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ISSUE 5, 2001

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MOTOR MAINTENANCE

Minimizing the Rise of Stator Insulation Failure on Critical Motors

By Mladen Sasic, Vince Green and Hugh Zhu

High voltage insulation in the stator winding of operating motors gradually deteriorates due to electrical, mechanical, thermal, and environmental stresses. Failure of critical motors due to insulation breakdown may cause catastrophic damages to the equipment and a heavy cost for repair and loss of service. Maintenance personnel are being pressured to reduce the amount and cost of maintenance and testing efforts at large industrial plants yet increase the availability of the critical motors. Many are moving away from overly conservative preventative maintenance schedules and instead doing more condition-based and predictive maintenance. This allows them to do the right maintenance on the right equipment at the right time.

Partial discharges (PD) are a symptom and a cause of stator insulation deterioration. In-service partial discharge measurements without interrupting normal motor operation have proven to be a successful technology for monitoring the stator insulation condition to forewarn plant personnel of possible motor failures.

A high-voltage capacitor is used as a sensor to detect PD in the Partial Discharge Analysis (PDA) system. Three capacitors are installed on a motor, one on each phase. Once the capacitors are permanently installed, plant personnel can perform in-service PD testing with a portable PDA instrument. The PDA instrument captures PD pulses and sends PD data to a PC. PD analysis software running on a PC can then enable a comprehensive data analysis and provide the following graphs:

- PD Magnitude-Number distribution;
- 3-D phase-resolved PD distribution;
- PD distribution varying with load and temperature;
- Historical trending of the PD distribution over time.

The Magnitude-Number graph displays the number of pulses per second and the magnitude of the pulses for both positive and negative polarity pulses. The phase-resolved PD graph displays the phase angle position of the PD pulses relative to the 60 Hz voltage sine wave. The 3D phase-resolved graphs can help identify endwinding discharges and phase-to-phase discharges.

