North American Policies and Technologies

# Electricity Today

## Transmission & Distribution

The Electricity Forum

January/February 2009
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# Drying wet transformers in the field

Examining the low frequency heating process page 8



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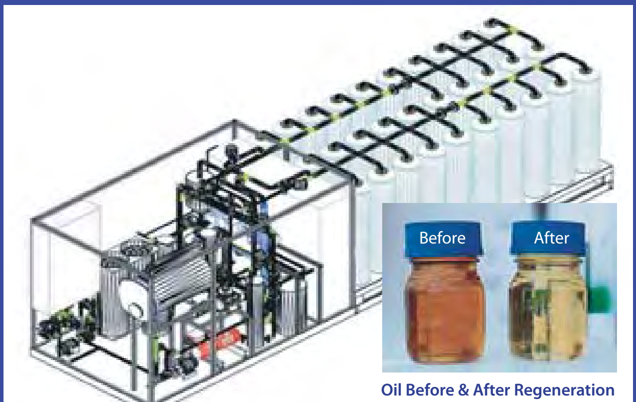


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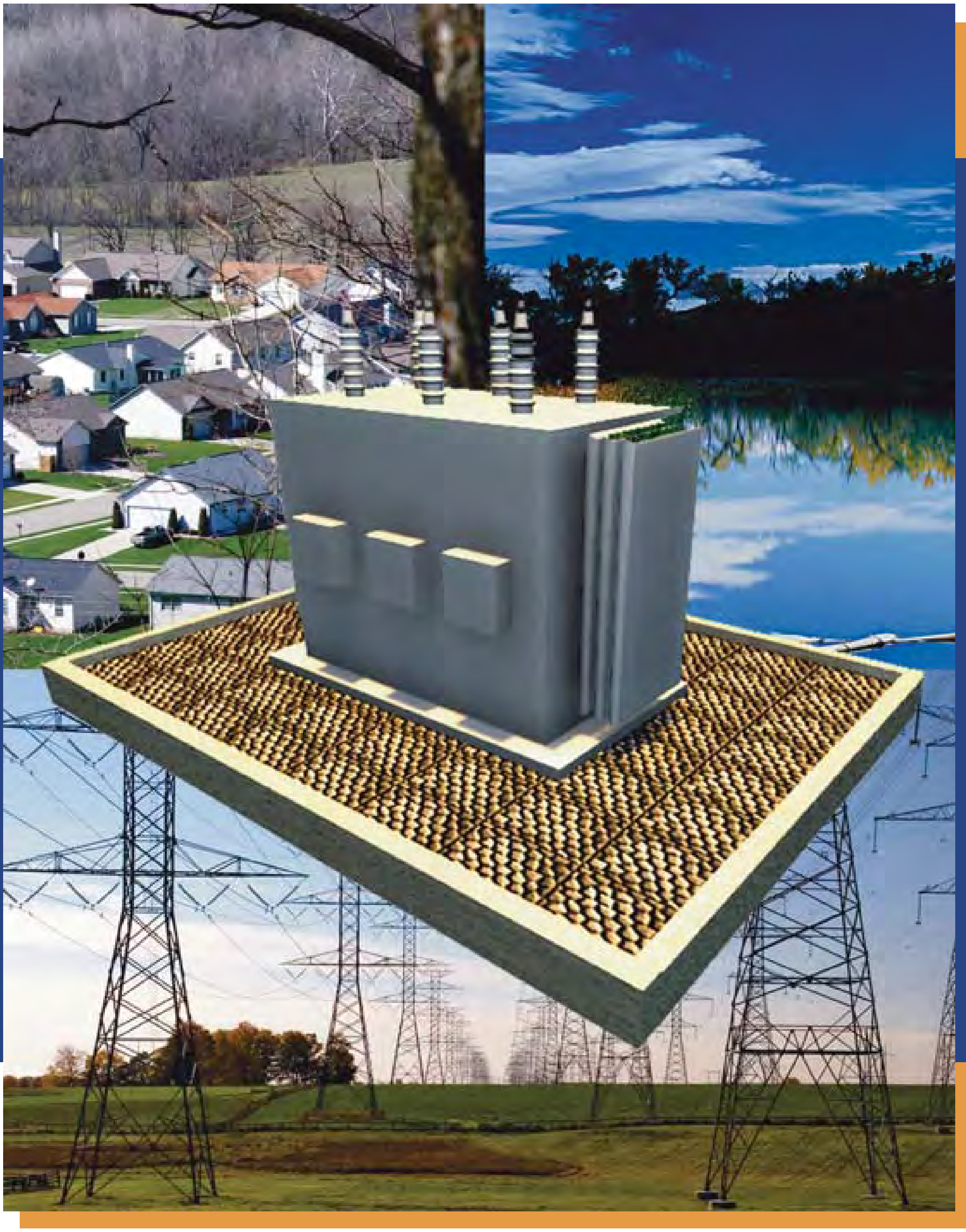

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# A MULTIBILLION-DOLLAR PUSH IN THE RIGHT DIRECTION

By Don Horne

It might have been overlooked among the hundreds of billions being handed out by Washington, but it is certainly going to help make the nation's grids a lot smarter.

The $700 billion Emergency Economic Stabilization Act, which was signed into law on October 3, 2008 after much pleading, rejection and eventual acceptance, included provisions for accelerated depreciation for smart meters and other smart grid equipment. Certainly these funds will stimulate greater utility investment in this much-needed technology.

Basically, the new tax provisions reduce the depreciation rate for smart grid technologies from 20 years to 10, bringing smart grid tax treatment in line with other similar high-technology systems.

The larger deductions will encourage increased spending on smart meters and related technology.

At the moment, a smart meter is roughly three times the price of an ordinary meter – and unfortunately, smart technologies are constantly evolving and making equipment once leading edge five years ago quickly obsolete. What occurs, instead of widespread deployment, is a plague of pilot projects – little better than window dressing to show customers that they are "going green" without spending a lot of green.

In Ontario, Canada, smart metering will be deployed provincewide by 2010. With strong government support, and a determination through public advertising campaigns and concerted pilot projects that were a springboard to wider deployment, this goal appears to be within reach.

Many utilities throughout the United States have crossed north of the border to examine Ontario's smart meter deployment, and it looks like the time is ripe for a nationwide explosion of smart metering, coupled with a smartening up of the various grids.

And a general smartening up is needed now.

Within the next few years, there will be a growing number of hybrid and all-electric vehicles in driveways across North America, all looking for a place to plug in. Also, the explosion of personal wind turbines, solar, geothermal and other renewable generation will be looking for smarter grids to handle any generation that might be flowing back into the grid.

This could be the time that North America may be looking to electricity as the liberator from foreign oil – becoming the primary source of power for everything.

The former director of the CIA Jim Woolsey spoke recently at the GEOINT Symposium in Nashville, Tennessee, urging Americans to embrace renewable power (yes, that means nuclear too), drastically improve the national grids and throw off the shackles of oil.

He pointed to an historical dependence on salt as a trading commodity (think back to your Latin studies, and you will remember that "salary" is derived from the Roman word for salt, salarium), and how that was ended once the technologies of refrigeration and freezing were developed.

So too could the development of battery storage and electric vehicles make oil unimportant in our lives.

This "smartening" of the grids has been going on for several years now, mostly to accommodate the wind and solar expansion that requires real-time monitoring to ensure that a steady flow of power is available whether the wind is blowing or not, or if the sun decides not to come out that day.

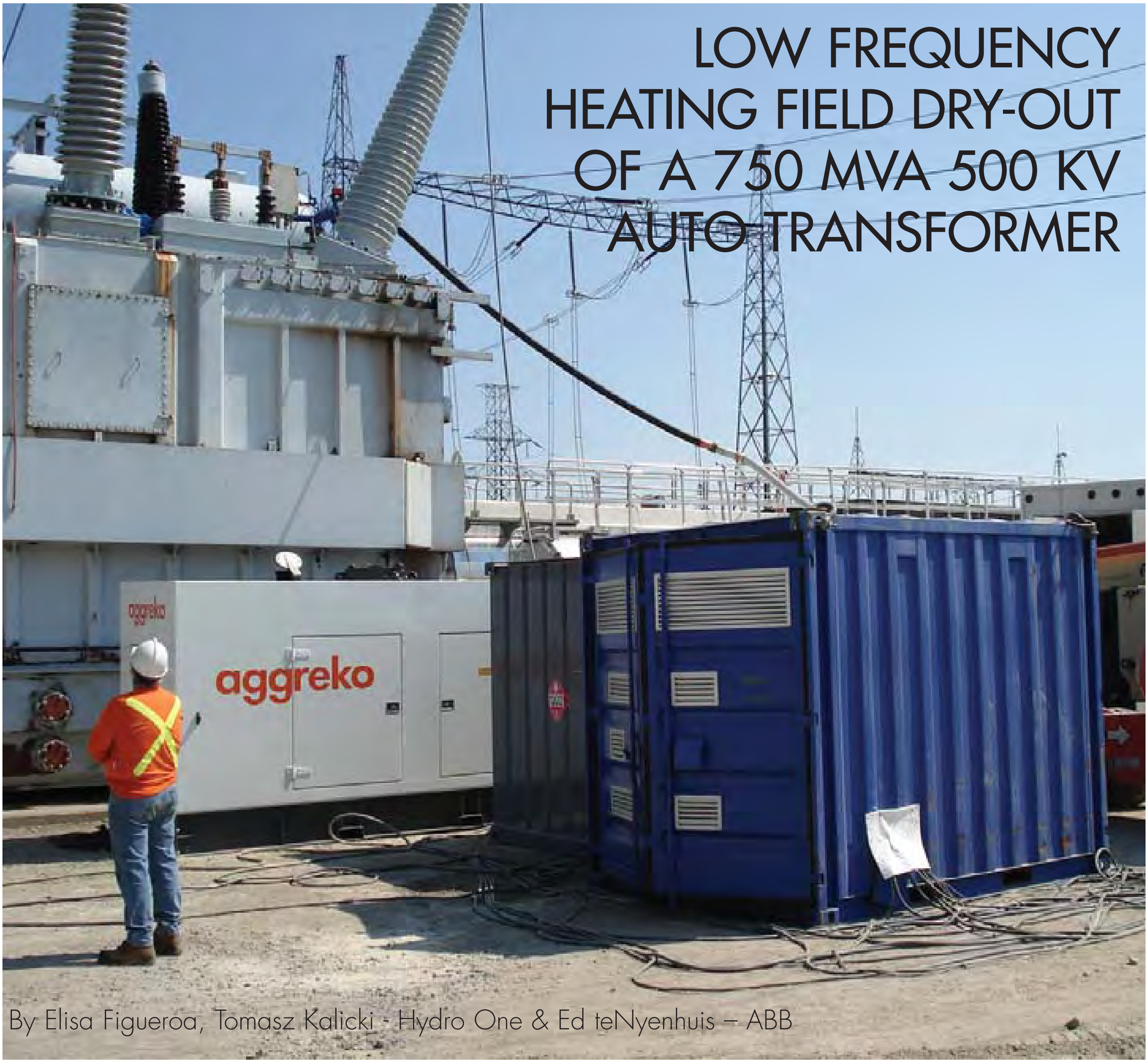
Also, the once proudly independent grid systems (like ERCOT), are only now reaching out to neighbours through better intertie connections – allowing for this blossoming of renewable development to bear full fruit.

There will be hiccups, trips (pun intended) and roadblocks along the way, but it is encouraging that even during these tough economic times, firm support from Capitol Hill will be there to rehabilitate the nation's aging infrastructure – and maybe even allow us to kick our century-old addiction to oil.

*don@electricityforum.com*

Keeping the skyline lit in New York will depend on new infrastructure money creating new transmission links to clean power sources north of the border.

# LOW FREQUENCY HEATING FIELD DRY-OUT OF A 750 MVA 500 KV AUTO TRANSFORMER




By Elisa Figueroa, Tomasz Kalicki - Hydro One & Ed teNyenhuis – ABB

Recently, two 30-year-old EHV 750 MVA 500 kV GE autotransformers were dried in the field using the Low Frequency Heating (LFH) process. It is generally difficult in the field to achieve acceptable dryness for wet EHV transformers using the traditional hot oil cycling method.

The LFH process applies near DC current to the windings allowing uniform winding temperatures progressively and safely up to 110°C.

The LFH drying process was completed for both units in two weeks with significant water removal and the moisture in cellulose brought down to below one percent.

These are the largest field applications of the LFH drying process.

Based on the limited number of measurements, it has already been concluded by Hydro One that the Low Frequency Heating (LFH) method is superior to the methods used previously. The results of less than 1.0 percent remaining moisture allow Hydro One to restore the transformers' overload capabilities without fear of bubble formation.

## INTRODUCTION

The primary purpose of performing site dry-outs of power transformers is to reduce the moisture content in the cellulose. Moisture comes from the aging process of the cellulose (it is a byproduct) or externally from the transformer (gasket, breather, leak, etc). Moisture deteriorates the electrical and mechanical properties of the transformer and can limit the allowed overload due to risk of water bubble formation.

Hydro One recently investigated a failure of an important system autotransformer which led it to invest in a program of site drying its fleet of 500/230 kV autotransformers. This group of autotransformers is the backbone of the transmission network in Ontario. One of these units, a 750 MVA 500/230/28 kV three-phase autotransformer, underwent a failure only hours after a sister unit at that station had been removed from service due to a high moisture alarm from an on-line monitor. The resulting investigation showed that moisture was a main contributing factor to the failure. It was estimated that the moisture level in the failed unit was approximately 1.5 percent. Further analysis indicated that similar moisture content existed on other units within that fleet of installed transformers. As a result, many of the units in service were de-rated and an extensive dry out program was initiated to reduce the risk of further failures.


Site dry-outs for this drying program were performed using a Hot Oil Circulation plus Vacuum (HOV) method, which is standard practice for smaller units. Due to the size of the units and the deep penetration of the moisture in the cellulose, numerous hot oil/vacuum cycles were required. This resulted in lengthy transformer outages. To improve moisture removal effectiveness, a diffusion pump was used to achieve a very deep vacuum - 50 microns. With all this, the final moisture results indicated that the effectiveness of HOV was marginal. While the surface moisture dropped, the average moisture levels hardly budged. The target level of less than one percent moisture content was not achieved. Furthermore, the outages lasted over two months due to the large size of the units and the consequently large volumes of oil. This effort also tied up significant resources (staff and equipment) and subsequently other transformer projects were also impacted. The deep vacuums required to extract moisture also caused new leaks to spring up due to aged component stress. At times the process had to be stopped before reaching target vacuum levels because of concerns regarding the structural integrity of the tank. A new method had to be found for the large transformers which led to the application of the Low Frequency Heating (LFH) technology on two 750 MVA, 500 kV autotransformer with much better results.

