. equipment refurbishments, retrofits and maintenance).

Delta Star
270 Industrial Road, San Carlos, CA 94070
Kevin Anderson; 650-743-3270
kevina@deltastar.com
Medium Power Transformers and mobile substations.

E Manufacturing Co., Inc.
7275 Industrial Park Boulevard
Mentor, OH 44060
Chris Francis; 440-951-0900
chris@emanufacturing.com
www.emanufacturing.com
- E Manufacturing is an original equipment supplier for Air Disconnect Switches and a replacement parts manufacturer for Load Tap Changers, Circuit Breakers, Switchgear and related equipment.

General Electric
4200 Wildwood Parkway, Atlanta, GA 30339
Kimberly Brennan; 770-999-7141
http://www.ge.com
- GE (NYSE:GE) is a diversified technology, services and manufacturing company with a commitment to achieving customer success. GE operates in more than 100 countries and employs approximately 315,000 people worldwide. Our products and services range from power generation technology, energy services and management systems to the latest technological products used to distribute, protect and control electrical power and equipment. GE provides equipment, services and management solutions across the power generation, distributed power and utility industries.

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Steven Peschel, Director of Sales & Marketing
518-329-3275
sales@hvinc.com
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LAPP Insulator
130 Gilbert Street, Leroy, NY 14482
Marlene D. Beil, Bushing Executive Assistant
585-768-5009, mbeil@lappinsulator.com

Yavuz K. Erkan, Bushing VP/GM
585-768-5144
yerkan@lappinsulator.com

Wayne Gibson, Bushing Application Engineer
585-768-5034
wgibson@lappinsulator.com

Eric Hildreth, Bushing Application Engineer
585-768-5227
ehildreth@lappinsulator.com

Chris Monoski, Supervisor QA & HV Lab
585-768-5057
cmonoski@lappinsulator.com

Mark Sommer, Bushing Marketing Director
585-768-5066
msommer@lappinsulator.com

W. A. (Bill) Young, Supervisor-Bushing Design; 585-768-5047
wayoung@lappinsulator.com

Shibao Zhang, Senior Engineer
585-768-5191
szhang@lappinsulator.com
- Lapp Insulator Company was founded in 1916 and soon became a pioneer in the design and manufacture of high voltage insulators. In 1922, Lapp developed a vacuum process for improving the strength of clay ushering in an era of rapid development of entirely new insulator types including line and station posts that are now utility design standards worldwide. In 1954, Lapp began the manufacture of high voltage bushings and today is a leading supplier of condenser bushings used for either transformers or oil circuit breakers up through 500kV. Lapp has been management owned since 1999 with facilities located in Georgia, New York and Germany. In the 21st century, our products are still the highest quality and we are continuing the tradition of leading the industry in new innovations.

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Nynas Transformer Oils USA Inc.
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Houston, TX 77027
Jeremy Kriska ; 713-586-3832 X106
jeremy.kriska@nynas.com
www.nynas.com
- Nynas is a Global Manufacturer and Marketer of Standard and High Grade Type I and II Transformer Oils. We are the global leader when it comes to Transformer Oil quality and knowledge. Product is currently available domestically. US production of our quality NYTRO grade transformer oils begins June 2004.

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Victoria Li; 416-364-4028
vli@petro-canada.ca

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www.reinhausen.com
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Becky Compton; 330-630-7000
Becky.Compton@sdmyers.com

Southwest Electric Company
6501 SE, 74th Street
Oklahoma City, OK 73135
Joe Garza; 713-849-9171
jgarza9171@aol.com
- Southwest Electric Company is an electrical repair organization which is headquartered in Oklahoma City, OK. We have been in operation for over 56 years and provide national services from five divisions: **1.** *Power Transformer Division,* **2.** *Field Service Division,* **3.** *Rotating/Switchgear & Breaker Equipment Division,* **4.** *Custom Switchgear Division, and* **5.** *Specialty Transformers Division.*

Uptime Solutions
6 Dorset Place, Durham, NC 27713
George Forrest; 919-544-8191
georgeforrest@uptime-solutions.com

Velcon Filters, Inc.
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Colorado Springs, CO 80919
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vfsales@velcon.com
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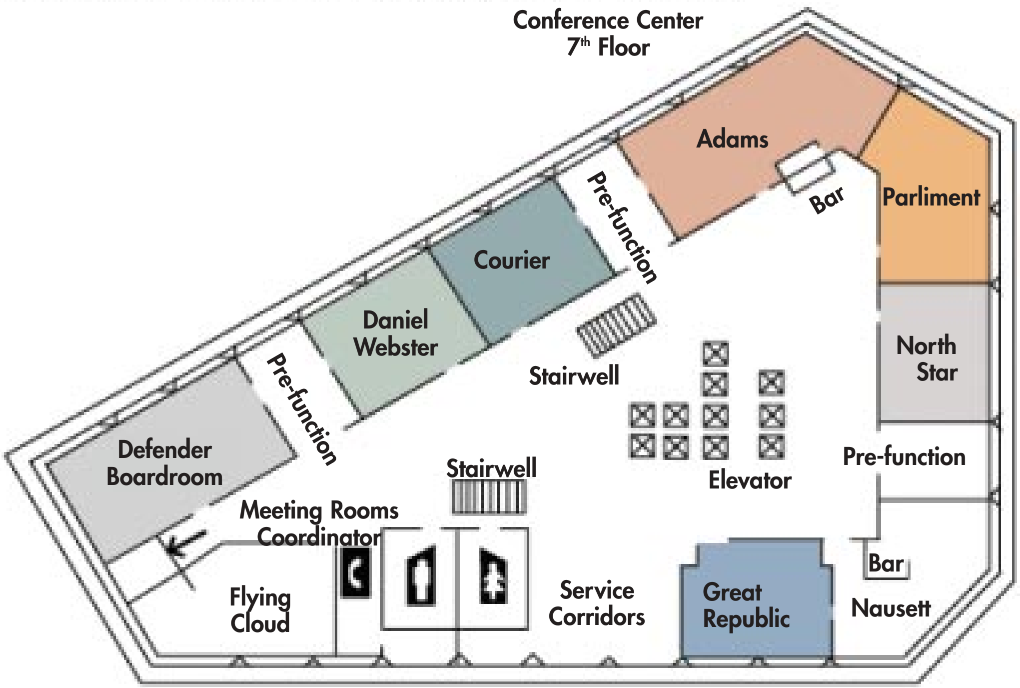
lbean@weidmann-systems.com
www.weidmann-acti.com
- The Weidmann Group specializes in providing the transformer industry with expertise in the fields of diagnostic testing and engineering, as well as a wide range of replacement parts and components dealing with all aspects of transformer maintenance and repair.