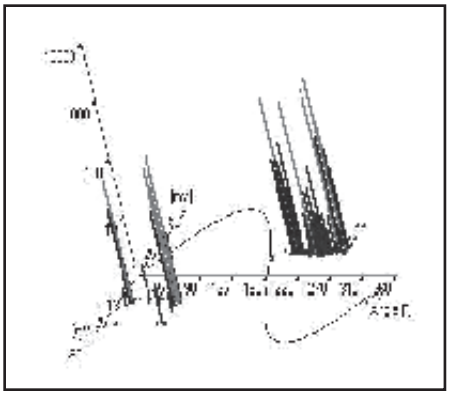

Figure 1: Partial discharge detected using 500 pF coupler

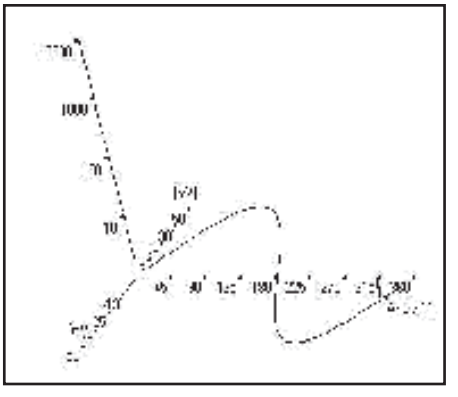

Figure 2: PD activity detected using 80 pF coupler

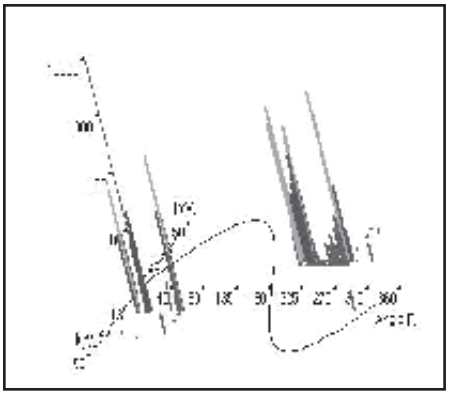

Figure 3: Second PD test using 500 pF coupler

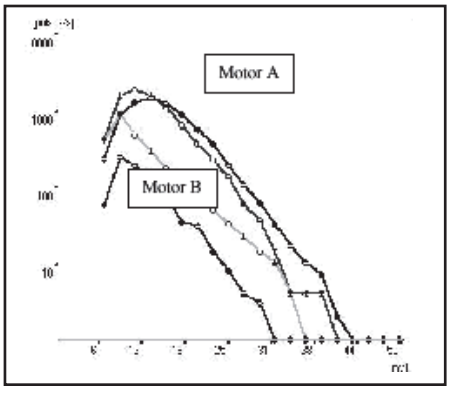

Figure 4: Camparison of PD levels on motor A and motor B

Partial discharge activity in the stator winding is often temperature dependent. When the temperature is increased in the operating motor, the conductors and insulation materials expand and tend to squeeze voids and gaps in the insulation close. Therefore, internal partial discharge activity, characterized by a predominance of negative polarity PD pulses, will decrease in the stator insulation.

PD activity in the stator winding is also frequently load dependent. One can identify winding looseness by analyzing on-line PD data to see if the PD activity varies with load. For example, a sharp increase in positive polarity PD activity from no-load and full-load is a strong indicator of a loose stator winding.

Trending analysis monitors the variation of the PD activity over time. A dramatic increase in the PD distribution pattern on the trending plot of PDA test results indicates that considerable insulation deterioration has occurred in the stator winding. The trending analysis can thus identify those motors that are more likely to have a costly stator insulation failure.

This article describes how to use in-service PD measurement technology to monitor stator insulation condition and therefore minimize the risk of stator insulation failure.

Increased Sensitivity of the PD Sensor

The detection sensitivity of the high-voltage capacitor has been improved by

Continued on page 6

Continued from page 5

increasing the capacitance value from the traditional 80 pF to 500 pF. The new 500 pF capacitors were tested on an operating motor in the field to verify their higher sensitivity.

A 6.9 kV, 6000 HP motor was rewound after 14 years of service as a boiler feed pump. After the rewind, three 500 pF epoxy-mica capacitive couplers were installed at the motor terminals. Normally, two or more capacitive couplers per phase are installed in a permanent coupling system on a rotating machine. In such configurations, each coupler pair rejects external noise using the "time-of-flight" method. On rotating machines connected to the power system by sufficient length of shielded power cable, external noise is greatly attenuated and only one coupler per phase is frequently used.

One of the PD tests using the 500 pF is shown in Figure 1. On this graph, the relationships among the PD pulse magnitude (mV), the number of pulses per second and the phase angle position of the pulse are displayed. PD activity is a voltage related phenomena and PD pulses are normally distributed between 0°-90° and 180°-270° of the AC voltage sine wave. Figure 1 indicates a typical, noise free PD test result. Five months later, three 500 pF capacitors were temporarily replaced by three 80 pF capacitors to see what effect this had on the PD data recorded. No events or repairs occurred on the motor during this period. New PD tests were made in very similar operating conditions using the same PD instrument. No partial discharge activity was recorded (see Figure 2).

The 500 pF couplers were put back on the same motor two months later. Subsequent PD tests were taken and the results are shown in Figure 3. The results showed the same level of PD activity as was recorded seven months earlier using the same 500 pF epoxy-mica couplers. Obviously, the 80 pF capacitors were not sensitive enough to detect the PD activity.

During the whole process of changing capacitive couplers from 500 pF to 80 pF and back to 500 pF, no repairs were made on the machine. All of the PD tests were performed under the same voltage and load conditions. Only the stator temperature differed slightly, but that did not cause significant change in PD readings. These PD results clearly indicate that significantly different readings were due to different capacitances of the couplers, not due to the change of the operating or