## LOW FREQUENCY HEATING OVERVIEW

With the LFH method, current is applied to the windings in order to heat the transformer more effectively at a higher temperature. The current is applied at 1 - 50 mHz that has two critical advantages.

First, the impedance voltage is much reduced with low frequency meaning the required applied voltage is low. The LFH is applied when the oil is removed from the unit but the applied voltage is thus low enough to eliminate any risk of flashover.

Second, the leakage flux is negligible so the temperature across the winding is uniform. Under normal AC operation, leakage flux causes uneven winding heating. Thus, the low frequency current allows higher temperatures to be safely achieved across the entire winding during the dry out.

The current is applied to the HV winding and is typically 20 - 50 percent of the rated current. The applied current is limited by the temperature of the winding and the induced windings. The frequency can be varied slightly to control the amount of transformation to the LV winding, which is short-circuited during the dry-out. Winding temperatures of up to 110°C are permitted during the LFH dry-out process and are monitored by constant winding resistance measurement. This peak winding temperature of 110°C has a negligible effect on the paper aging of the transformer.

The LFH unit has power converters to change the current from 50/60Hz AC to the desired low-frequency current. The control system monitors the winding temperatures, applied voltage & current, frequency, thermocouples (placed inside the transformer) and vacuum. The safety protocols ensure maximum individual winding temperatures are not exceeded and low vacuum is not used when LFH voltage is applied.

During the heating of the windings, a hot oil spray is applied over the core/coils to additionally heat the external insulation. Temporary spray nozzles are installed beneath the cover. The hot oil spray allows external insulation temperatures above 90°C.

A typical LFH process would be as follows:

- Initial heating/circulation of core/coils using hot oil and with LFH current applied to the windings
- Drain the oil and pull vacuum to remove moisture
- Break vacuum; apply LFH current and hot oil spray follow this with vacuum. Repeat this process and progressively raise the temperature to 110°C
- Pull final vacuum
- Break vacuum to remove temporary spray nozzles
- Vacuum fill the transformer with dry degassed oil

Due to the much higher achieved temperatures compared to traditional hot oil treatments (110°C versus 80°C) the moisture removal with LFH is more effective and is done in a reduced amount of time.

## HYDRO ONE SITE DRYOUTS WITH LFH PROCESS

Hydro One performed site dry-outs in 2007 using the LFH technology on two 750 MVA 500 kV autotransformers. The first dry-out was performed for a unit being repaired in a Hydro One facility. The second unit was dried in the field during an outage. Both units were 750 MVA 500/230/28 kV three-phase autotransformers and were 33 years in age. The moisture content in each unit was estimated to be 1.5 percent prior to the dry-out.

Since both units were autotransformers, the LFH unit injected current into the series/parallel windings and current was induced in the tertiary winding. The LFH unit monitored the winding temperatures (constant resistance measurement) since the windings did not each heat at the same rate. When required, the frequency was reduced so that current was not induced in the tertiary winding (since the tertiary winding heated faster). Thermocouples were placed on the core, windings, lead structure and in the drying tank to closely monitor the process. Oil spray nozzles were temporarily installed under the cover via a modified manhole cover.

A total of 11 LFH/vacuum cycles were performed for each dry out. Hot oil was initially circulated to remove the surface moisture. This hot oil was heated together with external equipment and the LFH, which raised the oil and windings to a temperature of about 80°C. This was followed by vacuum. At this point the 11 cycles of LFH current/hot oil spray followed by vacuum were done. The winding temperature was increased from 85°C to 110°C over the 11 cycles. The oil spray was raised to a temperature of 95°C during the LFH cycles.

Thermocouples confirmed that insulation external to the windings reached 95°C and that the temperature was uniform from the top to bottom. The injected current for these transformers was limited by the tertiary winding rating. Thus, the tertiary winding current was limited to 70% of rated current. The frequency of the injected current was 0.05Hz for when all windings were being heated and 0.0015Hz when only the series/common windings were being heated. The first dry-out took a total of 12 days while the second dry out was done in 11 days.

The water removed was calculated to be 150 liters for the first dry-out, and 160 liters for the second dry-out. Insulation samples were also taken from both units after the dry-out, which showed average moisture in cellulose result of 0.7% for the first unit and 0.3% for the second unit. The 150 liters and 160 liters of water removed during the two dry-outs translates to approximately one percent reduction in moisture content in cellulose. With an estimated pre-dry-out moisture in cellulose of 1.5 percent, the one percent reduction implies a final average moisture in cellulose of 0.5 percent, which is consistent with the sample block results.

## DISCUSSION OF LFH SITE DRY-OUT PERFORMANCE

The two dry-outs performed showed that the LFH method of site drying has a number of advantages compared to the traditional HOV method. The primary advantage is the superior drying effectiveness. As shown above, the final average moisture in cellulose result was less than 0.7 percent. Previous HOV dry-outs have not achieved results even less than one percent and the removed water has been less than 100 liters.

The duration of the LFH dry-out was about two weeks compared to up to eight weeks for the HOV dry-outs. This is a huge benefit considering the importance of these autotransformers for system operation and the severe difficulties in obtaining extended outages. Furthermore, the LFH dry-outs tied up fewer resources, as well as being required for a shorter time. The LFH dry-out requires less oil handling equipment and reduced personnel. Only two operators are required for the oil degasser/vacuum pumps and one LFH operator when LFH current is applied. HOV dry-outs typically require more personnel due to the extra equipment and the numerous hoses, valves and pumps to be operated and monitored during extended hot oil circulations.

Lastly, since the LFH vacuum requirements are not as low as those required by the HOV method, the stress applied to the transformer tank is reduced. Even if a transformer tank can sustain a deep vacuum (which is questionable for many older units), significant effort must be exerted to locate and eliminate all leaks.

A summary of the advantages of LFH compared to HOV is shown in Table 1.

TABLE 1
Comparison of HOV Drying Method versus LFH

| Method | Drying Effectiveness | Duration | Tank Stress | Resources |
|---|---|---|---|---|
| HOV | at best 1.1% | 4 to 8 weeks | Moderate to Severe | 100% |
| LFH | comfortably <1% | < 2 weeks | None to Minor | 75% |

## CONCLUSION

Although the number of confirmed measurements is limited, it has already been concluded by Hydro One that the Low Frequency Heating (LFH) method is superior to the previously used methods. The results of less than one percent remaining moisture allow Hydro One to restore the transformers' overload capabilities without fear of bubble formation.

It is believed that future dry-outs will give Hydro One more evidence to support the previous statement. More data, combined with the on-line monitoring of the moisture activity inside the transformer returned to service after the dry-out will further prove the effectiveness of this method.


## ACKNOWLEDGEMENTS

The authors wish to acknowledge Greg Isaacs, Steve Smith and Joe Manella, all from Hydro One, for providing field data during the site dry-outs procedures.



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# UTILITY WATER STRAINING: CHOOSING THE CORRECT STRAINER TECHNOLOGY

By Ed Sullivan

Whether used for cooling, or the process itself, the raw water drawn from lakes, rivers and reservoirs must first be strained to create acceptable water for use. In many industries, this means continuously straining tens of thousands of gallons of water per minute to remove dirt and debris that can wreak havoc on critical process systems and equipment.

In essence, the raw water strainers that accomplish this task are the first lines of defense for the entire plant's system. Choosing an inadequate strainer can lead to high maintenance and operating costs, periods of insufficient water supply, damage to process equipment, and expensive downtime. Worse, the straining media of an overwhelmed water strainer can rupture or collapse, permitting debris to compromise critical plant operating components. In the power industry, for example, clean water is crucial for a variety of tasks including, among others, extending the service life of turbine seals and for the protection of spray nozzles and heat transfer equipment.

Unfortunately, such failures are not unusual, particularly when the strainer design does not allow for sufficient straining surface area. In applications using raw water from rivers, for example, single basket strainers sometimes become overwhelmed and clogged during periods when there were high volumes of debris in water due to seasonal conditions such as rainfall carrying dirt, leaves and other loose particles into the water supply.

"You never really know what you're going to experience with river water," says Sang Partington, a Senior Engineer with Pennsylvania Power & Light (PPL's) Generation Technical Group. "It changes from season to season. During autumn and high water flow in the river, you may have a lot of debris such as tree branches, leaves and other solids in the water. Therefore, your water strainer has to be able to handle the solids and still maintain a continuous volume of water flow."

## WHICH STRAINER TECHNOLOGY?

Water strainers for mass raw water filtration have been around for decades, and today manufacturers offer a variety of designs, including those that operate automatically. One of the more significant advances in strainer design occurred in the 1960s when the first multi-element, automatic self-cleaning strainer design was developed.

This strainer design was particularly significant because it provided a durable and reliable alternative to the classic basket-type strainer that — although sometimes carries a lower price tag — is also limited by its strainer surface area, which can quickly become clogged and force excessive cleaning cycles (backwashing) and reduced water for process requirements.

By replacing the basket with multiple tubular elements, the design provides 3-4 times the straining surface area of a typical basket strainer. As a result, debris and solids — including from seasonal peaks — are efficiently removed without downtime.

Bulk raw water users, such as PPL Electric Utilities, protect process and downstream equipment by selecting multi-element water strainer technology.

The increased surface area of the multi-element design allows for fewer backwashes, equating to lower operational costs, less maintenance and greater overall efficiency.

## OPTIMIZING WATER FLOW AT PPL

About five years ago, Partington noticed that the old, basket-type water strainers at its Brunner Island plant required high maintenance and continuously shifted to backwash mode. "The old system was constantly backwashing," says Partington.

At PPL's electric power generation utilities, the priority is maintaining sufficient volume and pressure, although there is certainly concern about the debris and other solids that can be in the rivers that feed water to the coal-fired plants.

PPL began to upgrade the raw water strainers at its Brunner

Island and Montour plants, both feeding off the Susquehanna River in central Pennsylvania. Both are large generating facilities with approximately 1,500-megawatt capacity, and it is critical to ensure sufficient clean water to keep the plants on line continuously.

According to Partington, the outflow of clean, filtered water through the strainers was also at lower-than-optimal volume when backwashing was taking place, so he began to look for a more advanced and efficient strainer technology. After reviewing several more advanced designs, Partington selected the multi-element strainer from R. P. Adams.

Although initially designed for raw water applications, the R. P. Adams multi-element strainer can actually remove solids as small as 25 microns. So the multi-element strainer can be utilized as the "first line of defense" in water filtration, or can be installed at a point of use for critical plant operations requiring fine levels

Whether used for cooling, or the process itself, the raw water drawn from lakes, rivers and reservoirs must first be strained to create acceptable water for use. In many industries, this means continuously straining tens of thousands of gallons of water per minute to remove dirt and debris that can wreak havoc on critical process systems and equipment.

of separation.

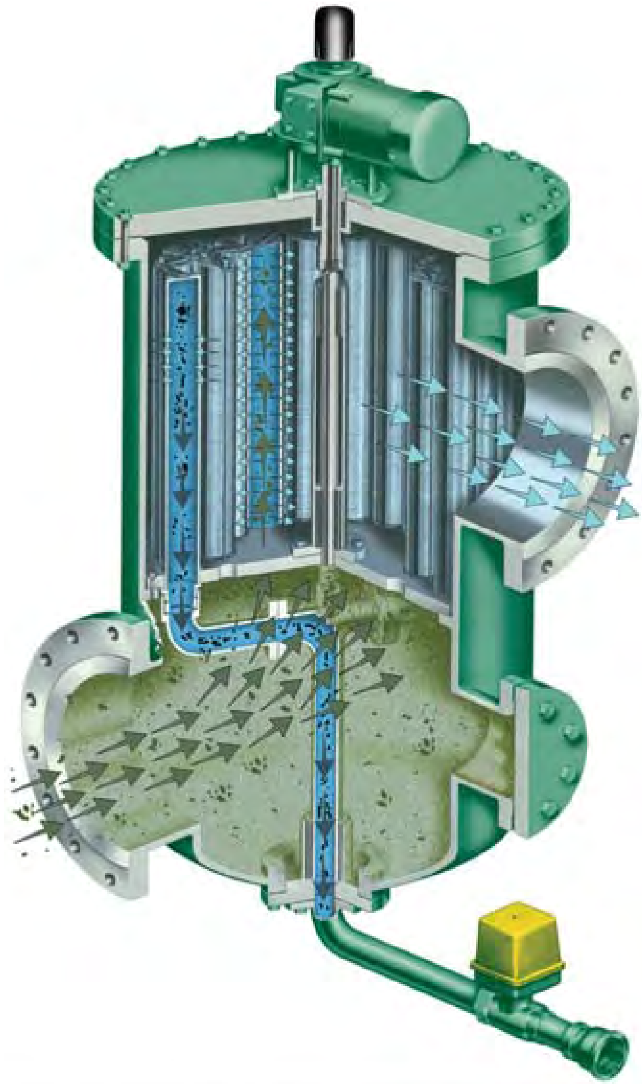
Another significant feature of the multi-element design is in the engineering of the backwash mechanism. With basket strainers, the backwash mechanism comes into direct contact with the straining media. This can be problematic, as large, suspended solids often encountered with raw water can become lodged between the straining media and the backwash arm. The result is straining media damage and/or rupture that can compromise plant operations.

The multi-element design utilizes a tube sheet to separate the straining media from the backwash mechanism. This prevents the backwash mechanism from coming into contact with the media and damaging the elements caused by large solids becoming lodged between the media and the backwash arm.

Furthermore, the multi-element design provides three to four times the surface area of a basket strainer. This translates directly into less frequent backwashing so less water goes to waste, less power is consumed, and there is less maintenance required. Partington's decision was also due to the fact that these strainers could provide the necessary plant water requirements even while in backwash mode.

"The new units will not backwash unless the differential pressure of the strainer is high enough to activate backwashing automatically or by the timer, thereby saving us money on the power consumption," explains Partington. "We should also save significant money on maintenance too, but we don't know how much yet because the units are so new."

Partington also appreciated the fact that R.P. Adams was willing to customize the strainers to meet PPL's design specifications, and also offered an exchange program whereby he could replace the strainer elements to a different micron size if he needed to do so.



A multi-element design provides three to four times the surface area of a basket strainer. This translates directly into less frequent backwashing so less water goes to waste, less power is consumed, and there is less maintenance required.