Preliminary Schedule of Events

2004 Hospitality Suite Floorplan

7th Floor Layout
Suites Open at 8:00 pm, Sunday March 21st
Suites Open at 7:00 pm on Monday, Tuesday & Wednesday evening



Organization	Suite Open	Suite Location
ABB Inc.	March 22 & 23	Daniel Webster/Courier
Areva T&D	March 23rd	Senator's Suite
Delta Star	March 23rd	Flying Cloud
E Manufacturing Co., Inc.	March 21, 22 & 23	Great Republic
GE Supply	March 21, 22 & 23	Presidential
High Voltage Inc.	March 22 & 23	Governor's Suite
LAPP INSULATOR COMPANY LLC	March 23 & 24	Parliament
Morgan Schaffer	March 22, 23, & 24	Nausett
Nynas	March 22, 23, & 24	Imperial
Petro-Canada Lubricants	March 24th	Great Republic
Reinhausen Mfg., Inc.	March 24th	Presidential
SD Meyers	March 23rd & 24th	Breakfast (Location TBD)
Southwest Electric Company	March 22 & 23	Adams
Uptime Engineered Solutions	March 21, 22, 23 & 24	North Star
Velcon Filters, Inc.	March 22 & 23	One Bedroom Senator Suite
Weidmann-ACTI, Inc	March 23rd	One Bedroom Suite

(yellow) Suite is located on another floor of the Westin Copley Hotel

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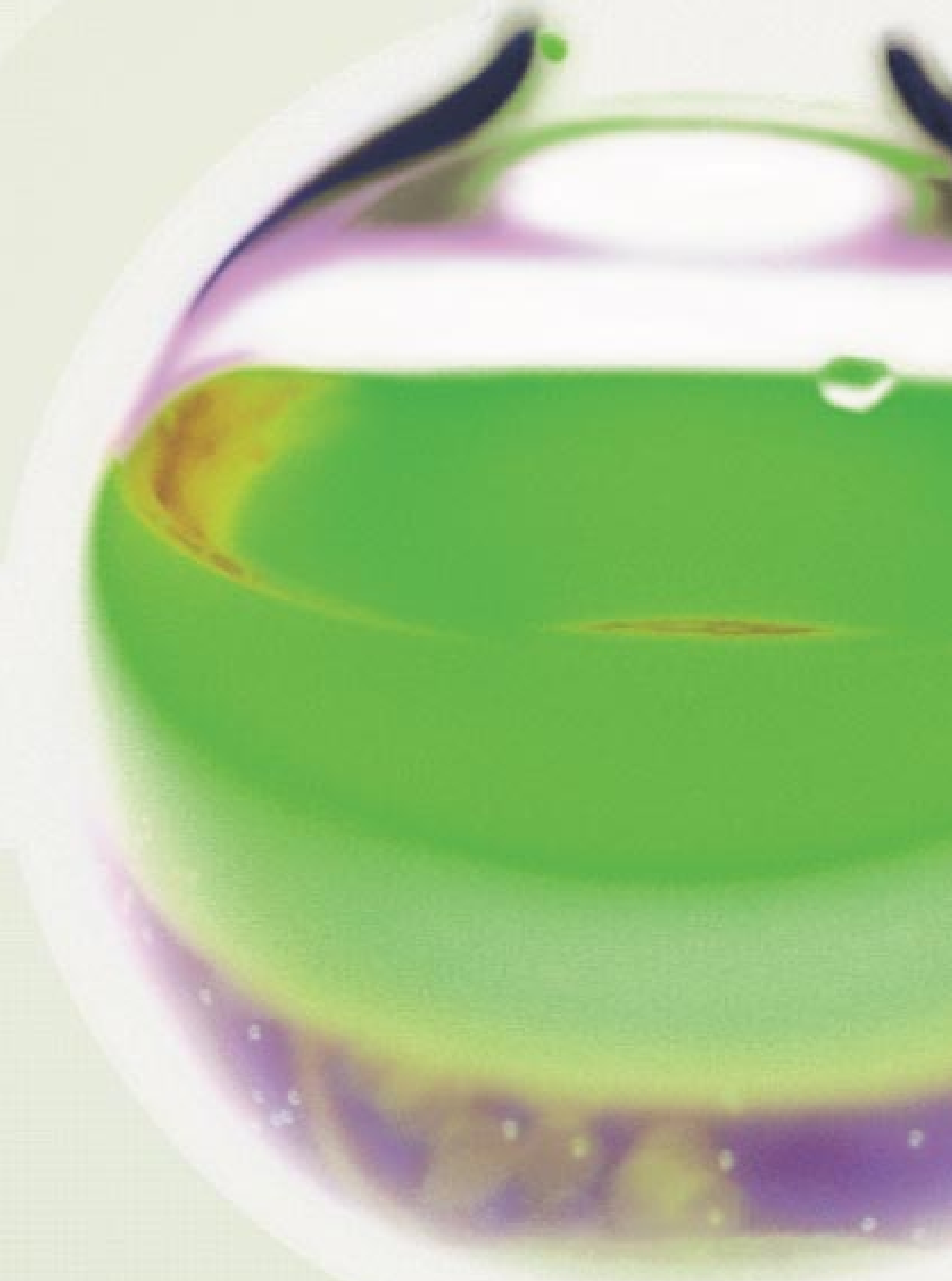
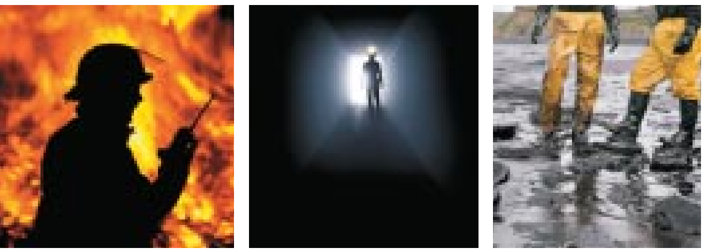


Circle 121 on Reader Service Card

Or you can continue to do business as usual. Until it's **unusual.**



Fire. Failure. Environmental catastrophe. Since you're in power delivery, you know what makes headlines, escalates costs, and breaks customer trust. But now there's a remarkable new asset protection product that will help you achieve higher levels of public and workforce safety, performance, and reliability, while keeping costs and liability down.

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2004 Doble Industry Expo Exhibitors

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Arbiter Systems Inc. **Booth 13**
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Paso Robles, CA 93446
Christine Greco; 805-237-3831
cgreco@arbiter.com www.arbiter.com
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Customer Care; 888-AREVA-TD
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- AREVA T&D offers a complete range of reliable T&D solutions to address the different needs of every stage in the equipment life cycle, including high voltage switchgear, large power transformers, power quality solutions (e.g. SVC, STATCOM, HVDC), and T&D services (e.g. equipment refurbishments, retrofits and maintenance).

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jhackett@coltonline.com
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- Doble PowerTest was created in 2002 when Doble Engineering purchased the National Grid Company plc. The National Grid Company was established on 31 March 1990 as the owner and operator of the high voltage transmission system in England and Wales. The company is a wholly owned subsidiary of National Grid Group plc, which is listed on the stock exchange and is one of the UK's FTSE 100 companies. The Company headquarters are in Coventry, England.