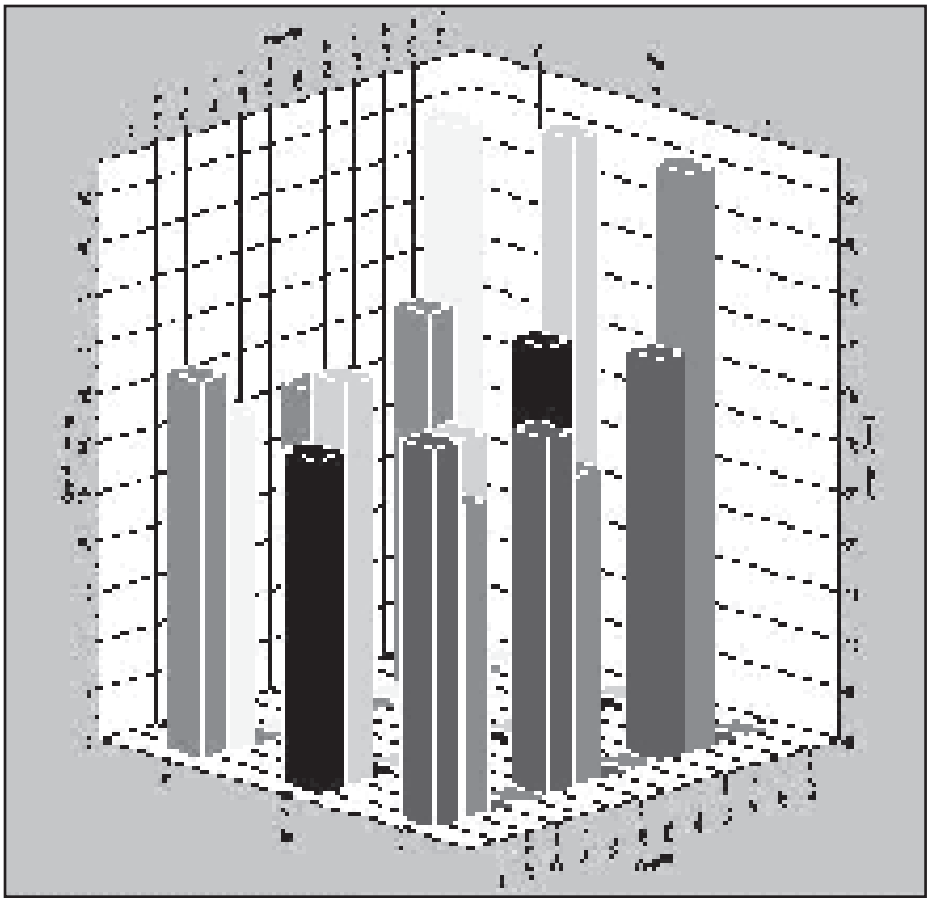

Figure 5: Stable Qmax values on motor A

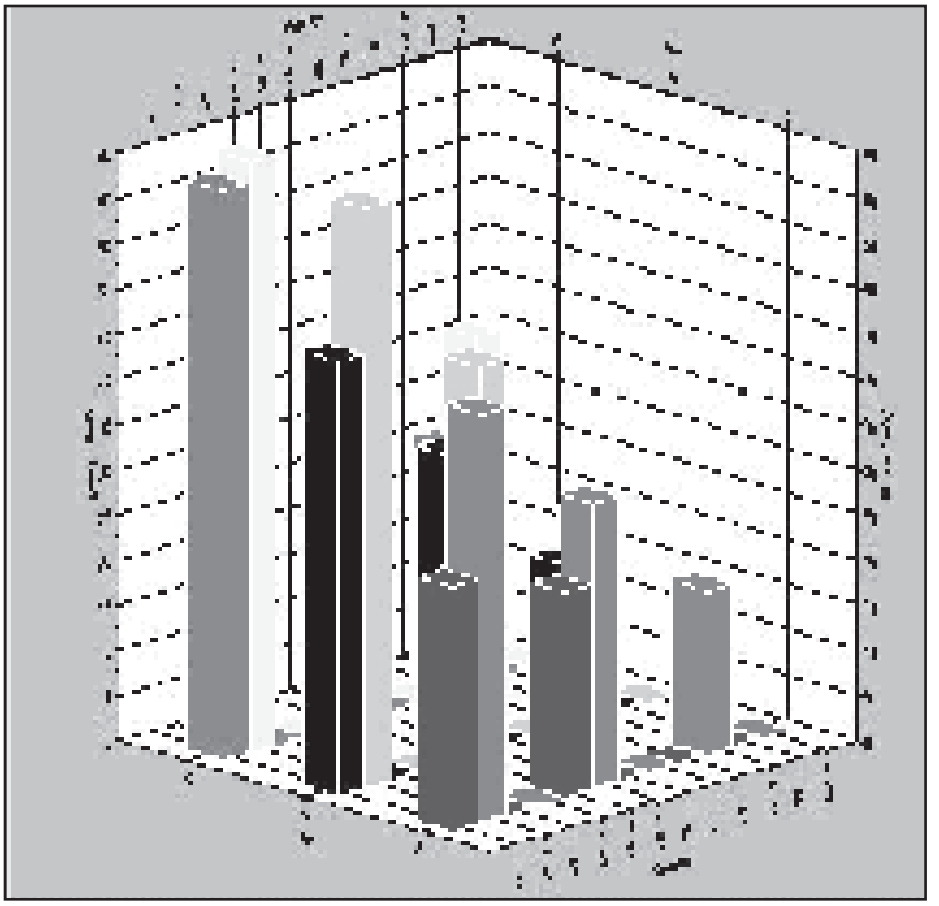

Figure 6: Steady increase over six months of Qmax values on motor B

insulation conditions.

Higher capacitance couplers provide many benefits in PD testing. They can make the difference between effectively monitoring the insulation versus waiting for failure to occur. For example, due to low sensitivity of 80 pF couplers, it was not possible to establish a trending of the PD readings at an ear1y stage of insulation degradation. To be detected by 80 pF couplers, much higher PD activity must occur. Therefore, the time between detection of higher PD activity and possible failure is dangerously shortened.

How to Assess Severe Stator Insulation Deterioration

Two quantities are frequently used in evaluating PD test results to express the PD activity in terms of a single number. The first, Normalized Quantity Number (NQN), represents the approximate area under the PD Magnitude Number distribution curve. It is roughly equal to the triangle whose sides are made up of lines indicating activity (positive or negative), x-axis (pulse amplitude) and y-axis (number of pulses per second). The second quantity, Q, is the magnitude at which the PD pulse repetition rate is at least 10 pulses per second. While the NQN and Qmax numbers are widely used, the greatest benefit of PDA measurements lies in the trending of the data. Due to the wide variety of designs and other factors (e.g. installation, maintenance and operating practices), there is no general rule or standard defining acceptable levels of PD activity for a particular