"The element exchange program allowed us to go for greater straining efficiency, which helped us optimize the raw water system," Partington says, "We elected to exchange the original elements for a smaller micron size. It has worked very well, so we're going to stay with that size for that particular installation. But as we continue to upgrade our water strainers at various locations, we can do the same thing - in effect, fine-tune the solid removal and water flow as the situation warrants."

To date, PPL has made upgrads to eight R. P. Adams strainers at the Brunner Island plant and has installed the first unit at its Montour site. PPL intends to standardize on the R. P. Adams design, and will phase-in new strainers as opportunities arise.

*Ed Sullivan is a Hermosa Beach, California-based writer. He has researched and written about industrial process equipment and power systems for over 25 years.*

# NONDESTRUCTIVE TESTING OF OVERHEAD TRANSMISSION LINES

By Stephanie L. Branham, Mike S. Wilson, Stefan Hurlebaus Zachry, Department of Civil Engineering, Texas A&M University; Brad M. Beadle, Lothar Gaul, Institute of Applied and Experimental Mechanics, University of Stuttgart

## 1. INTRODUCTION

Multi-wire cables find wide use in a number of engineering applications. For example, they are used for pre-stressing and post-tensioning in concrete structures; they serve as the load-carrying structures on cable-stayed and suspension bridges; they are found on elevators; and, they form the transmission lines which deliver power to our homes and businesses.

Monitoring the integrity of these cables becomes increasingly important as the cable ages.

This study focuses in particular on the structural health monitoring of overhead transmission lines.

Common failures associated with overhead power line installations include broken insulators, broken lightening rods, loose earth conductors, loose spacers (spacers are used to separate individual lines), and uncoiled or broken cable wires caused by wind-induced vibrations (Siegert and Brevet, 2005). Power line installations are periodically inspected using both on-ground and helicopter-aided visual inspections. Factors including sun glare, cloud cover, close proximity to power lines, and rapidly changing visual circumstances make airborne inspection of power lines a particularly hazardous task. Such factors have led to a number of fatal helicopter crashes in recent years. A summary of the helicopter accidents due to aerial observation is depicted in Table. 1 (U.S. Helicopter Summary Statistics, 1996-2004).

| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|
| Total Accidents | 176 | 163 | 191 | 197 | 206 | 182 | 205 | 214 | 180 |
| Fatal Accidents | 32 | 27 | 34 | 31 | 35 | 29 | 26 | 37 | 33 |
| Fatal Injuries | 54 | 43 | 66 | 57 | 63 | 51 | 41 | 67 | 68 |
| FAR 91 Aerial Observation | 10 | 6 | 6 | 13 | 7 | 5 | 8 | 8 | 9 |

Table 1: Summary of helicopter accidents due to aerial observation.

The risk associated with aerial inspection of power line installations could be substantially reduced through partial automation of the inspection process. The power lines themselves could be automatically monitored. Aerial and ground inspections could then focus on identifying problems associated only with the mast structures. Introduction of such an inspection approach not only reduces risks to human pilots, but it also speeds up the inspection process. The methodology developed in this study can also be applied to other cable monitoring applications, which would otherwise put human inspectors at risk.

The basic idea for defect detection in a transmission line is illustrated in Fig. 1. As shown, a transducer is used to both generate and detect ultrasonic bursts in the power line. Initially, longitudinal waves will be used for diagnostic purposes. When the ultrasonic burst interacts with a defect, such as a broken wire, a portion of the incident wave will be reflected. The reflected wave is then sensed by the receiving transducer. If the amplitude of the reflected wave is above a certain threshold value, then positive identification of a defect can be assumed. A wireless transmitter located at the transducer could be used to relay data to a central communication node or to a defect indicator located on the mast.

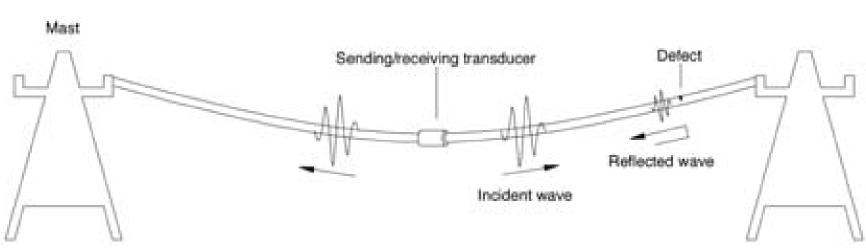



Fig. 1: Interrogation of a transmission line using ultrasonic pulses

## 2. SURVEY OF RELEVENT WORK

Meitzler (1961) studied the propagation of elastic pulses in wires having a circular cross section. He attributed pulse distortion to the propagation of several modes. His experimental and theoretical results suggest that coupling between the various modes of propagation were responsible for the observed pulse distortion. Rizzo and Lanza di Scalea (2002) generated and detected ultrasonic waves in single wires and seven-wire cables using magnetostrictive sensors. A formulation based on the Pochhammer-Chree theory is used to predict the change in the velocity of longitudinal waves as a function of applied stress (acoustoelastic effect). Results from acoustoelastic experiments are presented and compared to the theoretical predictions. Ways to enhance the sensitivity of the acoustoelastic measurements were investigated. The different behavior exhibited by the seven-wire cables when compared to single wires suggests the need for widening the theory to include acoustoelastic phenomenon in multi-wire cables. Additionally, the suitability of the guided wave method for the detection of defects in the critical anchorage zones is considered. Washer et al. (2002) also utilized the acoustoelastic effect for measuring the stress levels in post-tensioning rods and seven-wire cables. In a later study, Rizzo and Lanza di Scalea (2004) examined the wave propagation problem in seven-wire cables at the level of the individual wires. They used a broadband ultrasonic setup and a time-frequency analysis based on the wavelet transform for characterizing the dispersion and attenuation of longitudinal and flexural waves. They identified the vibration modes that propagate with minimal losses.

Such modes are particularly useful for long-range inspection of the wires. Furthermore they found that since the dispersion curves are sensitive to the load level, the elastic waves could be used for continuous load monitoring. In a recent paper, Rizzo and Lanza di Scalea (2005) employed a time-frequency analysis based on the discrete wavelet transform (DWT) for analyzing the ultrasonic signals. They found the denoising property of the DWT to be particularly useful in their analyses.

## 3. THEORY

Ultrasonic waves are used for material characterization in many structural health monitoring and nondestructive evaluation applications. Guided ultrasonic waves are particularly effective for interrogating large structural components, since they propagate far distances when compared to body waves.

Guided waves appear in a medium that constrains internal disturbances to move between the lateral bounding surfaces. In essence, standing waves are established in the lateral (short) direction whereas propagating waves are manifested in the normal (long) direction. For the case of a multi-wire cable, there exists no closed-form analytical solution that describes wave propagation. The following development therefore focuses on the simpler case of a single wire.

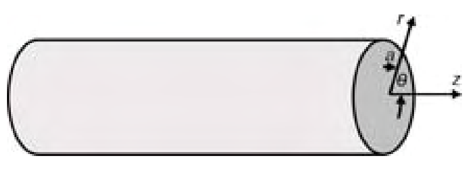



Fig. 2: Cylindrical rod with coordinates.

For the case of a solid, homogenous cylindrical rod with radius a (see Fig. 2), the substitution of the stress-free boundary conditions trr = trq = trz = 0 at the rod surface r = a into the Lamé-Navier equations leads to the so-called Pochhammer frequency equation for the longitudinal modes (Graff, 1991),

$$\frac{2p}{a}\left(q^2+k^2\right)J_1(pa)J_1(qa)-\left(q^2-k^2\right)^2 J_0(pa)J_1(qa)-4k^2pqJ_1(pa)J_0(qa)=0 . \quad (1)$$

Here, J0 and J1 are Bessel functions of the first kind of orders 0 and 1 respectively; and, p and q are given by

$$p^2=\frac{\omega^2}{c_B{}^2}-k^2, \qquad q^2=\frac{\omega^2}{c_S{}^2}-k^2 \quad (2)$$

where w is the circular frequency, k is the circular wavenumber, cB is the bulk wave speed in an unbounded medium, and cS is the shear wave speed. The radial and axial displacements for the longitudinal modes are, respectively

$$u_r(r,z,t)=-\left[pJ_1(pr)+CikJ_1(qr)\right]e^{i(kz-\omega t)}$$
$$u_z(r,z,t)=\left[ikJ_0(pr)+CqJ_0(qr)\right]e^{i(kz-\omega t)} \quad (3)$$
$$C=\frac{-2ikp}{q^2-k^2}\frac{J_1(pa)}{J_1(qa)}.$$

A similar analysis yields frequency equations and displacement mode shapes for torsional and flexural waves. This study however uses the fundamental longitudinal mode for defect identification. In the case of pulse-echo detection in which the ultrasonic source is also used as the receiver, as used in this study, the fundamental longitudinal mode is the fastest moving mode and can therefore be used for clear identification of defects. Fig. 3 depicts the group velocity-frequency characteristic for the first two longitudinal modes (L(0,1) and L(0,2)) and the first two flexural modes (F(1,1) and F(1,2)). The dispersion characteristic was calculated for the rods considered in this study (4.45 mm diameter, aluminum). At low frequencies, the group velocity of the fundamental longitudinal mode approaches the bar wave velocity $\sqrt{E/\rho}$; and at high frequencies, the group velocity approaches the Rayleigh wave velocity.

The radial variation of axial stress as a function of frequency for the fundamental longitudinal mode is depicted in Fig. 4. The stress curves were computed using the displacement functions in Eqn. (3). The curves were normalized by setting the largest values of radial distance and stress to one. At high frequencies, the elastic energy becomes concentrated near the surface. This skin effect is found in plates and in the case of Rayleigh wave propagation in a half-space.

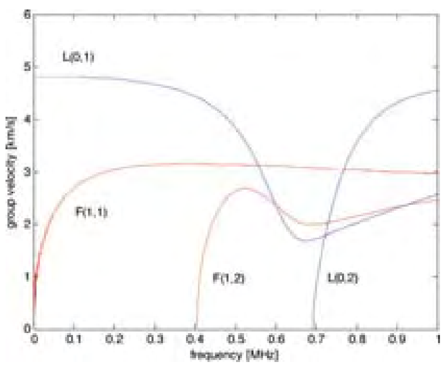



Fig. 3: Group velocity-frequency dispersion characteristic for a 4.45 mm diameter aluminum rod.

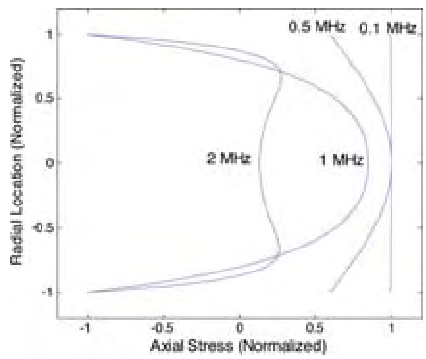



Fig. 4: Radial variation of axial stress for the 1st longitudinal rod mode.

The equation describing the longitudinal wave motion (Eqn. 3) does not account for attenuation due to material or geometrical effects. Introducing the complex wave number

$k^* = k1 + k2i$, the axial motion at a fixed radial distance can be expressed as

$$u_z(z,t) = Ae^{i(k^* z - \omega t)} = Ae^{-k_2 z}e^{i(k_1 z - \omega t)}. \qquad (4)$$

It is clear from Eqn. (4) that the k1 contribution is associated with propagation of the wave, and the k2 contribution is associated with spatial attenuation of the wave. It follows immediately that

$$k_2 = \frac{1}{\Delta z}\ln\left|\frac{u_z(z,t)}{u_z(z+\Delta z,t)}\right|, \qquad (5)$$

where $\Delta z$ is the separation distance between two measurement points.

## 4. EXPERIMENTAL CHARACTERIZATION OF THE 1ST LONGITUDINAL MODE

A cross-sectional view of the transmission line considered in this study is depicted in Figure 5. The transmission line is comprised of thirty-three steel and aluminum wires that are tightly wound

**Continued on Page 20**

## Nondestructive testing

Continued from Page 18

together. There are seven load-bearing steel wires in the middle of the transmission line, which are surrounded by twenty-six current-carrying aluminum wires. The diameter of each steel wire is 3.5 mm, and the diameter of each aluminum wire is 4.45 mm.

The diameter of the entire transmission line is 28.3 mm, and the length is 910 mm. In section 4.1, the experimental characterization of longitudinal waves in a single aluminum wire is presented. Specifically, the attenuation and dispersion behavior of the first longitudinal mode are determined. In section 4.2, the wave phenomenon in the transmission line as a whole is characterized. Cross-sectional measurements of the axial displacement are made in addition to attenuation and dispersion measurements.

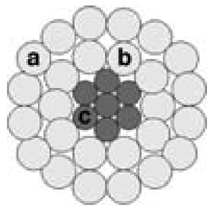



Fig. 5: Cross-sectional view of the transmission line.

### 4.1. SINGLE WIRE MEASUREMENTS

The experimental setup for characterizing longitudinal mode propagation in a single wire is depicted in Fig. 6. A single sine burst from the function generator is amplified with the radio frequency (RF) amplifier, and this signal is used to drive a piezoelectric disc transducer. The transducer, in turn, generates an elastic wave in the aluminum wire (4.45 mm diameter, 820 mm length). The elastic wave propagates through the aluminum wire and is detected by a laser Doppler vibrometer (LDV). The LDV is a powerful measurement tool that allows non-contact, high fidelity, point-like measurements over a wide frequency range. As shown, the LDV is used to measure the axial particle velocity at the left end of the wire. The output from the LDV is captured by an oscilloscope and is then transferred to a PC for processing. Figure 7 depicts the measured axial particle velocity at the wire end for different frequencies. The existence of three discrete signal bursts (as seen in the 500 kHz trace) is evidence of the dispersive nature of the fundamental longitudinal mode. The frequencies of the bursts themselves coincide with the natural frequencies of the disc transducer.

The LDV is particularly well suited to making attenuation measurements since it is noncontact and therefore does not influence wave propagation. The attenuation coefficient is estimated according to Eqn. (5), where the maximum amplitudes of the end reflections have been used in computations. Depicted in Fig. 8 is the LDV-measured axial velocity for a 100 kHz drive frequency. The attenuation coefficient of the first longitudinal mode at this excitation frequency is estimated to be k2 = 0.15 m-1. Thus, the elastic wave will propagate approximately 30m before the signal level falls below a measurable level, specifically when the signal-to-noise ratio (SNR) < 2. Obviously, this material damping estimate is somewhat high since the driving transducer partially absorbs the elastic energy.

