OHIO DEPARTMENT OF DEVELOPMENT

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Governor

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Director

May 6, 2003

Dr. Michael Karnitz
Oak Ridge National Laboratory
P.O. Box 2008
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Oak Ridge, TN 37831-6186

Dear Dr. Karnitz:

Subject: Oak Ridge National Laboratory State Partnership Program

The Ohio Department of Development (ODOD) Office of Energy Efficiency (OEE), enthusiastically supports Oak Ridge National Laboratory (ORNL), American Electric Power (AEP) and the Tennessee Valley Authority's (TVA) project – "Detecting and Locating Partial Discharges in Transformers" under the State Partnership Program.

OEE actively participates in a number of industrial technologies related activities and recognizes the potential for wide-ranging benefits to the power industry of accurately predicting impending failures in large transformers. As a result, OEE will participate with Oak Ridge National Laboratory, American Electric Power and the Tennessee Valley Authority in the State Partnership Program collaborative project to detect and locate partial discharges in transformers.

OEE agrees to assist the project team by serving as its state partner, enabling Oak Ridge National Laboratory to apply for special funding. We are willing to participate in partner meetings, and to monitor and to report research progress to interested organizations. Based on the successful completion of the project, we are willing to disseminate research reports to both industry and government interests to share the results of this project. The estimated value of OEE's support activities is $5,000 in-kind services, to add to the $95,000 in cash and in-kind committed by AEP, TVA, and Airak, Inc. to this project.

By this commitment, OEE is ready to assist Oak Ridge National Laboratory, American Electric Power and the Tennessee Valley Authority in the near-term commercialization and deployment of this technology.

Sincerely,

Sara Ward

Sara Ward, Chief
Office of Energy Efficiency
Ohio Department of Development

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Detecting and Locating Partial Discharges in Transformers

Participants: ORNL, State of Ohio Energy Office, American Electric Power, Tennessee Valley Authority, and Airak, Inc.

STATE PARTNERSHIP PROGRAM

May 5, 2003

Submitted by:

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Detecting and Locating Partial Discharges in Transformers

Project Participants: ORNL, American Electric Power (AEP), Tennessee Valley Authority (TVA), Airak Inc., and the State of Ohio Energy Office (OEO)

Accurately predicting impending failures in large transformers is of significant benefit to the power industry for three reasons. First, unplanned outages can be reduced, which improves the system's reliability. Secondly, since catastrophic failure of transformers can be very expensive, knowing when the transformer is starting to degrade and the location of the fault allows repairs that are less costly and time consuming. Planned repairs also reduce outage costs. Thirdly, equipment failures can result in exposure of personnel to the dangers of fire and deadly projectiles. Partial discharges (PD) are early indicators of faults within transformers and could provide an early warning system to operation personnel.

PD activity can be detected by the hydrocarbon gases produced in the insulating oil, measurement of the electrical activity during PD and acoustic measurements of the energy expended during a PD event. Hydrocarbon gas measurement is effective, but depends on having time to produce a volume of gas indicative of the developing problem. Electrical activity during transformer based PD is significantly lower in strength than the other forms of discharges on an electrical system. It can be difficult to separate and interpret in the working environment.

Current systems that detect PD typically monitor for the acoustic energy from the outside of the transformer. This remote acoustic measurement results in two problems: a low energy signal with background noise contamination and a significant difficulty in determining the location of the PD because of multiple sound paths. We are proposing to develop and demonstrate a laboratory-scale, on-line transformer fault early warning system by applying an in-situ novel fiber optic-acoustic measurement technique to detect the sound energy from PDs within large power transformers. A standard optical fiber is used as a line microphone within the transformer to detect acoustic waves. Acoustic waves, generated by PDs, exert pressure forces on the optical fiber resulting in a change in the fiber's index of refraction. By placing the fiber in an interferometer leg, the acoustic signals appear as amplitude modulations at the interferometer's light detector. Initial tests with this methodology in a simple experiment showed that the technique was quite sensitive. In addition to the detection of a PD event, a method has been devised to pinpoint the location along the fiber where the acoustic energy arrives and thus, the location of the PD and transformer fault. These optical fibers contain no conductive materials and therefore can be located inside the transformer to enhance the ability to detect very small discharges, their location, and provide diagnostics and prediction of transformer failures.

This proposal is requesting $50k in funds from the SPP. The project participants and their funding levels are shown in the table below.

Institution	ORNL/SPP	AEP	TVA	State of Ohio	Airak Inc.	Total
PI or Contact	Roger Kisner	Dale Krummen	Mike Ingram	Bill Manz	Paul Duncan	
Funds In	$50k	$25k	$25k	$0k	$0k	$100k
In-Kind Funds	$0k	$25k	$10k	$5k	$10k	$50k
Total	$50k	$50k	$35k	$5k	$10k	$150k

In summary, the request is for $50k of SPP funds and the partners will match with a total of $100k (funds in and in-kind funding).