machine. Therefore, users are advised to trend the PD activity, comparing results taken in similar load and temperature conditions. It is important to make all tests using the same gain (sensitivity) setting on the PDA instrument, since accuracy of the NQN calculation and the scale of the graphs will depend upon this.

Simple comparison of absolute NQN/Qmax numbers to a database of PD test results from similar conditions can be misleading in some cases. The most reliable way to assess a machine's stator insulation condition is to analyze the trend in PD measurements taken on that machine under similar operating conditions. This is the most effective method for scheduling maintenance and avoiding unexpected outages.

To effectively use the PDA testing, the user should establish base-line PD levels. This is done preferably at the start of a maintenance cycle or six months after commissioning of a new winding. The PD measurements are used thereafter to monitor the gradual deterioration of the stator winding insulation. As an example of the importance of trending, two 6.9 kV motors of the same age and design were monitored. Motor A had relatively high PD levels compared to motor B, see Figure 4.

However, motor A had stable PD readings (Figure 5), with essentially no change in a one year period while there was a noticeable increase of PD levels on motor B (Figure 6) in the same time period. In Figures 5 and 6, the height of the stack represents NQN value. Three measurement results are shown in each Figure, with positive and negative NQN values for each coupler. Comparison of Qmax (positive/negative) values for both motors is given below.