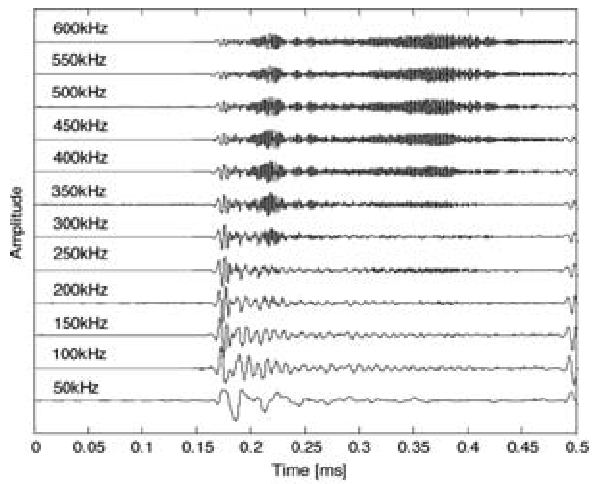



Fig. 7: LDV-measured axial particle velocity as a function of frequency.

### 4.2. TRANSMISSION LINE MEASUREMENTS

The experimental setup for measuring the longitudinal modes in a transmission line (28.3 mm diameter, 910 mm length) is depicted in Fig. 9. The transmission line setup is identical to the single wire setup, with the exception that a

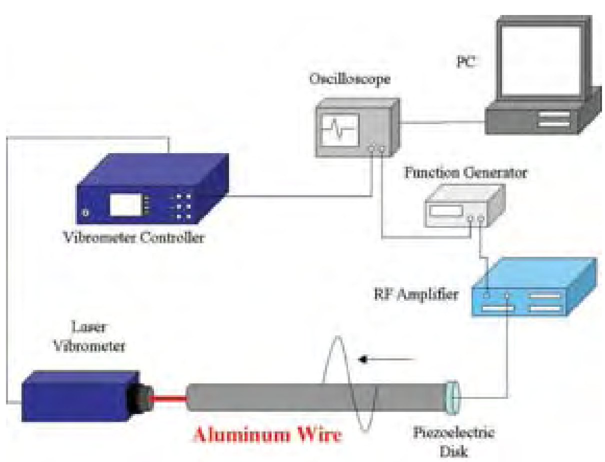



Fig. 6: Experimental setup for characterizing longitudinal waves in a single wire.

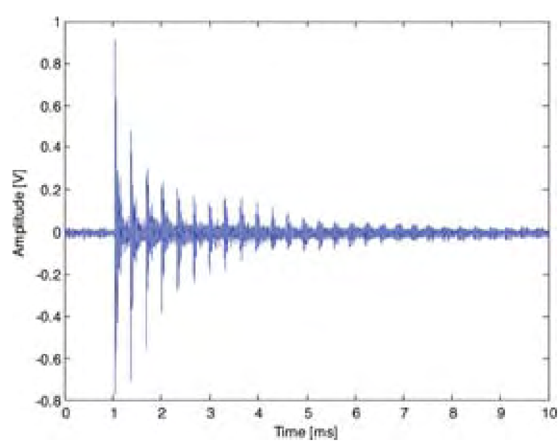



Fig. 8: Multiple reflections of a longitudinal wave in a single wire (100 kHz excitation).

piezoelectric ring is used as the driving transducer. Fig. 10 depicts the measured axial particle velocity for a surface wire at different drive frequencies. There exists two discrete signals (as seen in the 500 kHz trace). The first signal corresponds to the fast-moving longitudinal mode, and the second signal corresponds to a slower-moving flexural mode. The dispersion of the second signal at low frequencies (as seen in the 100 kHz trace) is evidence that this signal is indeed the flexural mode. A second feature worth noting is the prominent ringing of the transducer, as evidenced by the multiburst nature of the first signal (as seen in the 100 kHz trace).

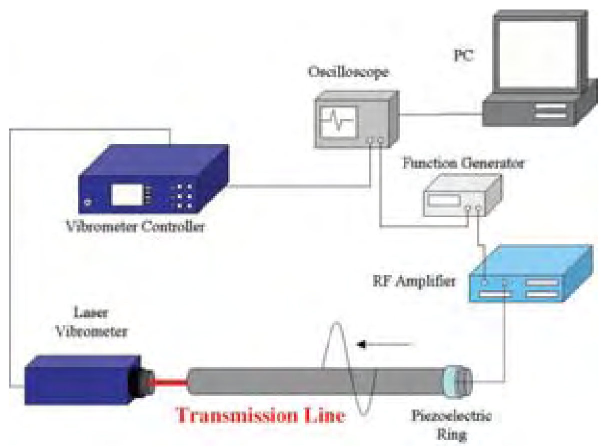



Fig. 9: Experimental setup for characterizing longitudinal waves in a transmission line.

The LDV was used to measure the axial particle velocity for three distinct wires in the transmission line, specifically an outer aluminum wire, an inner aluminum wire, and an outer steel wire (locations a, b, and c in Fig. 5, respectively). Results for a 100 kHz excitation frequency are shown in Fig. 11. Clearly, elastic waves are also present in the inner wires, and hence, it is possible to detect breaks in these wires. The amplitude of the elastic waves becomes smaller at increasing distance from the surface due to the weak coupling of energy to the inner wires. The attenuation coefficient for the first longitudinal mode in the surface aluminum wire is estimated to be k2 = 0.27 m-1, meaning that the elastic wave will propagate approximately 12 m before the signal level falls below a measurable level (SNR < 2).

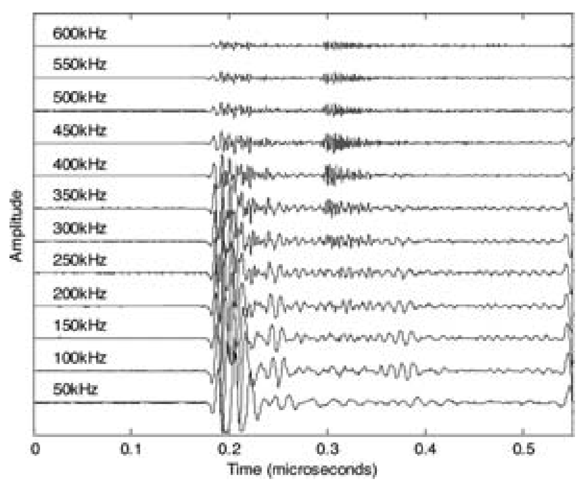



Fig. 10: LDV-measured axial particle velocity for a surface wire as a function of frequency.

## 5. DEFECT DETECTION

The main goal of this research is the monitoring of overhead transmission lines using elastic waves. In this section, two detection methodologies are considered. In section 5.1, a "global" scheme is described which uses a ring transducer to send elastic energy into every single wire in the transmission line. In section 5.2, a "local" scheme is described which utilizes smaller transducers for sending elastic energy into a select few surface wires.

### 5.1. GLOBAL DETECTION

The experimental setup for global defect detection in a transmission line is shown in Fig. 12. As shown, a pulser-receiver drives the piezoelectric ring with an electrical spike input which, in turn, generates an elastic wave in the transmission line. The piezoelectric ring, as it is attached to the transmission line, is illustrated in Fig. 13. The pulser-receiver then switches automatically from "send" to "receive" mode. The elastic wave is reflected from discontinuities in the transmission line, and the reflected wave is sensed by the piezoelectric ring. The signal from the ring is received and amplified by the pulser-receiver. Artificial damage in the form of a transverse cut is made using a handsaw. The cuts are made at a distance of 700 mm from the piezoelectric ring, and they

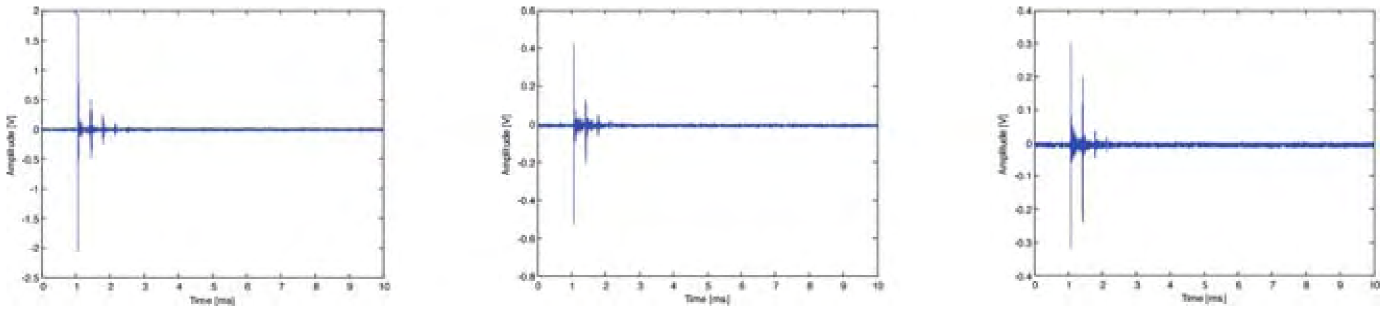


Fig. 11: LDV-measured axial particle velocity for an outer aluminum wire (left), an inner aluminum wire (middle), and an outer steel wire (right).

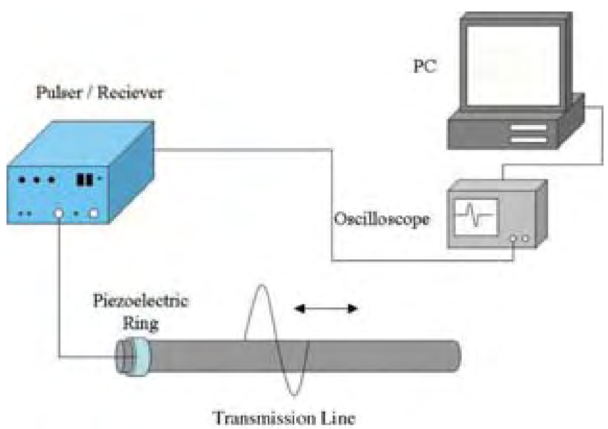



Fig. 12: Experimental setup for defect detection in the transmission line.

range from 2 mm in depth to a complete cut.

The received signal for a 7 mm cut is compared to the undamaged case in Fig. 14. The two signals are nearly identical until ~ 0.3 ms. The reflection of the fundamental longitudinal wave from the cut is responsible for the difference in the two signals. The presence of a signal before the arrival of this reflection is caused by the ringing of the piezoelectric ring.

That is, the ring continues to vibrate, thereby generating a voltage signal, even after the excitation has been removed. The maximum amplitude of the reflected wave as a function of cut depth is illustrated in Fig. 15. A linear relationship between the degree of damage and the maximum reflected wave amplitude has been observed. This relation could be used for monitoring purposes in order to identify the state of damage in a cable.

Fig. 14: Transducer output for a damaged and an undamaged transmission line.

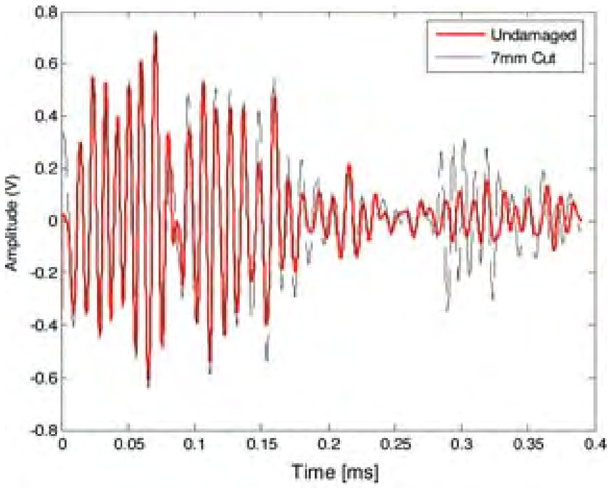



Fig. 15: Maximum amplitude of the reflected wave at various damage levels.

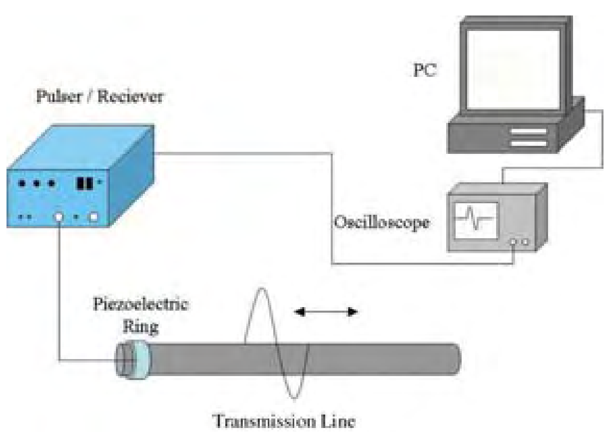



Fig. 13: Piezoelectric ring transducer attached to the transmission line.

*See the March issue of Electricity Today for the conclusion of this article*

# IPPSA 15TH ANNUAL CONFERENCE AND TRADE SHOW - 15 YEARS: 15 QUESTIONS

**BANFF, ALBERTA - MARCH 8-10, 2009**

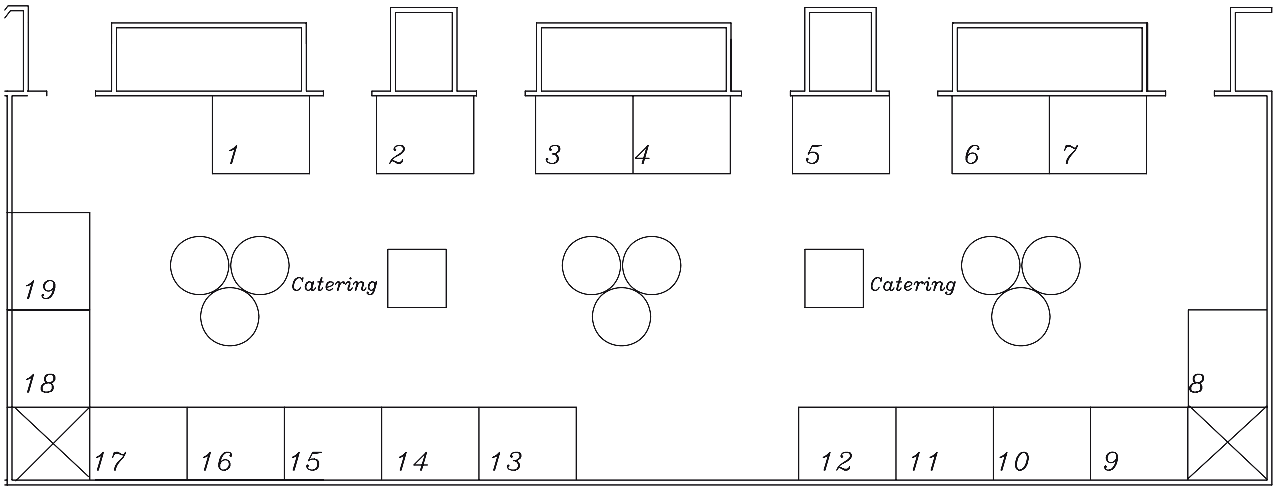
IPPSA's milestone 15th Anniversary Conference - "15 Years: 15 Questions" - reviews how far the Alberta electricity market has come and seeks to answer 15 residual questions facing the industry.