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info@doble.com
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Menomonee Falls, WI 53051
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Tony.pink@dynamicratings.com
www.dynamicratings.com
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Sébastien Riopel; 450-430-1181
s.riopel@eci-co.com www.eci-co.com
- ECI is a world leader in the design and manufacture of high voltage insulating systems for the energy business. We manufacture superior performance and durable polymer bushings up to 69kV for all types of applications and insulators for transmission applications up to 765kV and substation applications up to 161kV.

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Ontario, Canada, L1S 2B9
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Carol@electricityforum.com
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Electric Energy Publications **Booth 59**
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Electric Light & Power - PennWell Publishing **Booth 60**
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shirleyw@pennwell.com
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Environmental Protection Service **Booth 7**
4 Industrial Park Drive, Wheeling, WV 26003
Brad Joseph; 304-232-1590 ext. 42 (phone)
304-232-1599 (fax)
brjoseph@epsonline.com www.epsonline.com
- EPS specializes in the installation, maintenance and disposal of electrical equipment. This includes PCB, PCB-Contaminated and Non-PCB disposal, energized transformer dechlorination, energized hot oil reclamation, installation/ vacuum-filling and retrofills. EPS also sells Trans-X oil, a reclaimed mineral oil dielectric fluid that meets the standards of virgin but at considerable savings.

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Andover, MA 01810
Stacie Hamner; 617-835-6888
stacie_esbi@hotmail.com www.esbi.ie
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David M. Butler; 800-321-3895
sales@filmaxinc.com
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FISO Technologies Inc. **Booth 34**
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Quebec, PQ G2E 5R9 CANADA
Sharon Walsh; 418-688-8065
sales@fiso.com
http://www.fiso.com
- FISO Technologies is a leading supplier of fiber optic solutions for direct monitoring of substation assets. Products are EMI immune and designed for long-term reliability.

Flakt Coiltech, Inc. **Booth 43**
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Mike Martin ; 731-987-2228
mike.w.martin@flaktwoods.com
- Replacement FOA coolers for (W), GE, ABB, M-E, PA, and A/C large power transformers and most mobile transformers. Hydro generator cleanable coolers (new and replacement). Diesel generator air blast coolers (new and replacement).

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Tom O'Toole ; 978.901.8000
info@flir.com www.flirthermography.com
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Flowserve **Booth 7**
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Steve Baxley; 800-673-7385
sbaxley@flowserve.com www.flowserve.com
- Service Company that provides leak repairs on transformer oil and SF6 Gas.

General Electric **Booth 44-45**
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- GE (NYSE:GE) is a diversified technology, services and manufacturing company with a commitment to achieving customer success. GE operates in more than 100 countries and employs approximately 315,000 people worldwide. Our products and services range from power generation technology, energy services and management systems to the latest technological products used to distribute, protect and control electrical power and equipment. GE provides equipment, services and management solutions across the power generation, distributed power and utility industries.

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Sean McLenithan, MBA; 518-399-3616
www.MDAturbines.com
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Megger **Booth 20**
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214-330-3245
- Megger is a leading manufacturer and marketer of a wide variety of electrical test and measuring instruments for power applications.

Midsun Group Inc. **Booth 19**
135 Redstone Street, Southington, CT 06489 USA
860-378-0100
info@midsungroup.com
www.midsungroup.com
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1101 N Elevation, Suite 3, Hancock, MI 49930
John Chynoweth; 906-487-6060
kinn@mikroninfrared.com
www.mikroninst.com/
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Morgan Schaffer **Booth 27**
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William Morse; 514-739-1967
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- Team Industrial Services performs onsite, inplace, nondestructive repairs to transformers leaking oil and circuit breakers leaking SF6 gas and/or oil. Other services include onstream leak sealing, hot taps, line stops, freeze stops, field machining, bolt tensioning and torquing, onsite and inline valve repairs, fugitive emissions control (LDAR), plus non-destructive testing.

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David Burns; 504-468-8837
sales@tjh2b.com www.tjh2b.com
- TJ/H2b Analytical Services is an independent laboratory and consulting firm that specializes in the testing of insulating materials used in high-voltage electrical equipment. TJ/H2b has pioneered diagnostic programs for the condition assessment of transformers, load tap changers, oil-filled circuit breakers, and SF6 breakers.

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- Now a part of Doble Engineering Company, TransiNor was established in 1986 as a spin off from The Norwegian Electric Power Research Institute (EFI), which is now called SINTEF Energy Research. TransiNor offers diagnostic monitoring systems and services, electromagnetic transient studies and failure investigations. TransiNor's distribution network spans the globe in some 40 countries.

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sales@vtcucorp.com
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800-835-2732
wesinfo@waukeshaelectric.spx.com
www.waukeshaelectric.com
- Waukesha Electric Systems, Inc. (the largest manufacturer of medium-power transformers), along with its subsidiary, High Voltage Supply (Dallas, TX), will present an extensive range of products and capabilities, including Transformers and Accessories, Load Tap Changers, Modular Substations, Substation Transformer Condition Assessment Services, Reverse-Engineered LTC and Circuit Breaker Components, and complete Substation Repair and Maintenance Services nationwide. The company also provides systems-engineered EPC solutions through its subsidiary, PSD, Inc. (Canton, OH), including engineered switchyards, substations, overhead and underground transmission lines, and Wind Energy projects.

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Lisa C. Bean; 802-751-3530
lbean@weidmann-systems.com
www.weidmann-acti.com
- The Weidmann Group specializes in providing the transformer industry with expertise in the fields of diagnostic testing and engineering, as well as a wide range of replacement parts and components dealing with all aspects of transformer maintenance and repair.