PD Test Results from Motor A and B

Test Date	Oct. 1998	Dec. 1998	March 1999
MOTOR A	62/45	56/38	65/48
MOTOR B	20/0	36/26	48/30

The rapid increase of PD activity on motor B was a strong indicator of rapid insulation deterioration. Subsequently, this motor failed in April 1999, one month after the last PDA tests above, due to a groundwall insulation failure. Motor A, with stable PD trends, is still running.

Conclusion

The 500 pF capacitors with higher sensitivity can detect more PD pulses and higher PD magnitudes sooner than 80 pF capacitors. This enables one to earlier identify insulation deterioration and to decrease likelihood of stator winding failure. The ability of a PD measurement system to detect small partial discharges enables plant engineers to monitor the insulation problems in the stator winding at an early stage.

Trending of PD activity is the best way to identify those machines that are most likely to fail. A significant increase in PD activity within a certain period of time indicates severe stator insulation deterioration. The rate of increase in PD activity is a key factor in determining the likelihood of failure.

In-service partial discharge monitoring using capacitive sensors with greater sensitivity can give an early warning of stator insulation deterioration of motors. This early warning allows maintenance engineers to monitor the progress of stator insulation deterioration and to take action based upon the actual stator insulation condition, hence minimizing the risk of motor insulation failure. Regular partial discharge monitoring of motors can also help to implement a predictive maintenance program based upon the stator insulation condition. Switching from regular time-based maintenance to condition-based maintenance/predictive maintenance can save motor users considerable maintenance costs while still minimizing the risk of failure.

Mladen Sasic, Vince Green and Hugh Zhu are with ADWEL International. ET

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TRANSMISSION AND DISTRIBUTION

Installation of Lightning Surge Arresters Helps Control Outages at Newfoundland and Labrador Hydro

By Dominic Tarascio, P.Eng.

Newfoundland and Labrador Hydro owns and operates facilities for the generation, transformation and distribution of electricity to utility, industrial and residential customers in the Province of Newfoundland.

Two of Newfoundland and Labrador Hydro's 230 kV transmission lines, TL202 and TL206, extend approximately 141 km from its major hydro electric plant at Bay D'Espoir to the Sunnyside Terminal Station. They are on separate towers, sharing the same right-of-way and spaced about 40 meters apart (center-to-center). These lines are the major transmission facilities and major source of power servicing a large portion of the power system load for the Avalon Peninsula, which includes the City of St. Johns, and surrounding vicinity.

The lines are of a lattice steel (guyed and self-supporting towers) construction and are unshielded (i.e. there is no overhead ground wire), making them particularly susceptible to lightning-caused flashovers. Both lines have experienced approximately 10 simultaneous double circuit faults along with 77 single circuit faults as a result of lightning strikes within the last 25 years. These double circuit faults are presumed to be due to large magnitude lightning currents that flashover not only the stricken circuit, but also cause a backflash of the parallel circuit due to its close proximity and grounding.

As a result of studies conducted by an external consultant, the installation of lightning surge arresters was recommended as a means to mitigate these outages and decrease the double circuit simultaneous outage rates that have plagued these lines. The Hubbell/Ohio Brass Protecta*Lite® Arrester System proved to be the answer to some very difficult questions and required results.

The required results are as follows:

- The installation of such an application must be carried out so as not to compromise the present daily operations and reliability of the line.

- A rate of one (1) double circuit outage in every 35 years is sought through the use of station class varistor blocks — 60 mm in diameter.
- The lightning arresters are to be fitted to one of the line's structures only — TL206.

A total of 365 Structures, 3 phases each, were fitted with lightning arresters over a period of just over one (1) year.

The upgrade of TL206 represented a significant technical challenge in order to meet the long-term performance improvements required. The Hubbell Team, including Hubbell Canada Inc., The Ohio Brass Company, Harris & Roome and various consultants tracked this project with great interest through various stages of investigation and analysis. The project had also been scheduled on a fast track basis requiring delivery of complete arrester assemblies in order to facilitate an April installation. The actual timeline proceeded as follows:

The first phase of the project spanned a period from February 2000 until May 2000, which included the tender review, award of project in March 2000, supply of complete arrester assemblies in April 2000 and installation completion by the first week of May 2000.