These questions include: "Is electricity a commodity?" "How do we get transmission built?" "Is it time to lift the price cap?" and "what can we learn from other markets?" among others. IPPSA invites you to join them for this special event March 8-10, 2009!

## About Independent Power Producers Society of Alberta (IPPSA)

Founded in 1993, IPPSA represent Alberta's power suppliers, power marketers and their supporting industries in the province's competitive power market. IPPSA's vision is to promote an open, fair market for power suppliers in Alberta's competitive electricity industry.

## IPPSA Trade Show Floor Plan and Exhibitors




For further information about IPPSA, the conference and the trade show please visit **www.ippsa.com**.

**Booth - Exhibitor**

| Booth | Exhibitor |
|---|---|
| 3- | Alberta Electric System Operator |
| 12- | AltaGas |
| 19- | Canadian Hydro Developers Inc. |
| 2- | GE Energy |
| 10- | Golder Associates Ltd |
| 1- | NRGSTREAM |
| 9- | TransCanada |
| 5- | Victaulic |
| 15- | Wellons Canada Corp. |
| 13- | ZE PowerGROUP INC |

If you would like information about purchasing a booth at the IPPSA Conference and Trade Show please call (403) 210 0596 or email capitol@shaw.ca.

# TRANSFORMER FIRE CONTAINMENT WALLS INSTALLED IN RECORD TIME

In less than twenty-four hours, a six-man crew at Imperial Irrigation District (IID) retrofitted three large transformer firewalls at a critical transmission substation. The firewalls are needed to contain transformer oil fires from spreading between three 230 kV transformers, a control house, and other equipment at the Coachella Valley Substation. This substation is a vital power hub for power transfers between Arizona, California and Mexico; hence, outage time must be minimized. The key to such a construction success lies in IID management's selection of TruFireWalls.

Each firewall measures 40 by 24 feet. The walls were quickly assembled in the field from fire resistant precast columns and panels. First, the columns were bolted to the existing foundation and aligned. Next, the panels were slid down the grooved columns and assembly was then complete. Disassembly of these removable maintenance-free firewalls is equally simple and quick.

Simple and Quick Installation: One Day - One Wall (above)

Step One - Position, align, and secure the columns (left).

Step Two - Slide in the panels (below) and…

## SUBSTATION FIRE HAZARD CONDITIONS AND POTENTIAL CONSEQUENCES

A power substation by its nature contains all the right ingredients to generate the perfect firestorm. A typical transmission transformer bank consists of three or more transformer tanks, each containing 10,000 to 45,000 gallons of mineral oil. The initial spark is likely to come from electrical arcing inside the tank, which also generates heat and pressure high enough to rupture the tank. Oxygen immediately rushes into the tank. The oil violently explodes accompanied by a blast of intense radiation, flying shrapnel, and flaming oil. The radiation's effect is instantaneous and has been documented to ignite other transformers more than 60 feet from the initial fire.

The temperature of an oil fire is in the range of 960°C to 1,200°C. A power transformer's fire duration ranges from 4 to 28 hours, which is, in most cases, the time it takes the fire to burn itself out. As larger substations are often located in outlying areas, the fire department's response time is long. In addition, fire trucks are rarely equipped to suppress these supersized oil fires.

Firewalls are only a third of the total solution to effectively protect a substation against fire. The other two components needed are an early detection and alert system and the correct fire suppression system. Hence, the installation of effective firewalls is the bare minimum to protect a transformer bank and neighboring equipment.

In general, existing standards and codes do not realistically address the actual conditions of large hydrocarbon pool fires in open air. Therefore, performance-based criteria need to be applied to ensure effective fire protection in substations. To replicate real-world requirements, a transformer firewall must be exposed to a four-hour fire followed immediately by a high-pressure water jet blast on the same test sample.

The replacement cost of a large transformer is about $1.5 million to $2.5 million per phase. However, the higher cost by far is the replacement energy, which must be purchased from the spot market at premium prices. During peak hours, rates could spike up to $200,000 per hour.

Compounding the problem, the delivery time on a rush basis for these transformers is about 18 months. Insurance premium increases may be imposed (conversely, insurance companies have reduced rates when fire walls are installed), and long-lasting unfavorable public relations with the community, regulators, and investors can result.

### EFFECTIVE CONTAINMENT OF TRANSFORMER FIRES

Effective transformer firewalls must be:

(1) made from materials that can withstand the intense high temperature and long duration of these fires;

(2) designed such that both thermal and mechanical requirements are met before, during, and after the fire.

Traditionally, transformer "fire walls" have been built from reinforced concrete and/or concrete blocks. The initial cost of these walls is deceptively low, because these materials do not perform as needed under high temperature. At 650°C, concrete retains only about 35% of its room temperature strength, and steel has practically no strength left at that same temperature, which is about 350°C lower than the oil fire's 'working' temperature as shown below.

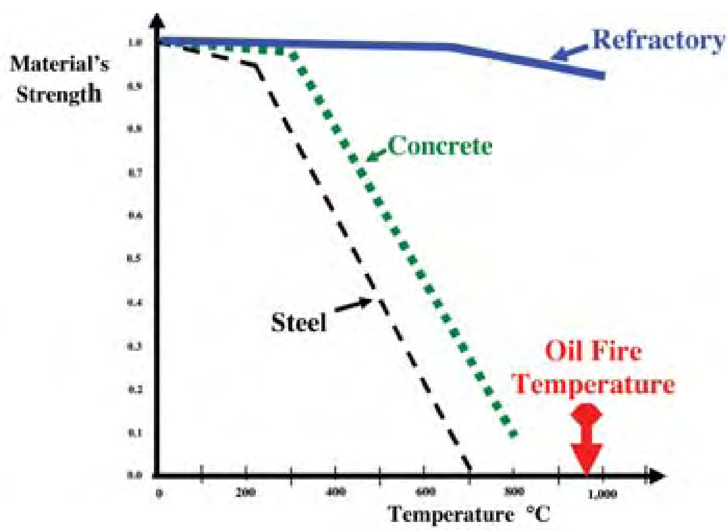
Hence, concrete walls fail under the actual conditions of a transformer fire. Furthermore, concrete walls are large and heavy, requiring deep reinforced foundations, and they must be torn down and rebuilt when major transformer maintenance is performed.

The firewall must also have sufficient impact resistance to survive shrapnel impingement because it is quite possible that the fire will initiate a transformer explosion. As there is yet no standard for firewall impact loading, ballistic and explosion experts have recommended applying UL Standard 752. This is equivalent to a firewall panel stopping a 44 Magnum projectile with no through-penetration, as the IID wall panels are capable of doing.

Refractories, as used in the IID firewalls, are water-based and totally inorganic with nothing to burn. The relatively lightweight thermal panels and columns are cast from time-tested refractory concrete. Refractories emit no volatile organic compounds or hazardous material when manufactured, during the fire, or when disposed. The time-proven refractory cements that have been used for centuries to handle molten metal in foundries and smelters clearly meet the thermal and mechanical requirements over the service life of the substation.

Field-proven refractories and the well-established manufacturing process by Oldcastle Precast, with 80 plants throughout the United States, ensure that the required thermal and mechanical performance is achieved at a competitive cost. TruFireWalls by ThermaLimits are designed and certified to meet thermal, wind loading, seismic, and substation layout requirements. The modular design reduces manufacturing and installation costs.

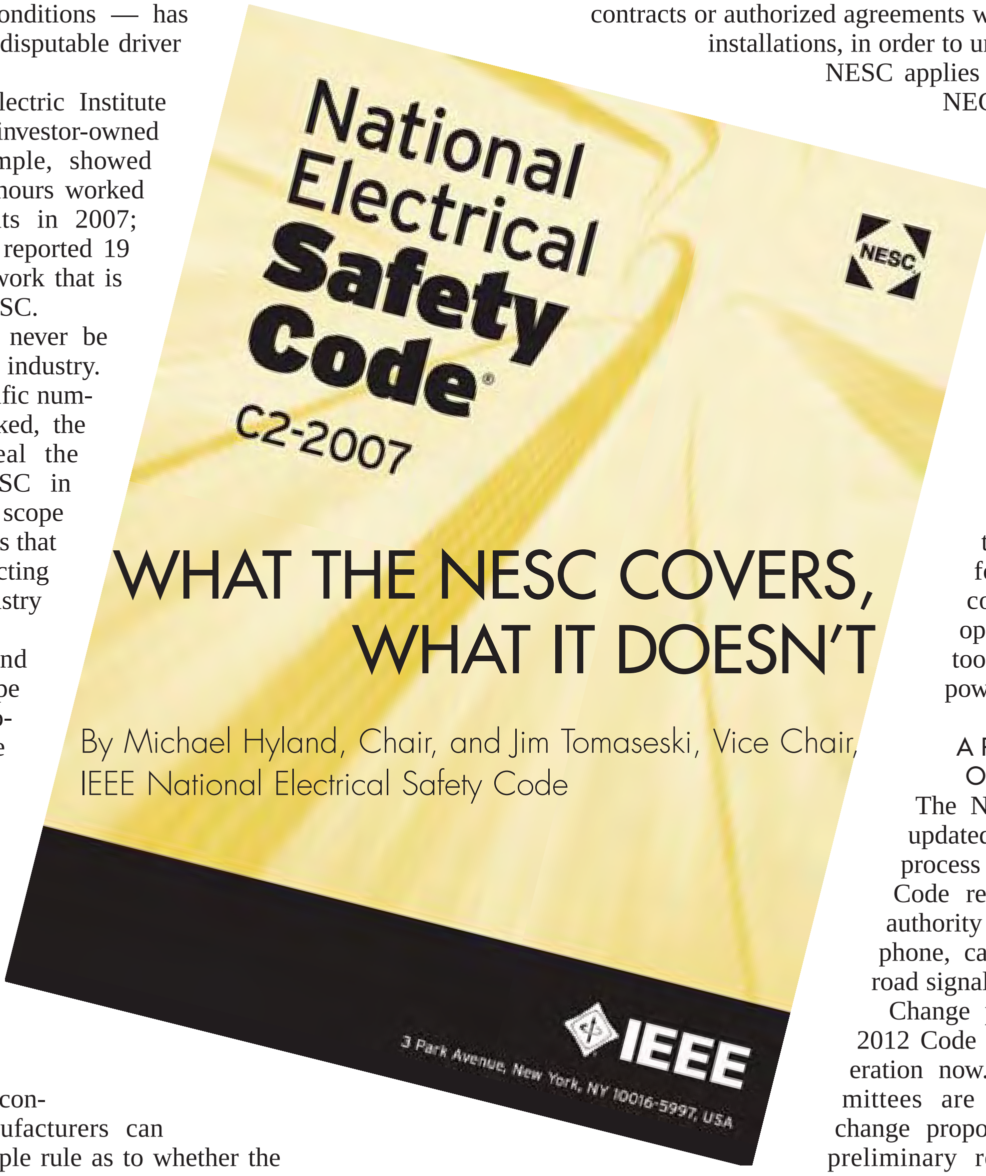

The installation is COMPLETE!




An IID firewall panel stops a 44 Magnum bullet.

# WHAT THE NESC COVERS, WHAT IT DOESN'T

By Michael Hyland, Chair, and Jim Tomaseski, Vice Chair, IEEE National Electrical Safety Code




A culture of safety has gathered across the electrical community, and the ongoing refinement of the National Electrical Safety Code (NESC) — outlining the basic provisions necessary for the safety of employees and the public under specified conditions — has proven to be an indisputable driver in the trend.

An Edison Electric Institute (EEI) survey of investor-owned utilities, for example, showed over 765 million hours worked among respondents in 2007; those respondents reported 19 deaths related to work that is covered by the NESC.

Injuries must never be conceded in our industry. But, given the terrific number of hours worked, the survey does reveal the success of the NESC in working within its scope to create work rules that contribute to protecting the electrical industry and users.

Defining and redefining that scope has been an ongoing effort since the NESC was first published in 1914.

## KEEPING THE CODE VIABLE AND REALISTIC

In most cases, utilities and their employees, contractors and manufacturers can fall back on a simple rule as to whether the NESC applies to the work they are doing: The NESC covers everything up to the service point — the point of demarcation between where power is handed off from utility to end user. On the other hand, the NESC does not cover premises wiring or utilization equipment, which are addressed in the National Electrical Code (NEC).

But there do exist numerous and varied instances where no meter exists to provide a well-defined service point. For example, area lighting might be installed in the parking lot of a retail business or in the backyard of a residence. In some cases, the connection is made directly off the distribution line, and, in others, on the load side of a meter. Or, the entry point for power might be a locked vault or closet inside a building or a weatherhead on the roof of a home.

The service point in instances such as these might be a point of debate. Utilities follow local jurisdictions' regulations, contracts or authorized agreements with regard to such installations, in order to understand how the NESC applies in relation to the NEC or other specifications.

Shapers of the NESC consider these gray areas in working to keep the 94-year-old Code realistic, practical and useful. They also must address innovations in the transformers, breakers, conductors, fiber optics and the other tools used to provide power.

## A PROVEN PROCESS OF ENHANCEMENT

The NESC is regularly updated via a five-year process that ensures the Code remains the safety authority for power, telephone, cable TV and railroad signal systems.

Change proposals for the 2012 Code are under consideration now. NESC subcommittees are reviewing these change proposals and making preliminary recommendations. This effort will yield the NESC Preprint, scheduled to be available on September 1, 2009. A period of comment will then continue through May 2010, with a proposed revised Code to be made available for public review in January 2011. The next, completed NESC will be published August 1, 2011.

The U.S. Department of Labor Occupational Safety & Health Administration (OSHA) considers the NESC in writing its regulations. Also, public service/utility commissions or other bodies that oversee

View the survey online at:
http://standards.ieee.org/nesc/

utility operation in 48 states and more than 100 countries other than the United States mandate adherence to the Code in part or whole.

In these ways, the NESC provides the foundation for the holistic safety programs of utilities around the world — informing the manuals, "tailboard discussions," weekly and monthly meetings, etc., that all combine to help keep electrical workers and users safe. By design, the NESC leverages the ongoing lessons learned across the electrical community and works hand-in-hand with utilities' mandated best practices.