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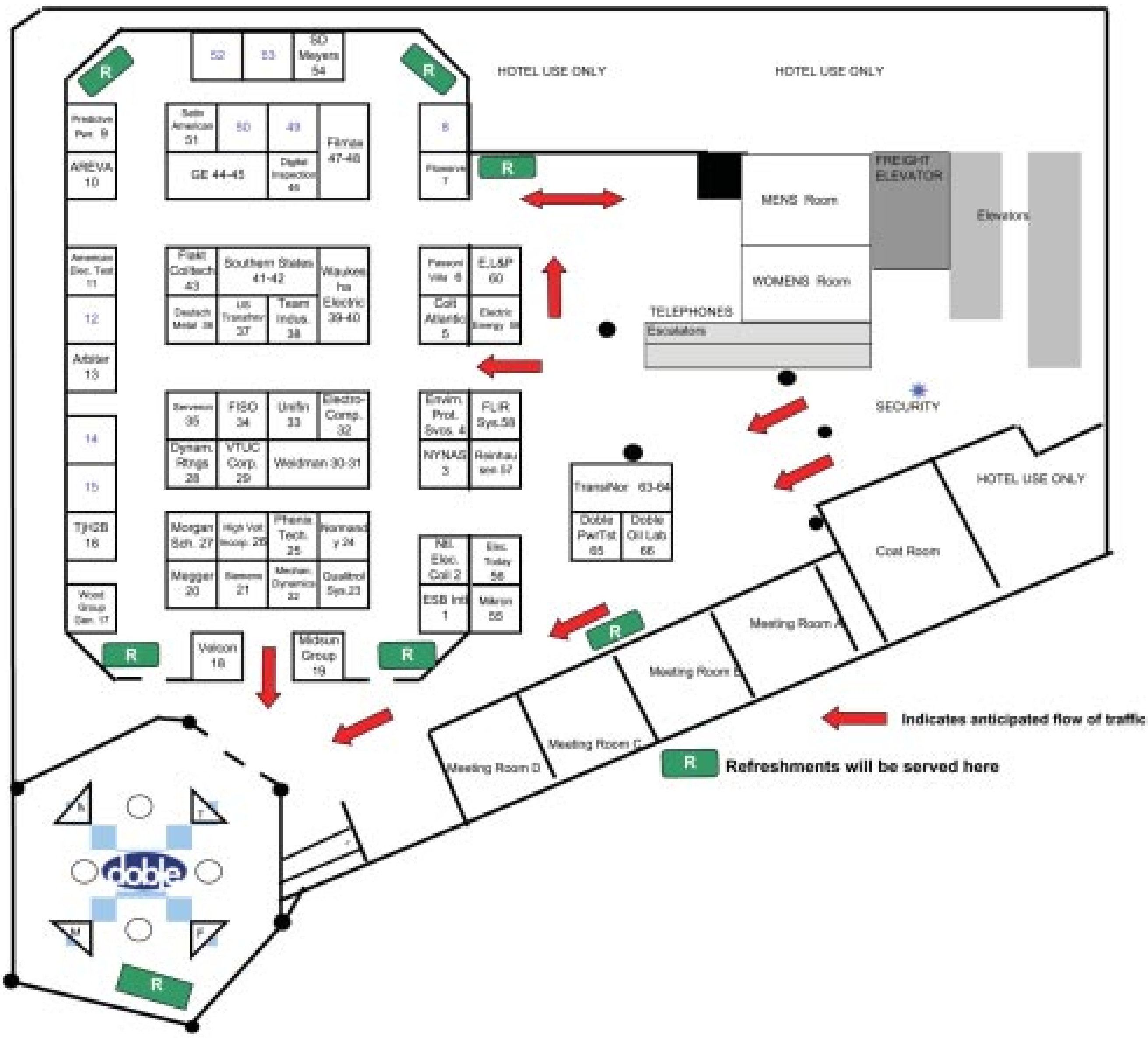
David Y. Robinson; 505-327-6363
davidr@irscoil.com
Wood Group Generator Services, Inc. is a manufacturer of high and medium voltage coils and Roebel bars. Our service facility specializes in inspection, in-plant and field service, coil installation, repair and rewinding of generators and high voltage motors.

2004 Industry Expo Floor Plan

(3rd floor of Westin Hotel Copley Place)



2004 Doble Industry Expo

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Seed Oil-Based Dielectric Coolant Serves as a Solution for Aging Transformers

By: *P. McShane, Product Line Manager for Dielectric Fluids, Cooper Power Systems.*

Introduction

The importance of safe and reliable power in today's world was never more apparent than on August 14. Beginning in late afternoon and lasting mere minutes, the largest blackout ever on the North American continent rolled across the northeastern and north central United States and into Canada. Upwards of 50 million people lost power, including all of New York City, with estimated economic losses hovering at $6 billion.

The blackout of 2003 is an extreme illustration of reliability issues electric utilities face everyday. The media is filled with examples of these more common, but still troublesome, events. Last summer, a distribution transformer serving the St. Louis Arch caught fire and forced the evacuation of 8,000 visitors. A substation fire in San Francisco caused a power outage for 120,000 customers the Saturday before Christmas. Both incidents translated energy company dollars into damage, restoration, and labor fees. In St. Louis, vacation days were ruined, and Bay Area retailers lost essential revenue during one of the busiest shopping days of the year.

The reliable distribution of power, what many of us take for granted, is performed through a complex choreograph of generation, transmission and distribution sectors of the industry. Though the blackout of 2003 shed serious media and regulatory light on the transmission component of this delivery system, many industry experts believe strengthening the distribution system will better ensure a higher level of reliable power. Transformers play a key role in making it happen.

In St. Louis and San Francisco, transformer malfunction was either directly responsible, or part of the larger problem, that caused these events.

Current Transformer Concerns

The economic boom created to feed the World War II war machine continued into the 1950's and 1960's. Power was needed to drive the strong national manufacturing base and fulfill the demands of suburban development. Power delivery systems were constructed, and substation and distribution transformers were a part of each and every one. The transformers, which adhered to fire safety and environmental codes and standards on the books at that time, were built to last with a life expectancy of up to 40 years. They were installed and often forgotten about.

The country's reliance on power grew as it expanded. Populations increased and power tools and appliances replaced equipment that didn't require electricity. Recent electric utility deregulation further taxed the grid. More has been asked of the installed equipment than it was designed to

handle. Much of the older installed equipment, including transformers, is now coming to its useful end.

The number of aging transformers still active has concerned many in the industry. Factory Mutual (FM), a major insurance group, recently reported that the number of substation transformer failures is expected to rise by 500 percent within the next 10 years due to aging systems. The small amount of construction of new power systems and increasing loads on old systems is especially worrisome.

A survey reported by Hartford Steam Boiler, another insurance group, shows that most current failures occur in transformers with an average age of 18 years. As a result of failure incidents, utility companies have reported significant profit losses due to downtime and equipment replacement. One Northeastern power company recently estimated that 50 transformer incidents occur per year at a rate of approximately $10,000 per incident, costing the company $500,000 annually. The majority of these costs are directly related to the actual incident – taking the transformer offline, maintenance or equipment replacement, and getting the new or fixed transformer back online.

With aging transformers, the real risks to utilities and their customers are the potential ancillary costs in case of an eventful transformer failure. Many of these costs are related to the conventional petroleum-based mineral oil used in these older transformers. Mineral oil's relatively low fire point and negative environmental profile place utilities at greater risk for property damage claims, extensive cleanup, casualties, environmental liability, and negative publicity should a transformer fail.

Shrinking capital expenditure budgets make it difficult for utilities to replace aging, and potentially dangerous, transformers with newer units. Fortunately, utilities have new options.

Changing the Standards

Short of costly equipment replacement, solutions to aging transformers must incorporate the following:

- Adhere to stricter current environmental and fire safety codes and standards
- Maintain or improve transformer performance to better deal with the slow but steady rise in load
- Extend the useful life of the transformer to forestall any capital purchases

Years ago, industry and regulatory bodies tried to address some of these issues by creating a demand to produce a power delivery system focused on safety, equipment efficiency, and environmental protection. This movement included transformers. The focus was on transformer oils.

In 1978, a group of less-flammable transformer fluids were developed and approved by the National Electric Code® (NEC). The NEC created an industry standard that required a minimum open-cup fire of 300°C to be considered safer than conventional transformer oil. In 1984, the Underwriters Laboratories® (UL) collaborated with transformer manufacturers to combine fire resistant fluids with other methods of transformer protection. In the 90's, Factory Mutual Engineering and Research produced the first Occupational Safety & Health Administration (OSHA)-recognized standard for liquid-filled transformers, suitable for indoor and outdoor installation, with greatly reduced fire safeguard requirements.