The first phase of installation included 50 per cent of the arrester assemblies that amounted to 560 assemblies.

The second phase included the timeline from November 2000 to March 2001.

Newfoundland and Labrador Hydro had to balance the cost of the solution against the desired improvement in line performance. With the assistance of the superior staff at Newfoundland and Labrador Hydro and the contracting group J&J Line Construction, all site specific installation challenges were quickly overcome, and the project proceeded within budget and to critical timelines.

The initial feedback concluded that the line had not experienced any outages through the first lightning season.

Dominic Tarascio is Manager Engineering Services for Hubbell Power Systems Canada. He can be reached at dtarasci@hubbell-canada.com. ET

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POWER QUALITY

Mystery Problems Are Often Related to Grounding

By Cathy Harris

How many times have you heard "I thought you'd already fixed that" when electrical maintenance personnel have to deal with a recurring problem? The disabled unit is repaired and all local cabling and grounding checks out, everything looks fine and works well. However, since the real cause of the failure is not uncovered, predictably, the problem reoccurs. Then the problem is tossed into the category of "bad power quality".

Mystery Problems Are Often Related to Grounding

In statistical records, we find that 80 per cent of power quality problems involve grounding. In fact, not surprisingly, it turns out that proper grounding is more important than surge protection in ensuring reliable electronic function.

The consequences of poor grounding are significant because ground is a reference for logic in any electronic device. This means that any irregularity in the ground can directly affect performance of the logic at the chip level.

In fact, a comparatively small change in ground can produce a large effect in equipment operation.

For instance, computers operate on the simple binary or "on/off" system. If logic 1 is triggered by a 5 Volt potential, then low levels of noise can confuse these signals. Even if impulses are only as high as 50V, they can do severe damage to the chip which is referenced to that ground.

Typical Grounding Problem Prevention Strategies

The reasons for grounding are several, the most important of which is providing personnel safety. The second is protecting assets, and a third is assuring equipment performance. Traditionally, three approaches to grounding have been used:

- Bond everything
- Rely on standards and specifications
- Applying isolated ground

Let's look at these options in detail.

Bonding everything involves a systematic and careful bonding of each structural point in a building, as well as each piece of equipment, cable and metallic surface. This approach was developed by Bell Laboratories (USA) in the 1950s and is still being used by the TelCo/cell industry today.

If a single point is overlooked, it can allow a ground potential to develop — circulating ground current — and problems result. Outside the TelCo industry this approach is often badly executed because it is time-consuming and therefore costly. It needs to be constantly maintained through any structural or equipment changes your facility experiences and you need to ensure that connections remain solid. Even within the Telco industry the application is often disputed especially in relation to lightning protection.

An alternative approach is to rely on standard specification codes designed for personnel safety rather than system performance. In North America this code views the main frequency to be so low that it is considered equal to DC and consequently grounding is designed on resistance only and does not allow for the requirements of high frequency impulses and noise.

The problem with this arrangement is that while it prevents injury to humans, equipment can be damaged by the smaller voltages which can build up.

However, as indicated in recent code changes, the isolated ground system remains isolated only to the first point of reference.

Unfortunately, the isolated ground approach is often misunderstood. The term 'isolated' only applies to connections between equipment and the first point of reference. The system can be enhanced by using a ground connection suitably installed between the reference point in the distribution panel and the ground reference in a separately derived source. However, this is not a requirement of an isolated ground system.

Only one of these approaches addresses all requirements

effectively and that is the isolated ground system.

How to Find the Culprit

If fixing the affected component alone does not solve the case, sleuthing is necessary. A power quality specialist will be able to gather the clues. Here are two examples of how effective detective work can lead to an inexpensive solution.

The Mystery Behind Crazy Computers Every Other Friday

A testing laboratory for a major medical service suffered repeated attacks of malfunctioning computers at regular intervals during the first few months of computer room operation. The units were fixed, parts were exchanged, and still the problem persisted. The computer service technician could not find the overriding fault until the regularity of the problem was noticed and a power quality specialist was called in. The specialist looked at the equipment, the computer room, the site facility and studied the logs. The computers were compromised every second Friday.