2012 National Electrical Safety Code (NESC) Schedule

**2008**

| | |
|---|---|
| *July 17, 2008* | Final date for receipt of proposals from the public for Revision of the 2007 Edition of the NESC, preparatory to the publication of a 2012 Edition |
| *September - October 2008* | NESC Subcommittees consider proposals for changes to the NESC and prepare their recommendations |

**2009**

| | |
|---|---|
| *September 1, 2009* | Preprint of Proposed Amendments for incorporation into the 2007 Edition of the NESC published for distribution to the NESC Committee and other interested parties |

**2010**

| | |
|---|---|
| *May 1, 2010* | Period for study of proposed amendments and submittal by interested parties of recommendations concerning the proposed amendments. Submit recommendations to the Secretary, NESC Committee, at the above address |
| *September - October 2010* | Period for NESC Subcommittee Working Groups and NESC Subcommittees to reconsider all recommendations concerning the proposed amendments and prepare final report |

**2011**

| | |
|---|---|
| *January 15, 2011* | Proposed revision of the NESC, Accredited Standards Committee C2, submitted to NESC Committee for letter ballot and to the American National Standards Institute for concurrent public review |
| *May 15, 2011* | NESC Committee approved revisions of the NESC submitted to the American National Standards Institute for recognition as an ANSI standard |
| *August 1, 2011* | Publication of the 2012 Edition of the National Electrical Safety Code |

## CONCLUSION

The electrical community has been doing work on facilities and equipment in an energized state since Thomas Edison invented the light bulb in 1879. The U.S. Congress in 1913 asked the Bureau of Standards to investigate the hazards of electrical practice, resulting in the first publication of the NESC one year later.

Although working de-energized may pose less of a risk to the worker, it may not be possible or practical. Today, we are in an age when shutting off the power in order to do electrical work is sometimes not even an option. Public safety and global commerce require electricity 24 hours a day, seven days a week. In turn, energized work must be performed around the clock every day.

The NESC has successfully contributed to the trend toward safety in the electrical industry, and the commitment to craft and refine a strong Code has never been stronger.

*Michael Hyland, PE, is chair of IEEE NESC and vice president of engineering services with the American Public Power Association (APPA), the service organization for the nation's more than 2,000 community-owned electric utilities that serve more than 45 million Americans.*

*Jim Tomaseski is vice chair of IEEE NESC and director, safety and health department, with the International Brotherhood of Electrical Workers (IBEW), which represents approximately 750,000 members who work in a wide variety of fields including utilities, construction, telecommunications, broadcasting, manufacturing, railroads and government.*

# PROVIDING OIL SPILL CONTAINMENT IN A REMOTE AREA

An environmental assessment was carried out on a utility's substation built in the early 1980s in northern Alberta. This substation consists of two transformers each containing approximately 70,000 liters of mineral oil.

This substation is in a remote area, unmanned and on the banks of a river.

The site was deemed to be at high risk due to the fact that the transformers on site contain a very large amount of oil and, second, the site is very near a river.



Due to the possibility of damage to the environment and monetary penalties that this could bring, the utility came to the conclusion that it was in their best interest to determine a preventive solution that would be most compatible with the site.

This substation supplies a vast amount of electricity in the northern Alberta area and it was not possible to take the two transformers off line to install a secondary oil spill containment system.

Any secondary oil spill containment system had to effectively work in all weather conditions, given the remoteness of the location.

Given that utilities everywhere have less manpower than in the past, little or no maintenance of any secondary oil spill containment system was also a criterion.

Research by the utility was done on various types of secondary oil containment systems. Given that the transformers had to remain energized and that the system had to function in all weather conditions down to –50 C, the utility came to the conclusion that the SorbwebPlus secondary oil containment system offered by Albarrie Canada Limited was the only choice. The utility's insurance company also examined the SorbwebPlus system and deemed that the SorbwebPlus system was a viable option for not just this particular substation but all of their substations for secondary oil containment.

SorbwebPlus is a no maintenance passive system, which can be installed around existing energized transformers and will function in all-severe weather conditions. It is designed to contain 110% of the volume of oil within the transformers along with a historical 24-hour rainfall over the past 25 years.

Albarrie was the general contractor for the complete job, including the installation of a firewall between the two transformers.

The installation of the SorbwebPlus secondary oil system required that Albarrie take into consideration all cable trays within the perimeter of the containment system, including a concrete subsurface cable tray (trewna). We also, given the area that was available to the

SorbwebPlus system had to lower the grounding grid from 0.5 meters to one meter. All this had to be accomplished while the transformers were live.

Inasmuch as there was to be installed a firewall between the two transformers, two containment systems had to be built one for each of the transformers.

The substation sloped towards the river at a three-degree angle, requiring the excavation of the containment system for leveling; this eliminated the contour of the land causing the oil to spill out of one side.

The soils were determined through an independent laboratory to be permeable, therefore no special drainage system had to be designed. SorbwebPlus is designed to allow the permeation of water in the form of precipitation or melted snow into the subsoil.

If the soil had been impermeable, a drainage system can be built underneath the SorbwebPlus to move the water away from the containment system.

Upon excavation, the cable trays (which ran along the surface of the containment) had to be supported with wooden planks. Upon reaching the 0.5-meter depth the grounding grid had to be exposed so that there would be no damage to the grid. The grid was made visible so that further excavation could be made down to the 1-meter depth.

Further excavation was necessary between the two secondary oil containments for the two transformers to allow for a foundation that would support the firewall. The two containment systems would abut to the foundation of the firewall.

A surface cable tray ran through the foundation for the firewall, so allowance was made for passage of the cable tray through the foundation. This would later be sealed preventing any seepage of oil from one containment system to the other.

Slings lifted the cables in the trewna and the trewna was lined with the oil mat to prevent any seepage of oil into the ground as the bottom of the trewna was earth. Once lined, the cables were then replaced and the top of the trewna was sealed with concrete lids.

Once excavation was completed, the grounding grid was dropped to the 1-meter depth. As the substation was built in the early 1980s, upgrades to the grounding grid were done at the same time.

All the excavated areas were installed with the SorbwebPlus system. This includes the impermeable liner around the perimeter and the special oil mat at the bottom of the containment which will seal upon contact with oil, yet if no oil is present, will allow the passage of water into the subsoil.

Once the SorbwebPlus system was installed, rock was added to the system. The rock was 19 mm to 38 mm in diameter, which typically gives a void area of 40 to 45%. It is this void area that the 110% of oil within the transformer and the 25-year, 24-hour rainfall event will be contained in the event of a catastrophe. The layer of rock serves as an effective retardant in the event of fire.

The firewall completed the entire installation.


The high risk for this substation was eliminated with the addition of a no-maintenance, passive, secondary oil containment system which operates in any severe weather conditions.

# DISTRIBUTION AUTOMATION AND DEMAND RESPONSE - PART II

By Nokhum Markushevich and Alex Berman, Utility Consulting International

CONTINUED FROM AN ARTICLE IN OUR OCTOBER ISSUE

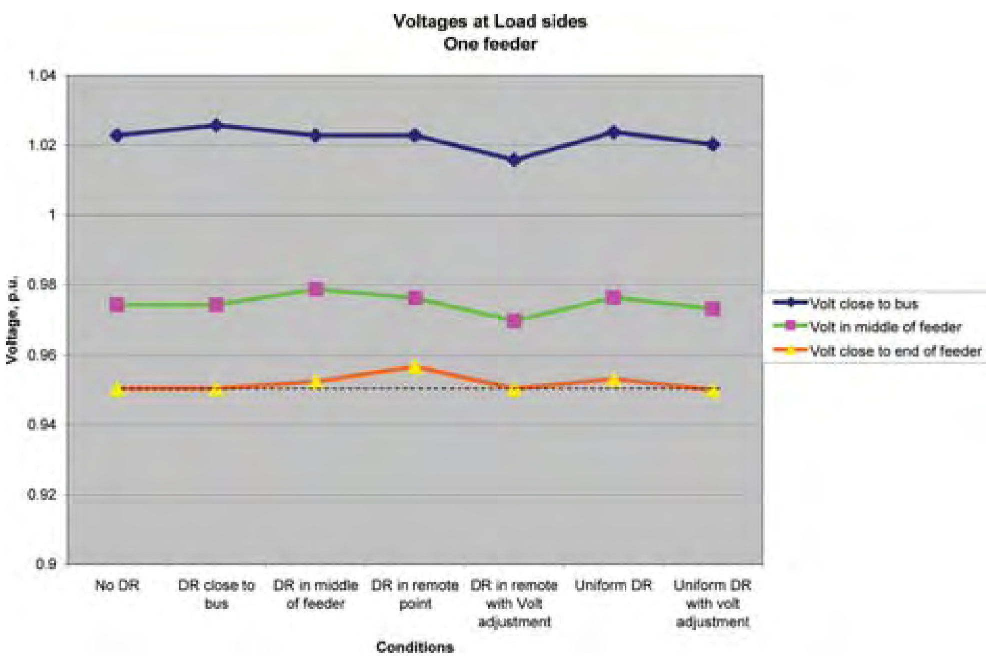



Figure 8. Changes of voltages at load sides for different locations of DR with and without coordinated VVO.

The results are more expressed when DR is applied to the load in the end of the feeder. The increase of voltage is greater in this case, which reduces the effect of the load reduction, but the reduction of losses is greater, and, therefore, the reduction of generation is about at the same level. The changes of voltages for the corresponding conditions are seen in Figure 8. The model of this example assumes that the voltage change at the substation bus due to DR applied in distribution does not typically exceed the bandwidth of the voltage controller, and therefore this change does not result in LTC operations. In some cases, when the voltage is initially close to the boundary of the bandwidth, the voltage controller can move one step of the LTC. To account for these cases, the example model includes simulation of continuous line-drop compensation.

Typically, the line-drop compensation does not fully compensate for changes of voltage caused by the change of load in a portion of the distribution system, especially in the secondaries. If there were no line-drop compensation, the load reduction due to DR would be even smaller (as can be seen in Figure 9).

If the rise of voltage is eliminated by a coordinated Voltage and Var control function, so that after the DR is applied, the voltage in the lowest point of the circuit is returned to low standard limit, then the overall load and losses in distribution are additionally reduced, and the generation is also reduced by an amount greater than the initial DR value (See point “DR in remote with Volt adjustment). If the same amount of DR is applied uniformly to all loads along the feeder, the effect of the voltage adjustment to the results of DR is smaller.

If the transmission losses are taken into consideration, the effect of demand response in reduction of the generation needed to cover the distribution demand is greater (see Figure 10). It depends on the connectivity and loading of the transmission system and on the location of the incrementing generation.

When more than one feeder is connected to the same substation bus, the effect of DR applied in the same manner as above to the load in one feeder only is smaller (see Figure 11). This is caused by the increase of voltage at the substation bus due to reduction of the voltage drop in the substation transformer. But, in this case, the voltage increase is applied to a greater load of more than one feeder.

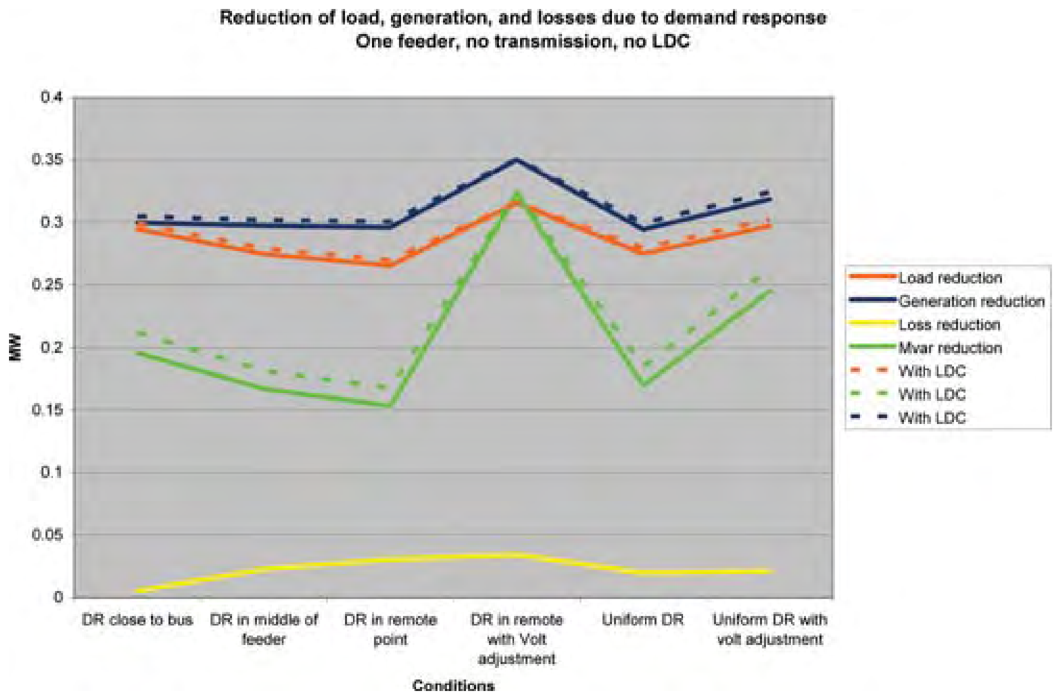


Figure 9. Impact of Line-Drop Compensation on results of DR

If the bus voltage is adjusted to compensate for the increase of voltage in this case, the effect of the combined DR and voltage control is greater than in the case with one feeder.

A similar analysis was performed for cases where the demand response is applied to the primary of distribution feeders. Our example assumes that a Distributed Energy Resource (DER) is connected to the primary distribution either in the middle of the feeder, or close to the end. The size of the DER is assumed to be 1 MW. The results are presented in Figure 12 through Figure 14. As seen in the figures, if the voltages are not adjusted, the remote location of the DER results is a slightly smaller effect of the DER contribution to the reduction of distribution demand and generation. If the voltages are adjusted, the remote location of the DER produces greater benefits. The increase of the benefits due to bus voltage adjustment is smaller than it was with the Demand Response applied to the secondaries, because the voltage rise from the injection of the real power in the primary circuits is smaller. For the same reason, the increase of voltage at the substation bus in negligible, because the impedance of large substation transformers is predominantly reactive.