ORNL will be providing the laser interferometer, optical fiber, and signal processing expertise as well as developing the technology to provide partial discharge location along the fiber. AEP and TVA will be supplying expertise in transformer technology, functional requirements for the detection system, expected acoustic energy from partial discharges, design reviews, and insights into signal interpretation and analysis. AEP will also provide a transformer model/tank for testing including shipping the model to ORNL and support personnel traveling to ORNL for assistance in operating the model and testing. AEP will provide conventional acoustic PD detection instrumentation & expertise for comparison. Airak Inc., a manufacturer of fiber optic sensors for the power industry, will provide single point fiber optic-acoustic demonstration system. This system can be used to compare with conventional methods as well as our new omni-directional approach. The OEO will actively participate in partner meetings, and monitor and report research progress to all interested organizations. Based on the successful completion of the project, OEO is will disseminate research reports to both industry and government interests to share the results of this project.

This project will develop, design, assemble, and test a fiber optic-acoustic system to detect PDs in transformers. Development and design tradeoffs will include sensitivity versus extraneous noise pickup and filtering via signal processing techniques, location resolution compared to distance from the event and acoustic wave broadening, and the application of low-cost laser, optics, and fiber to achieve reliable results in a cost effective solution. The prototype system will be demonstrated in air and oil and the system sensitivity and resolution (acoustic energy level and location) determined. The next step is to test in a transformer model/tank. Discharges will be simulated at various energy levels and locations in the tank. The ability to detect and locate the PDs will be characterized and documented. It would be good to investigate the effect of external acoustic sources, such as simulating rain impinging on the tank, which renders current technology unusable. Eventually, the impact of flowing oil, oil temperature, pump/fan noise, core vibrations (particularly Barkhausen noise), rattling nameplates, etc., will need to be investigated.

In this approach, the acoustic energy produced by PD event is sensed as a phase shift between two light-beams applied to two single-mode optical fibers installed inside a transformer. The two beams are generated in the fibers by splitting the same light from a

coherent light source. An interferometer receives the reflected light beams from both fibers and determines the phase shift by analyzing the resulting pattern of light and dark bands (fringes). When one fiber is disturbed relative to the other, a phase shift occurs which can be detected precisely by the interferometer. If the light beams in both fibers are exactly in phase upon recombining, they constructively interfere with an increased light intensity. If they are out of phase; however, a destructive interference occurs and the received light intensity is reduced. As this process is repeated, a fringe pattern is produced that is directly modulated by the acoustical disturbance caused by a PD.

The tasks to be undertaken in this proof-of-principle/laboratory demo project are:

1. Work with AEP and TVA personnel to develop the functional requirements for the transformer fault detection system. **Deliverable is a functional requirement document one week after project start.**
2. Develop and design the fiber-acoustic sensing system (hardware and software). **Deliverable is a measurement system design one month after project start.**
3. Procure and assemble the system including hardware and developed signal processing. **Deliverable is an assembled and functioning system four months after project start.**
4. Demonstrate the ability to "hear" PDs in air and oil. The main objective of this task is demonstrating the ability to detect PDs in real-time, in the laboratory using the optical techniques describe above. The minimum levels of detectable PD will be established and documented for the detection technologies. Key issues in this task are: 1) understanding the physics of the optical measurement and 2) exploring ways to make one fiber more sensitive to the disturbance than the other when both fibers are placed inside the transformer (using different fiber materials and cladding, different coating materials, variation in fiber size.) **Deliverable is the demonstration of detecting PDs with the system five months after project start.**
5. Demonstrate the ability to localize the PD along the fiber length. This task is to develop the technique for estimating the location of the PD. A method will be applied to the interferometer system that allows determination of where along the fiber length the ultrasonic signal was received. It is equivalent to separating a continuous length of fiber into individual omni-directional microphones. The challenges in this technique will include developing unwanted noise suppression and subtraction to allow the desired signal to be extracted from the background noise. **Deliverable is to demonstrate the ability to determine the location of the acoustic energy striking the optical fiber six months after project start.**
6. Conduct laboratory experiments to evaluate system sensitivity (magnitude of PDs measured, distance from PD source, and resolution of locating the source), operation with system noise, and operational stability). Testing would include comparisons with our new technique to conventional methods and Airak's new measurement prototype. **Deliverable is system characterization as to PD sensitivity and accuracy of PD source location 7-8 months after project start.**

7. Document results and work with OEO to disseminate project findings to appropriate parties. **Deliverable is a report for dissemination 9 months after project start.**

In addition to the application of the partial discharge detection, this fiber optic-acoustic measurement system has the potential to detect and locate leaks in pressurized piping over relatively long distances, ~15km per system. The measurement system may also be able to be configured to measure temperature in transformers or piping systems as well. These two additional potential applications can also save significant energy through rapid detection of steam or natural gas leaks and temperature changes indicating insulation loss or degradation. It would be desirable to demonstrate the technology to a point where the potential of these applications, as well as others, could be clearly supported.

We believe this proposed partial discharge detection and location system has exciting potential for significant impact in the power industry. This enthusiasm is demonstrated by the assembled team that includes the largest public and private electric producers, an active state energy office, and an instrument supplier that are contributing time and funds to this effort.

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