What was special about the schedule? The investigation revealed that on each Friday a delivery van brought supplies to the Cold Room. The Cold Room door was propped open to allow access for deliveries, the temperature rose and caused the back-up compressor to kick-in. Right next to this compressor was the "special ground wire" for the new computer room. The noise induced on this wire by the compressor was directly delivered to the isolated ground bus for the computer. The inexpensive solution was to remove the connection for this wire from the IG-ground bus and rely on the connection to the transformer bonding point.

The Case of the Flying Flag and Blown Interface Boards

A commercial equipment supply operation in a typical industrial complex was facing blown interface boards whenever a thunderstorm passed over. Surge protection was installed and did help to some extent, but the problem continued to occur. Both the head office and warehouses were located in the facility and each was rechecked by the power quality specialist. Everything appeared fine. The mystery deepened until the relationship between the storms and the flagpole in front of the building was noticed. The flagpole attracted lightning which dissipates through the earth like a wave, changing ground potential as it passes. It turned out that different parts of the computer system were connected to different parts of the building. This meant that when the wave of the lightning discharge passed under the building, severe voltage differences were created on different parts of the system. Extending the IG Receptacle System from the Computer Room to the associated equipment protected the system from lightning.

Application of appropriate technology

As we have shown, when an electrical problem occurs repeatedly for no apparent reason, it takes extra detective work to get the complete picture and to actually find the problem. It also takes informed evaluation of the strategic options to solve the problem.

If equipment exhibits recurring faults, you need to question its suitability for the application. Even the best equipment is no good if it is compromised by incorrect grounding or other system incompatibilities. Equally, the best electrician can be undermined if the analysis of conditions does not extend beyond the affected equipment. The application of inappropriate technology worsens the problem and increases costs.

For example, a power factor correction capacitor bank was installed at a facility to reduce demand costs and improve power quality. When the system was switched to adjust for changing load conditions,z the unit caused a sag and switching transience that damaged the equipment. This problem could have been avoided by choosing a better power factor filter and by installing the unit differently.

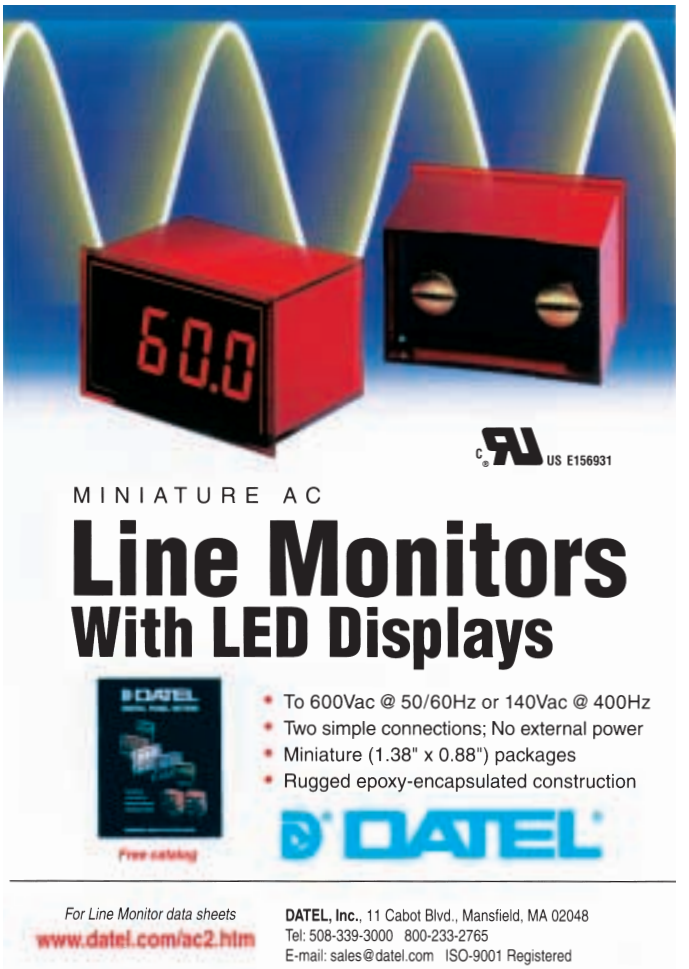
It is essential to think "outside the box" and understand the structural and procedural conditions in and outside the plant. A process of elimination should take place following a clear and complete methodology. Finally, appropriate tests should be carried out to check for impedance and other factors.