Examples of applying DA applications, which include the simulation of DR, to a realistic distribution system are presented below. The selected distribution system is fed from one bus with an LTC and consists of two 12.5 kV feeders with about 1,200 distribution transformers and 3,850 customers. Different DR means are allocated at 114 distribution transformer loads. The load is represented in four load categories: residential load with a small amount of direct load control, industrial load with significant DR capabilities, including embedded DER devices and the ability to shift the load from high demand to low demand times, commercial loads with significant demand response capabilities, and a small group of loads with demand response and energy storage.

In these examples, it is assumed that the demand response reacts on a price signal proportional to the real-time LMPs. The signal in p.u. is presented in Figure 15.

It is also assumed that the DR of industrial customers is triggered when the signal exceeds 1.4 p.u., and the DR of other customers, when the signal exceeds 2.2 p.u. The energy storage and load shifts to the minimum-demand times starts, when the price signal is below 0.6 p.u.

The Distribution Operation Model and Analysis application [5-8] shows the following simulation results for the case without DR and with DR:

As seen in the table on the previous page, DR at peak time reduces the kW and Amps and increases the voltage.

At the low-price times, the load is increased due to the shifts of load or due to the energy storage.

As seen in Figure 15, the triggers for DR exist not only at peak time. If there is no limit on the number of times per day when DR can be activated, the demand response would change during the day as presented in Figure 16.

The coordinated Volt/Var Optimization application [8-12] was applied in this example with an energy conservation objective during the daytime, firstly, without DR and, secondly, with DR.

The results are presented in the table to the right. As seen in the table, when VVO adjusted the bus voltage to reduced voltage drops along the feeders due to DR, the VVO-related reduction increased by 14%.

In this example, the load in the voltage-critical points in the secondary distribution did not have DR. This means that the voltage drop was reduced by DR in the primary feeders only. If the DR means were implemented in the voltage-critical points in the secondaries, the amplifying effect of DR on load reduction by VVO would be significantly greater.

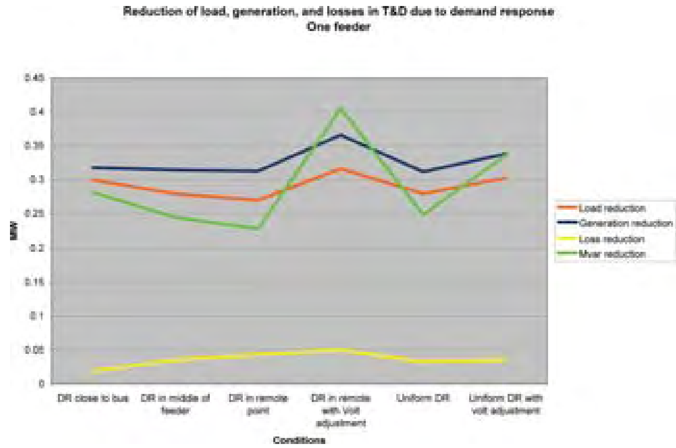
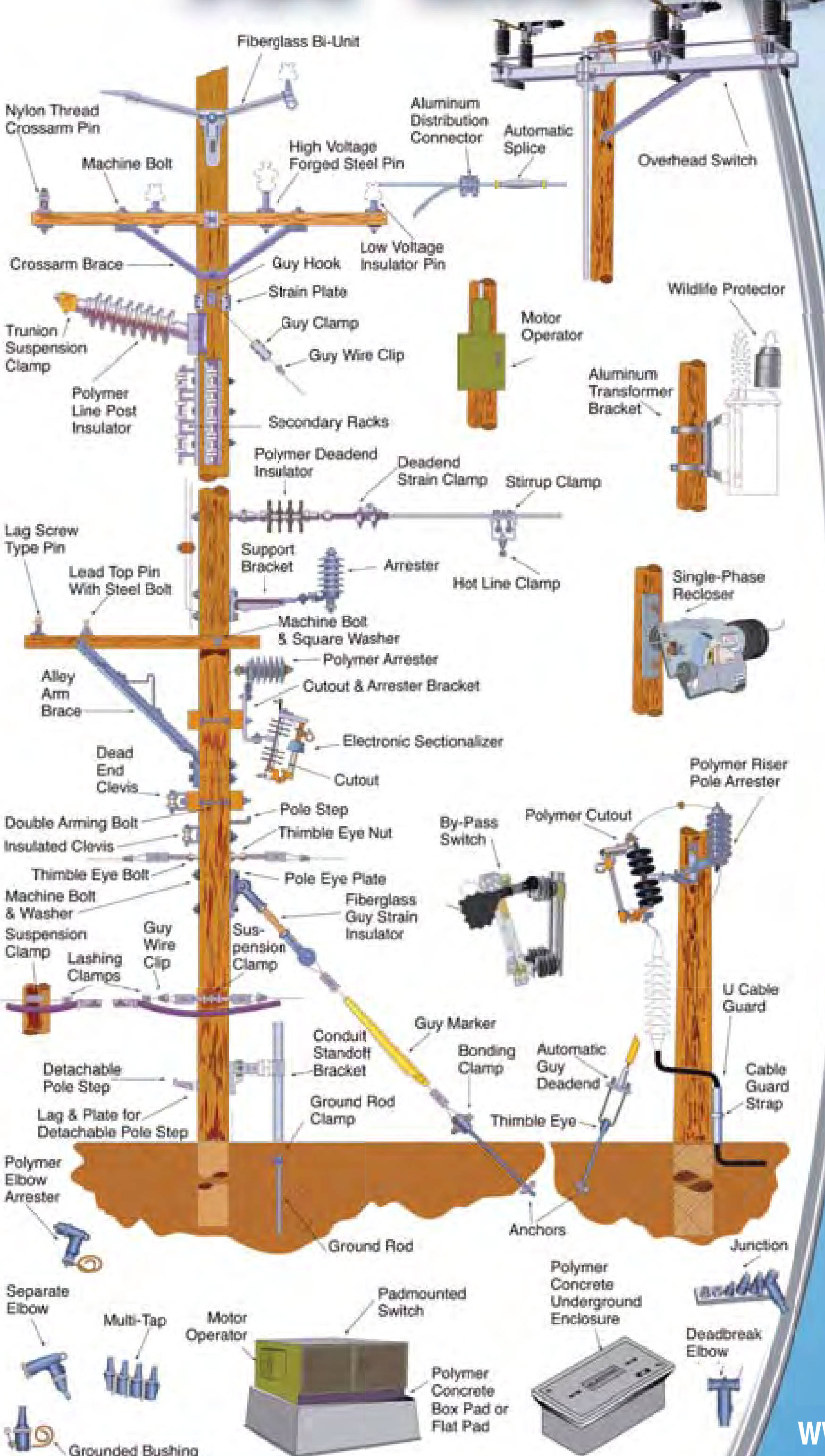



Figure 10. Changes of operational parameters for distribution system due to DR with and without coordinated Volt/Var Optimization, for one feeder, taking into account transmission losses.

**Continued on Page 36**

# Come here for distribution

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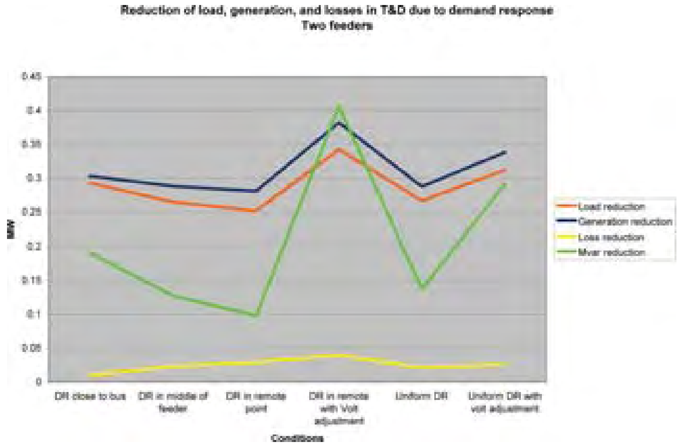


Figure 11. Changes of operational parameters for distribution system due to DR with and without coordinated Volt/Var Optimization, for two feeders, taking into account transmission losses.

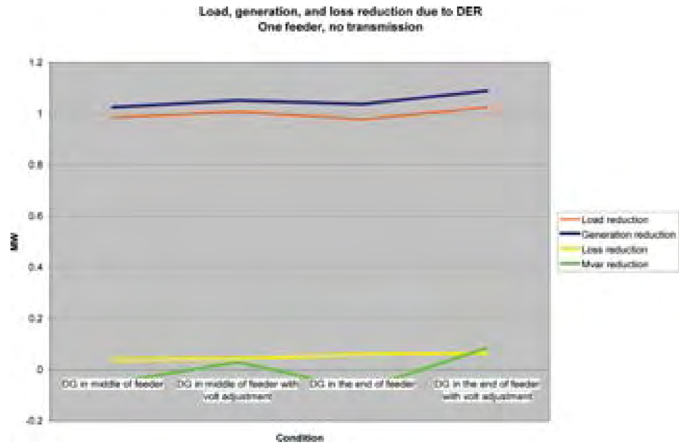


Figure 12. Changes of operational parameters for distribution system due to DER with and without coordinated Volt/Var Optimization, for one feeder.

## Demand Response

**Continued from Page 34**

Another example relates to using DR during a partial service restoration [13-14] after a fault in distribution is cleared. The example represents a case, when not all the load connected to healthy sections of the faulted feeder can be restored due to an overload of the backup feeder. When the demand



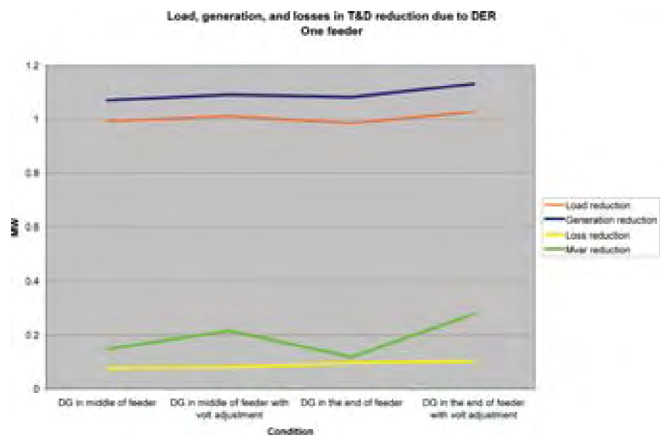


Figure 13. Changes of operational parameters for distribution system due to DER with and without coordinated Volt/Var Optimization, for one feeder, taking into account transmission losses.

response is applied to the loads of the backup feeder and to the loads of the healthy sections of the faulted feeder, all healthy sections can be restored (see Figures 17 through Figure 20). As seen in Figure 19, without applying the DR, section S16-T21 with 1173 kW should be de-energized. With DR, the section can be restored without the overload of feeder 3 (Figure 20).

The amount of load reduced by DR is 841 kW, which is smaller than the load of the de-energized section and, in addition, reducing load by DR is less intrusive than shedding load.

The difference in applying the demand response for service restoration is that the recommendations, which become a portion of the switching order, should be made for future time, for when the restoration problem is solved, and for the loads of a disconnected feeder, from which the real-time measurements may not be available.

Similarly, the Demand Response can amplify the effect of Feeder Reconfiguration application [14], for instance when the objective is elimination of overloads in distribution and trans-

**Continued on Page 38**

# Demand Response

Continued from Page 36

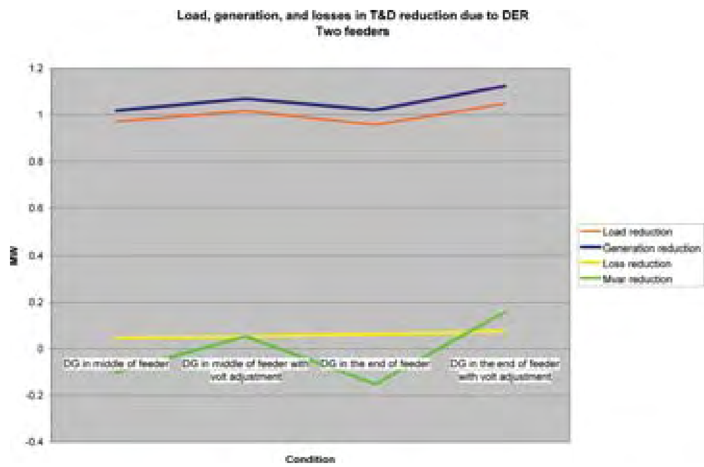


Figure 14. Changes of operational parameters for distribution system due to DER with and without coordinated Volt/Var Optimization, for two feeders, taking into account transmission losses.


Figure 15. Daily price signal for DR in p.u., where the average value is = 1.

| Parameter | Without DR | With DR | Effect of DR |
|---|---|---|---|
| Maximum load, kW | 19436 | 18255 | -1181 |
| Minimum load, kW | 9644 | 10133 | +489 |
| Most loaded segment at load peak time, A | 559 | 532 | -27 |
| Lowest voltage at load peak time, V | 115.9 | 116.6 | +0.7 |

mission systems. When the reconfiguration is limited by a voltage violation or by an overload, DR can expand the operational tolerance, and more load can be transferred from the overloaded element to other feeding buses.

CONCLUSIONS

1. The significant penetration of Demand Response means

Continued on Page 40

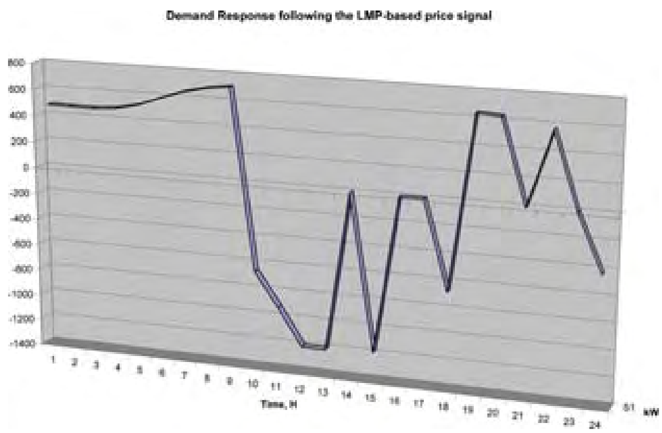


Figure 16. Change of load due to demand response

| Parameter | W/O DR and VVO | With DR, no VVO | With VVO, no DR | With VVO and DR |
|---|---|---|---|---|
| Peak load, kW | 19436 | 18255 | 19019 | 17778 |
| Load reduction, kW | | 1181 | 417 | 1658 |
| Load reduction by VVO, taking into account DR, kW/% | | | | 18255 -17778 = 477/+14% |

## Demand Response
**Continued from Page 38**

in distribution increases the uncertainty of the nodal load models. Additional sources of information for adequate load mod-

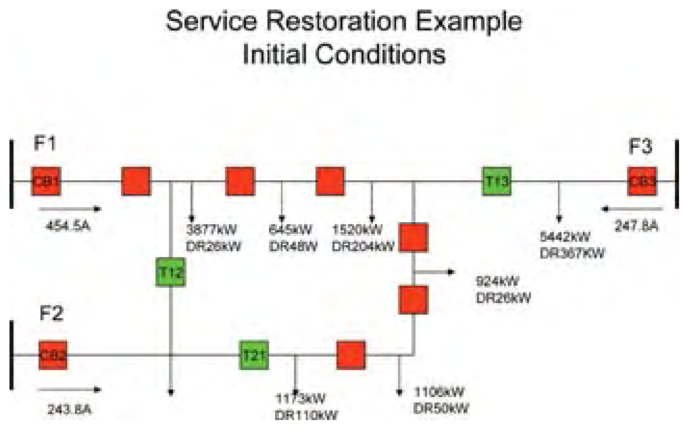


Figure 17. The example distribution circuits for illustrating the service restoration scenario.