Since the late 1970's, thousands of less-flammable liquid-filled transformers have been in service, and 10 less-flammable dielectric coolants have been approved as an alternative to mineral oil. Approved coolants include high molecular weight hydrocarbons (HMWH), dimethylsiloxanes (silicone), synthetic polyol esters (POE), and polyalphaolefins (PAO).

Despite their success and improvement in many ways over traditional transformer mineral oil, none of these fluids provide the total solution utilities require in the 21st century to deal with aging transformers.

The Ester-Based Solution

The most beneficial transformer fluids must provide a better balance of performance internally and better degradability externally than most of the newer transformer coolants can provide. New fluids to the market look beyond the fire safety improvements of the coolants manufactured in the 70's and 80's to better fulfill today's utility needs – regulatory adherence, life extension, and improved performance. The search for this solution led manufacturers to investigate ester-based fluids.

Synthetic ester dielectric fluids have excellent dielectric properties and are considerably more biodegradable than mineral oil-based fluids. Yet, the high cost of synthetic ester dielectric fluids restricts its mainstream usage. Synthetic esters are used mainly for traction and mobile transformers and specialty applications.

Natural esters such as seed (vegetable) oil-based fluids were historically known to be unsuitable in transformers. This changed after the development of environmentally safe performance improvement additives and stabilizers. These products, combined with modern transformer design practices, limit fluid exposure to moisture and oxygen. In addition, beneficial properties of the natural esters were identified that were not provided by other dielectric fluids.

Transformer Fluid	Immediately Prior to Retrofill	Two Weeks After Retrofill	Six Weeks After Retrofill
Flash Point	147°C	236°C	234°C*
Fire Point	165°C	352°C	>345°C
Relative Humidity	11.6%	4.6%	3.4%
Absolute Water Content	7ppm	46ppm	36ppm

Fire Safety and Environmental Compliance

In 1997 a transformer containing the world's first seed oil-based dielectric coolant was introduced. The transformer fluid had the highest fire and flash points in the industry and was quickly and completely biodegradable. The use of a food grade natural ester base – in this case soy oil – enabled the manufacturer to produce a transformer coolant that met or exceeded current industry environmental and fire safety standards and codes.

Since the time of this introduction, seed oil-based dielectric coolants have continued to meet the needs of the marketplace, including fire safety and environmental compliance.

At least one natural ester fluid has the highest published flash and fire points, at 333°C and 360°C, respectively. FM and UL list some natural ester fluids as a less-flammable dielectric liquid for use in complying with NEC and insurance requirements. Both FM and UL list natural esters for indoor and outdoor installations, typically without fire extinguishing provisions or firewall requirements.

More importantly for utilities with an installed base of mineral-oil transformers, the fire point and flash point properties of natural esters are transferable in retrofill applications. One natural ester manufacturer states that up to 7.5 percent mixture of mineral oil has little impact on the fire point of their product.

When it comes to the environmental protection, food grade seed oil-based dielectric coolants have significant advantages. One seed oil-based transformer fluid is the first transformer material to receive the U.S. Environmental Protection Agency (EPA) ETV (Environmental Technologies Verification) status confirming its published environmental claims.

Life Extension and Improved Performance

Transformer performance typically relates directly to the condition of its paper insulation. As the insulation paper begins to age and weaken, so does the transformer. Water generation and retention is one of the primary causes of accelerating paper insulation degradation an lowering the dielectric performance of the insulation system.

Traditional mineral oil transformer fluids allow the insulation paper to gather water in its fiber. Seed oil-based coolants actually help draw existing moisture out of the paper and prevent water generation from the paper. Accelerated insulation life testing has shown that with seed oil-based coolants paper life can be extended 5 to 8 times, in comparison to aging in mineral oil. Dielectric performance retention also remains high.

Because of this, transformers filled with seed oil-based fluid can 1) be run within their standard operating parameters longer, doubling or better the life of the transformer, or 2) be operated beyond the faceplate ratings without loss of insulation life. (It is important that other transformer components be assessed to determine if they can support the higher operating temperatures.) In either case, using seed oil-based transformer coolant offers utilities a competitive dollar per KVA capacity, while reducing fire and environmental risks.

For utilities operating transformers within standard parameters, the benefit is obvious; they can delay the eventual replacement of the transformer, significantly improving the cash flow of the utility. As even medium power substation transformers can cost upwards of $500,000 to $1 million, this is a major benefit to organizations managing ever-shrinking capital expenditure budgets.

However, some utilities find themselves in the second scenario. Using seed oil-based coolant allows them to provide up to 15 percent more power to their consumers with equipment already in operation. This also provides savings, as they may not have to upgrade transformers to accommodate a larger demand.

Other potential functional benefits of the seed oil dielectric coolants include: reduced minimum clearance insurance requirement to equipment and buildings, elimination of water vapor formation under sudden overload conditions, elimination of detectable sludge, lower gassing tendency, and potentially an improved internal voltage stress distribution.

Field Test

Alliant Energy initiated a study in 2001 to determine the feasibility of changing to a seed oil-based dielectric coolant in a traditional substation transformer. Alliant reviewed test data on the extension of the life of the transformer, fire safety characteristics, and the environmental profile with hopes to bring financial benefits to the company. The study included replacing mineral oil in a 50-MVA transformer at a substation in Cedar Rapids, Iowa with a seed oil dielectric fluid. The step-up transformer was manufactured by Pennsylvania Transformer in 1957, having a primary voltage of 69 kV and 350 kV BIL rating. The unit was retrofilled on October 28, 2001 and is currently functioning as anticipated.

The study completed by Alliant Energy was the first of its kind in the United States to test seed oil fluid in a medium power transformer. Based on positive results generated through the prototype retrofill (see table), Alliant Energy has recently initiated a systematic program of mineral oil replacement in power transformers.

Conclusion

Transformers play a critical role in the delivery of safe and reliable power essential to the nation's economic growth, security, and our overall quality of life. Transformers installed during the heyday of electrical infrastructure growth, the 50's and 60's, are coming to the end of their lifecycle at a time when shrinking capital expenditure budgets and the uncertain ROI brought on by deregulation has made it difficult for utilities to invest money purchasing new transformers.

Electric utilities can now purchase distribution and power transformers and retrofill existing mineral oil filled transformers with tested seed oil-based coolants. These natural esters provide reduced fire and environmental impact risks and improved insulation life. The new coolants will help ensure a higher-level of overall performance from the power delivery system.

About the Author

McShane is Product Line Manager for Dielectric Fluids at Cooper Power Systems. Professional activities include IEEE TC Task Force Chair for Ester Based Dielectric Coolants. He is the principal inventor of four US patents relating to dielectric fluids. Several of his safety related proposals have been adopted by US and International Codes and Standards.

He can be reached at pmcshane@cooperpower.com

Transformer Maintenance and Diagnostics
Using Frequency Response Analysis

By: *Jeffrey A. Britton, Chief Engineer, Phenix Technologies, Inc.*

440 MVA Three Phase Auto GSU Transformer Being Prepared for an FRA Test

Motivation for Performing Frequency Response Analysis (FRA) Measurements

Many dielectric and mechanical failures in large power transformers are preceded by mechanical changes in the winding structure. These changes, or displacements in the winding structure, may be the result of transportation damage occurring between the manufacturer and the service location, short circuit forces imposed on the windings resulting from a low impedance fault occurring close to the transformer, or natural effects of aging on the insulating structures used to support the windings. Detection of these displacements in advance of a dielectric failure can reduce unplanned maintenance costs, and provide the possibility to improve system reliability by preventing outages. Additionally, when damage is discovered, repairs may be targeted to a specific phase winding.

Background of Frequency Response Analysis Used in Transformer Diagnostics

The idea of using frequency response analysis to monitor the condition of critical power transformers running in the transmission and distribution network is not a new one. The knowledge that the AC impedance (or admittance) of any RLC network is a function of frequency is almost as old as the discipline of electrical power engineering itself. The realization that the impedance (admittance) versus frequency characteristic of certain critical power system equipment might be used as a diagnostic tool to assess the electrical and mechanical condition of the equipment is a somewhat newer development. Over the past approximately 30 years, much work has been done to try to understand how to first obtain and then to use the powerful information contained in what electrical engineers refer to as the "Transfer Function".

Transfer function is a generic term defined by the IEEE Standard Dictionary as "a complex frequency response function that defines the dynamic characteristics of a constant parameter linear system. For an ideal system, the transfer function is the ratio of the Fourier transform of the output to that of a given input."

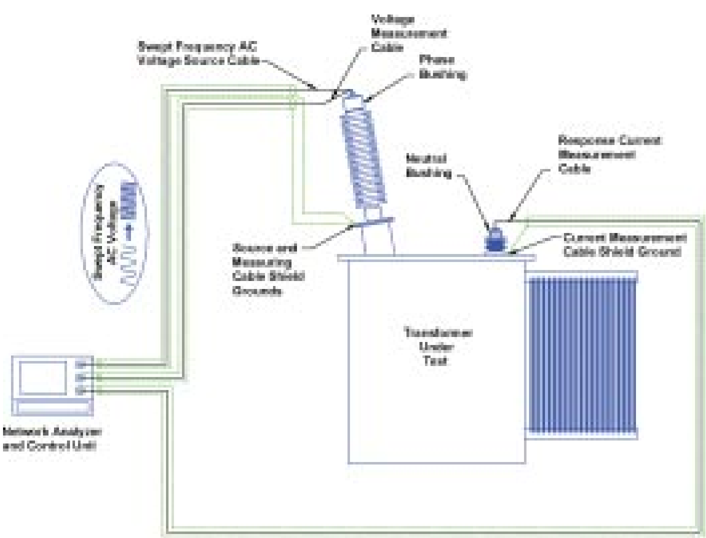
In general, an engineer may define a transfer function based on inputs and outputs that he or she selects. In order for this notion to have value when assessing the condition of large power transformers, the input and output used to calculate the transfer function must be practically measurable, and the chosen inputs and outputs must exhibit some change when the parameter of interest, such as the geometric structure of the windings, changes. As it turns out, the traditional electrical engineering interpretation of AC impedance (or admittance) as a function of frequency, especially at relatively high frequencies in the range of 100 kHz to 5 MHz, has been shown to be highly sensitive to even minor displacements in the geometric structure of large power transformer windings. In fact, even changes in the dielectric parameters of the insulation system, such as those affected by the temperature and moisture content of the insulating oil and cellulose paper, have the possibility of being revealed through relatively inexpensive FRA measurements.

The Objectives for FRA Measurements

Large power transformers represent a complex RLC network. For such a fixed electromechanical system, the frequency response represents a unique characteristic or fingerprint that may be used to assess the electrical and mechanical condition of the unit. From a theoretical standpoint, the above statement is straightforward. In practice however, the realization of a technique that can produce meaningful results is more complex, especially at frequencies above 2 MHz. The objective of FRA measurement is therefore twofold, and is stated in the following questions:

1) How can a repeatable transfer function be obtained through practical measurement techniques?
2) Once the FRA result is obtained, how can it be interpreted to explain what it means for the transformer?

The remainder of this article will attempt to answer these questions, with emphasis on newly developed techniques for improving the repeatability, sensitivity, and interpretation of results.



Typical Test Connection and Setup for a Swept Frequency FRA Measurement

Traditional Methods of Obtaining Transfer Functions Through Measurement

There have been two basic methods used in the past to measure the low voltage frequency response on power transformers:

Swept Frequency Method

The first method, known as the swept frequency method, makes use of the simple truth that the sinusoidal AC impedance (or admittance) of a transformer winding varies with frequency.

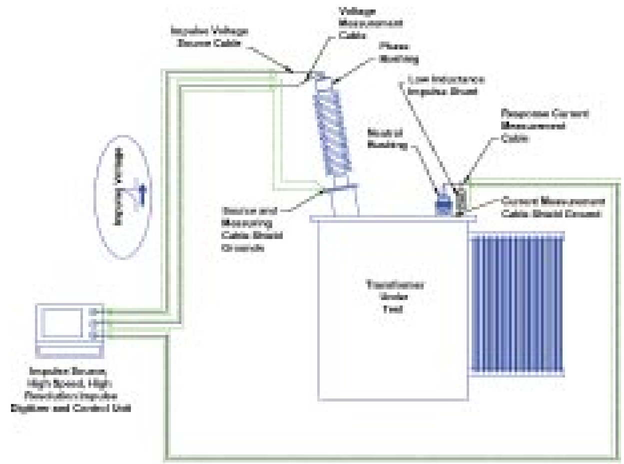
Traditionally, a network analyzer is used to apply a sinusoidal AC voltage to one terminal of a transformer winding, while the resulting response current is measured via conversion to a voltage at the 50 ohm input to the network analyzer. The frequency is then swept over the range of interest, and a transfer function is directly measured when the admittance (magnitude and phase angle) of the winding is plotted as a function of frequency.

This method is, from an intuitive point of view, the most straightforward means of measuring a transfer function, which may be considered a benefit of this technique. There are however some serious practical difficulties associated with this technique when it is applied to large power transformers. These measurements have traditionally been made using a network analyzer that applies a low amplitude AC voltage (10 volts for example), to the test object. At very low frequencies (in the range of some hundreds of Hz to low kHz), these instruments tend to lack sufficient power to appreciably excite a large power transformer, due to the heavy inductive load presented by the steel core. At very high frequencies (in the range of 2 MHz to 5 MHz), sufficient power may be lacking due to the heavy capacitive load presented by the high capacitance of the winding insulation system. The resulting low signal levels in the response voltage may result in high measurement error, and poor repeatability. This problem is especially troublesome on transformer windings with low series inductive impedance, as commonly encountered on high current windings.