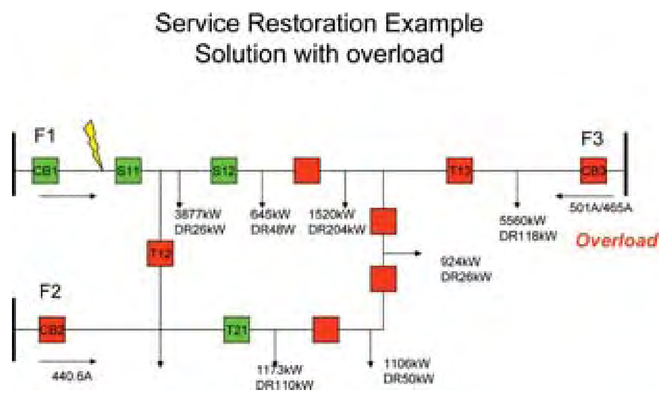


Figure 18. Topologically possible solution with an overload of feeder 3

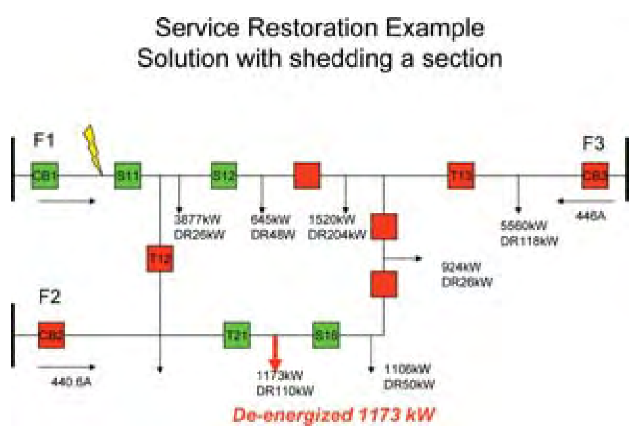


Figure 19. The solution with de-energized section S16-T21

eling are needed.

2. In order to be adequate for the near real-time monitoring and control of distribution operations, the simulation models and optimization procedures used in Distribution Automation applications should take into account the behavior of the variety of Demand Response means.

**Continued on Page 42**

## Demand Response
**Continued from Page 40**

3. Distribution Automation applications coordinated with Demand Response may provide additional benefits, e.g. the Volt/var optimization in load reduction mode may utilize the additional room for voltage reduction created by Demand Response.

4. If the Demand Response can be triggered by a DA application, when and where it is needed, it would also significantly increase the efficiency of the DA applications, as in Service Restoration or Feeder Reconfiguration cases.

5. Taking into account the impact of the integrated application of DA and DR, the location of the Demand Response means should be planned and encouraged first in areas where it can maximize the efficiency of both the DR and the DA.

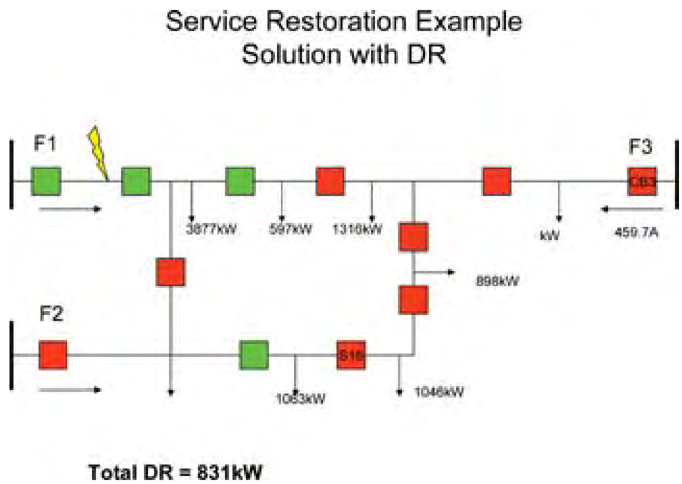


Figure 20. Solution with DR applied to the loads of faulted and backup feeders

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# HAWAIIAN ELECTRIC MAKES AMI CHOICE AFTER TWO YEARS OF TESTING

Pictured from left to right: Karl Stahlkopf – Sr VP Energy Solutions and CTO, John Stafford - Sensus Director of Sales Western Region, and Dave Waller – VP Customer Service.

Officials of Hawaiian Electric Company and Sensus Metering Systems announced a 15-year definitive agreement for mass deployment of Sensus Metering Systems' FlexNet wireless smart grid solution. The decision comes after two years of rigorous field testing of the FlexNet system, where thousands of smart electric meters were tested in a variety of settings, terrains and environments on Oahu.

Subject to Hawaii Public Utilities Commission approval of Hawaiian Electric's AMI plan, approximately 430,000 residential and commercial electric customers will be transitioned to the Sensus FlexNet smart meters between 2009 and 2015. Just 19 tower network sites throughout Oahu, Maui, and Hawaii Island will provide the advanced, two-way radio frequency ("RF") network coverage.

The FlexNet system provides Hawaiian Electric with two-way communications to Sensus' iCon smart electric meters, which enables on-demand reads, remote connect/disconnect services, notifications of outages and restoration, and remote firmware upgrades. FlexNet also establishes the platform for additional customer and utility system related benefits in the future.

These features will support new pricing and demand-response initiatives to help Hawaiian Electric customers manage their own electricity use by taking advantage of various pricing options, and programs designed to enhance energy conservation efforts.

"We have carefully evaluated the FlexNet AMI system over a series of pilot tests including meter deployment and performance, customer billing and outage management," said Dr. Karl E. Stahlkopf, Hawaiian Electric Senior Vice President Energy Solutions & Chief Technology Officer. "The results demonstrate that Sensus clearly delivers the technology solution we require for urban and rural coverage, with the power and flexibility for future advanced applications that will benefit our customers and our operations."

Stahlkopf further noted the deployment of the smart meters is a key action to help achieve the goals of the recently announced Hawaii Clean Energy Initiative agreement between Hawaiian Electric and the State of Hawaii to expand Hawaii's renewable energy portfolio and move towards a sustainable, clean energy future.

Peter Mainz, Sensus' Chief Executive Officer, noted that the Hawaiian Electric field test was accomplished amid some challenging areas. "But as a technology leader, Sensus produced reliable results. Therefore, Hawaiian Electric's decision to select FlexNet for company-wide deployment reaffirms our position as a leader in two-way AMI systems. Our partnership with the utility has also proven valuable in shaping the product and business direction for Sensus."

# ABB SHARES EMPLOYMENT OPPORTUNITIES WITH UNIVERSITY GRADS

Representatives from all five of ABB Inc's U.S. divisions met on August 26 with students who have graduated from universities across the country to profile the trove of engineering opportunities within the host of Local Business Units that comprise the five divisions.

The students, recently hired by ABB, were handpicked for ABB's "Engineering Leaders for the Future" program, and ABB division business professionals met with them at ABB's division headquarters for Power Products on Campus Drive in Raleigh, North Carolina.

"It was exhilarating to be able to introduce a global company with so much reach, and a deep product line that is evergreen, to a room of college students genuinely interested in the future of electrical energy and a rewarding work opportunity," said Kathleen Watson, who presented on behalf of ABB's Automation Products division. "Employment opportunities exist all along the ABB electrical chain — from generation through to how electricity is deployed and used inside buildings and processing facilities."

Watson is the product manager for component and machinery drives lines at the company's New Berlin, Wisconsin, drives headquarters.

"We started the program this summer to give students with an expressed interest in engineering a very concrete track from study/graduation to employment," said Noelle Heinrich, who administers the program. Over an 18-month period, graduates with mechanical, electrical or industrial engineering degrees go through three rotations across ABB's five divisions, and visit businesses located in the U.S., Canada and/or Mexico.

At the end of the program rotation, the graduates are sought by, and placed into, the divisions and countries that graduates identify as a high point of interest – and where ABB managers have identified the opportunities they want to place graduates into.

"ABB and this program are part of something larger than our individual businesses and divisions," said Heinrich. "Like all technology driven, and automation-based companies, ours needs to identify, attract and retain engineers who want to work in electrical, mechanical and/or industrial applications; this need is growing exponentially, right alongside the tremendous success and growth of this company!"

Watson joined fellow presenters from all ABB divisions; these presenters included: Kathy Doherty, vice president, Human Resources, Robotics and Power Systems; Connie Nigro, director, Human Resources, Power Products; Jonathan Bretzius, P.E., East Regional channel manager, Process Automation; and Erwin DiMalanta, business development manager, Robotics. Allen Burchett, vice president Strategic Initiatives, presented the Divisional business overview.

The global nature of ABB's business is attractive to students, according to the team of presenters.

"We try hard to communicate that the opportunities are virtually limitless," said Heinrich, "because ABB is far flung in its geographic reach, with deep local-market service to customers; so new employees can choose among opportunities that span from the oil-sand fields of Calgary, to pursuing work in one of the most deeply funded R&D centers — among all automation suppliers — in Zurich, Switzerland."

The early success of "Engineering Leaders for the Future" is creating momentum and interest, as it continues.

# NEW YORK'S STRICT NOISE REGULATIONS A PERFECT FIT FOR ABB TRANSFORMERS


An ABB ultra-low-noise transformer en route to ConEd for use in New York City. These technologically-advanced transformers do not need Sound Enclosures or Sound Panels, and satisfy New York's stringent noise regulations.

ABB has developed the technology for ultra-low-noise power transformers to help Consolidated Edison (ConEd) meet the newly enforced noise regulations of New York City, considered by many to be the toughest in the world.

The transformers are the successful result of an intensive research and development effort over a number of years by a team of ABB engineers and scientists in the United States, Sweden, and Germany. Included in the team were experts in the fields of vibrations as well as sound generation, transmission, and radiation.

The project also involved the development of appropriate measuring methods of ultra-low-noise levels at discrete frequency components, as well as appropriate trans-

**Continued on Page 48**

# Waterpower XVI

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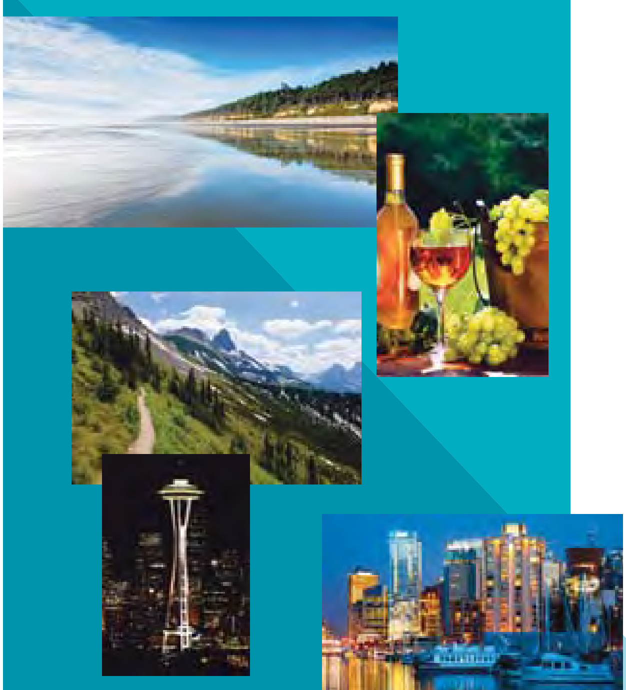

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## Noise Regulatioons

**Continued from Page 46**

former mounting. The newly developed technology has set new industry benchmarks for transformer noise emissions.

Dr. Ramsis Girgis, the leader of the development effort with ABB, said, "This achievement is a testimony that true technology advancements can only be achieved through vision, hard work, persistence and physics."

The noise requirements of these ConEd transformers are not only 20-25 decibels lower than is typical for this size of transformers, but limits were also set on the noise level of each frequency tone when the transformers are operating at full load and over-excitation.

In addition to meeting ConEd's stringent standards for noise, ABB had to ensure that the transformers meet tight limits on weight, width, and height to permit transportation in Manhattan and other areas of New York City. The transformers must also comply with technical requirements like significant overload and extremely tight limits on the range of transformer impedance.

ABB delivered the first ultra-low-noise transformer to ConEd in 2005. This transformer had to be provided with a sound enclosure. As the ABB team developed the technology further, subsequent transformers delivered to ConEd did not need a sound enclosure and, in fact, were much smaller in both size and weight. Several of these transformers have been delivered to ConEd and a number of them are already in operation. Additional transformers of even lower noise levels are scheduled for delivery late 2008, early 2009.

The ultra-low-noise transformer technology resulting from this intensive development effort is now being used to produce optimum designs for low and ultra-low-noise transformers for other noise-sensitive metropolitan areas around the world.

These accomplishments would not have been possible without the support that the ABB technical team received from many in the ABB St. Louis facility and globally. The challenge and cooperation received from the ConEd technical team, headed by Donald Chu and Harold Moore, provided exceptional commitments throughout the technology development process that were pivotal.

> Dr. Ramsis Girgis, the leader of the development effort with ABB, said, "This achievement is a testimony that true technology advancements can only be achieved through vision, hard work, persistence and physics."

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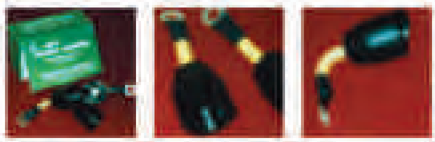

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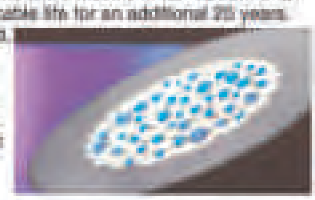

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