An additional limitation associated with the use of the network analyzer is that the response current must flow over the length of the measurement cable (usually 50 feet or more when connecting to large power transformer bushings) back to the network analyzer, where it is converted to a voltage via the 50 ohm input impedance of the instrument. This technique by design inserts the current measuring cable impedance in series with the transformer winding under test, thereby making the result highly dependent on the particular length and characteristics of the cable. In addition, the relatively high 50 ohm impedance significantly damps the high frequency portion of the FRA response. The result is poor sensitivity in the upper frequency ranges, and poor repeatability whenever the test is repeated with different measuring cables. In some cases, the true frequency response of the transformer above 2 MHz may be completely attenuated by the limitations associated with the measurement technique.

Traditional Impulse Method

The second method of measuring a transfer function, the traditional low voltage impulse method, makes use of Fourier analysis to arrive at a transfer function through the results of a low voltage impulse test.



Typical Test Connection and Setup for a Low Voltage Impulse FRA Measurement

In this technique, an impulse is applied to one terminal of the winding under test, and the resulting current is measured immediately at the transformer by means of a voltage developing, low inductance impulse shunt connected in series with a second terminal of the winding under test. The value of the shunt may be selected to produce much less damping of the high frequency response than is possible with the 50 ohm input impedance of a network analyzer. The impulse amplitude is typically some tens of volts to several hundred volts, with a maximum rise time that corresponds to 1 divided by the highest frequency to be considered in the FRA. This means that for a frequency response up to 5 MHz, the exciting impulse must have a rise time of less than 200 ns. Test circuit ground is considered to be the tank of the transformer under test.

The traditional technique is to measure and record the exciting impulse and the resulting response current using a digitizer with sufficient amplitude resolution (generally accepted as at least 9 bit, or 1 part in 512 resolution), and sufficient sampling rate to preserve the highest frequency to be included in the transfer function result. Once the time domain record of the voltage (input) and current (output) are recorded, the transfer function is calculated as the Fast Fourier Transform (FFT) of the output divided by the FFT of the input.

One great strength of this technique is that the applied voltage and resulting response current are physically measured at the transformer. Unlike the swept frequency method, this method is minimally intrusive as far as the impact that the measuring cables have on the true impulse response of the transformer, as long as a proper, repeatable, low inductance connection is placed from the response current measuring terminal to ground.

Although this method has the potential to produce a much better representation of the transformer's true frequency response, there are again several practical problems with the application of this technique which make it difficult to achieve repeatable results. Chief among these is the sensitivity to noise influences that may have a drastic effect on the transfer function result. In order to reduce the influence of noise, the traditional approach has been to average the results of a series of applied impulses (for example ten impulses) in the time domain, and then perform the FFT on the time domain averaged results. It turns out however that the resulting frequency response produced by this method of time domain averaging is very sensitive to even minor time domain differences in the impulse wave shapes. Achieving repeatable results using this technique has therefore necessitated the use of expensive impulse source equipment, capable of producing a series of precisely repeatable impulses, both with regard to wave shape and time between applications. This traditional low voltage impulse method therefore, while having some distinct advantages over swept frequency, is not easy to apply in a way that repeatable results can be achieved, especially in noisy field environments.

A New FRA Measurement Technique

Modern computational methods and high speed, high resolution, low cost digitizers have made sensitive, high quality FRA measurement much more achievable than in the past. A patented new technique developed by the National Electrical Energy Testing Research and Applications Center (NEETRAC), a center of Georgia Institute of Technology, promises both the possibility of a highly repeatable FRA result, as well as an objective software evaluation package to assist in interpreting the data gathered.

The new technique is based on the low voltage impulse method, which overall can be shown to best preserve the frequency response of the transformer itself, with minimal dependence on lead characteristics when compared to the swept frequency method. Although the test voltage type (impulse) and the test connections are the same as those used in the traditional impulse method, the method of calculating the transfer function is completely different when compared to the traditional ratio of the FFT of the output to the FFT of the input. The quality and repeatability of the results show great improvements over past techniques. Key points of the new method are listed below:

- Individual impulses are applied, with each impulse and its resulting response current recorded as a time domain signal, for a series of ten impulses per winding connection.
- An auto spectral density estimate (SDE) is computed separately in software for each of the ten voltage and current pulse pairs recorded. In addition a cross SDE is computed for each voltage / current pulse pair. These SDE's may be thought of as a representation of the power present in the measured impulses, as a function of frequency.
- Once ten pulse pairs have been acquired and their respective auto and cross spectra computed, an average frequency domain SDE is computed over the ten pulses acquired.
- The transfer function is calculated as the ratio of the average cross spectra to the average auto spectra.

In this technique, averaging is still employed to reduce the influence to noise and random error, however applying the averaging after the transformation to the frequency domain effectively removes the sensitivity to slight variations in the time domain impulse records. This was the greatest limitation in the traditional low voltage impulse method.

The possibility to vary the impulse shape without introducing serious time domain averaging errors into the transfer function result means that impulses with different power levels at different frequencies may be applied. Using the new technique, the impulse shape is intentionally varied over the application of the ten impulses per winding connection. This eliminates the need for an expensive impulse source, while at the same time improving the repeatability. The overall transfer function result is improved by averaging the response of the test object to a number of applied impulses having varying amounts of power residing in the different frequencies. The result is that the repeatability of the final transfer function calculated using SDE's is enhanced if the ten applied impulses are different in the time domain.

Interpretation of FRA Test Results

In general, FRA relies on the principle that the impedance (or admittance) versus frequency characteristic exhibits resonances, or peaks, at locations in the frequency domain where certain inductive and capacitive reactances that make up the equivalent circuit for the transformer are numerically equal in ohms, or alternatively their admittances are numerically equal in Siemens (or "mhos" as engineers in North America might recognize).

Since the true transfer function of a large power transformer is not known, analysis of FRA test results always involves comparing two or more measured FRA responses. Traditionally, this has been the comparison of two FRA results obtained at different times on the same transformer, or perhaps FRA results obtained from sister units – transformers of the same design whose frequency response characteristics are expected to be similar.

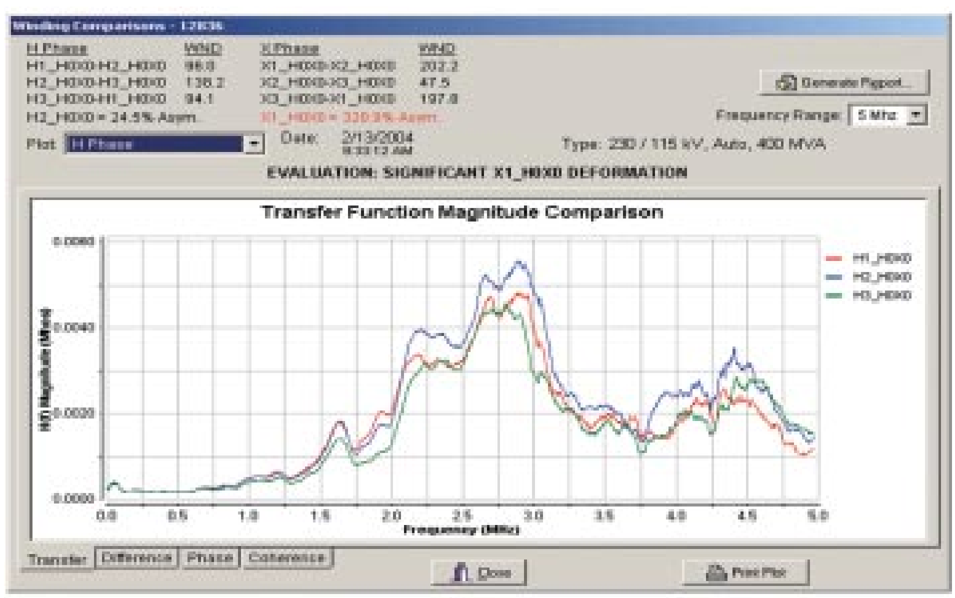
Following a brief summary of traditional interpretation techniques, a new method will be discussed that quantifies the FRA result. Of greatest significance is the possibility this new interpretation technique offers to make a conclusion as to the condition of a transformer, even without historical data or the availability of a sister unit for comparison.

Traditional Interpretation of FRA Results

Traditional methods of interpretation have been purely subjective, with a high degree of expertise required to judge whether a difference in FRA results is detrimental to the transformer. There is little to say on this subject since little progress has been made on the interpretation question until very recently. When comparing two transfer functions, the general approach has been to look at the location (frequency) of the resonant peaks in the transfer function magnitude plot. Shifts in frequency of a particular resonant peak, or the appearance or disappearance of peaks in the transfer function at a particular frequency represent cause for concern. In the past, it has really required the experience of an engineer in interpreting FRA test records to make a judgment as to whether a difference is significant enough to merit further testing and inspection of the transformer prior to energization in the network.

A New Approach to Interpretation of FRA Results

The lack of any objective comparison between two transfer functions has traditionally been one of the primary limitations associated with all diagnostic FRA techniques. A method of evaluating the difference between transfer functions has been developed at NEETRAC that provides a single condition number or Weighted Normalized Difference (WND) to quantify the difference between any two transfer functions being compared.



Example of FRA Analysis Using Modern Software to Perform Objective Analysis Techniques

The key points of the WND calculation are as follows:

- The arithmetic difference between transfer function magnitudes is computed at each frequency.
- Each data point is normalized.
- Each data point is weighted according to an error function at that frequency.
- WND = a constant times the average of the weighted values.

The error function is based on a coherence function calculation that estimates the linearity of the transfer function result at each frequency. This information is used to devalue the contribution to the total WND number in frequencies where a poor input to output coherence is recognized.

The WND numbers have been divided into three ranges as follows:

5 - 25	No Change to Minor Change
26 - 75	Some Change
76 - 300	Significant to Major Change

These ranges were determined based on extensive development testing, and have proven to be good reference values for use in both field and laboratory tests, to indicate the significance of the winding deformation existing within the transformer.

The Concept of Objective Winding Asymmetry (OWA)

Perhaps the most significant outcome of this technology is the ability to perform an objective comparison between transfer functions obtained from different phases of three phase transformers. This technique, also patented, has proven successful in detecting damages in three-phase transformers when no historical data is available. Geometric symmetries that exist in typical three-phase core form transformer designs can be used to draw conclusions when comparing transfer functions across phases. Comparison of WND numbers across phases has been shown to have the ability to identify individual windings that have shifted, even when no past FRA fingerprint is available for comparison.

The OWA technique has also been shown to have significant value when comparing to historical data. In many cases, differences in the condition of the oil, or even differences in temperature can lead to differences in the transfer function that may be difficult to distinguish from differences resulting from mechanical changes. In this instance, the phase to phase characteristics that are highlighted by the OWA analysis have proven to be considerably less sensitive to variables such as oil condition and temperature, owing to the fact that such changes affect the phase to phase comparisons equally, and therefore the overall effect of the variable change is somewhat cancelled out in the OWA analysis.

In OWA analysis, the WND numbers are calculated in the same manner as presented earlier in this article. The difference is that instead of comparing results taken on different dates or from sister units, each high voltage winding is compared to the other two high voltage windings on the same transformer, and similarly, each low voltage winding is compared to the other two low voltage windings. The OWA is given in percent and is defined by the average of the highest two WND numbers divided by the lowest WND number for the 3 separate winding phase comparisons. Then subtract one from the result and convert to percent.

Through extensive development testing, the following ranges of acceptability have been established for three phase core form type transformers.

Low Voltage (X) Windings

0 – 50%	No Change to Minor Change
50 – 100%	Some Change
>100%	Significant to Major Change

High Voltage (H) Windings

0 – 100%	No Change to Minor Change
100 – 200%	Some Change
>200%	Significant to Major Change

These ranges have been developed through analysis of field testing results on transformers ranging from a few MVA up to approximately 500 MVA.

The Future of FRA Testing

The power of frequency response analysis to look into large power transformers and detect mechanical damages is evident. The future of this technology looks positive, with significant new developments that hold the promise of greater sensitivity and repeatability than were previously thought possible. Constant advancements in high speed low cost digitizer technology will aid the improvement of this method of predictive maintenance.

In addition, new evaluation techniques that make use of powerful computational software packages will lead to increased opportunities to provide objective comparison of results. Over time, these objective comparison techniques will replace the old subjective methods of comparison that rely heavily on expert analysis. New technologies that offer these improved techniques will set the course for the future of FRA as a viable testing tool. ●

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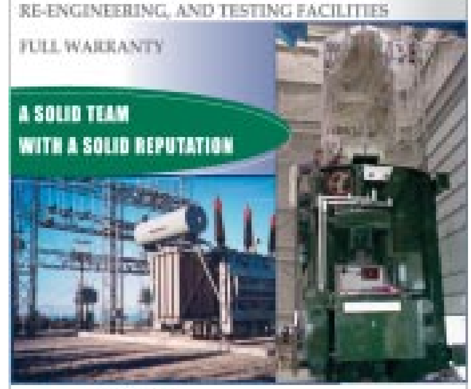

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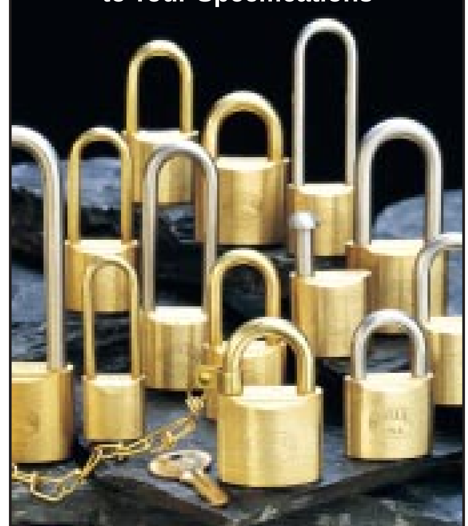

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