Solving the Case

Many of these mystery problems are put down to "bad power". It would be more accurate to say that our plants and facilities are more susceptible to poor power quality as they increase in technological sophistication. These kinds of power quality problems will likely increase after deregulation of the electricity market. Spikes and other interference will magnify the consequences of poor grounding.

A good power quality specialist can analyze your facility, perform proper testing and recommend the most effective solution. This need not be expensive or complex and will likely solve more than the initial problem. The results will increase reliability and reduce unscheduled downtime.

Cathy Harris is with CHH Editorial. She can be reached at 416 606 4828 or chheditorial@look.ca. ET



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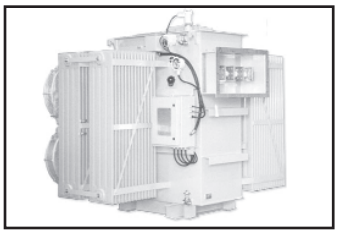

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GENERATION

The World's First Wave-Energy Generator

By John Madeley

Anyone who has ever paddled into the ocean and been knocked sideways by the power of a wave might have wondered: "If only that power could be harnessed and turned into energy".

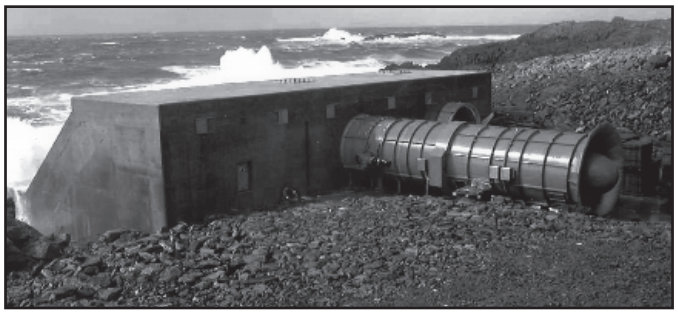
For more than five decades, engineers have had the same thought, working on plans for generating electricity from wave power. In the 1950s, for example, a company based in the United Kingdom devised a plan to harness waves off the coast of Mauritius.

But, until very recently, such schemes have remained just a good idea. Now, in a remarkable development, the ocean's waves are being tapped commercially for the first time.

From the coast of a beautiful Scottish isle, Islay, waves are being harnessed to feed the world's first commercial wave-power station. Late last year, the station successfully began to feed electricity into the UK's national grid.

Known as Limpet (short for land-installed marine-powered energy transformer), the system has been developed by an Inverness-based renewable energy company, Wavegen, and Queen's University Belfast, Northern Ireland. The European Union has helped with funding.

The Limpet device is a half-megawatt commercial wave-energy converter, providing power to the national grid with enough electricity for about 400 homes. Limpet harnesses the Atlantic Ocean waves that pound the Islay coastline with the aid of two basic devices: a collector chamber to capture the wave energy, and a turbo-generator to transform its power into electricity.



The Limpet device is a half-megawatt commercial wave-energy converter, providing power to the national grid with enough electricity for about 400 homes.

The wave-energy collector is in the form of a partially submerged shell into which sea water is free to enter and leave. External wave action causes the water level in the collector to oscillate. As the water enters or leaves, the level of water in the collector chamber rises or falls in sympathy.

The turbo generator then comes into play. This makes use of Wells turbines. "These have the unique property," said Wavegen, "of turning in the same direction regardless of which way the air is flowing across the turbine blades".

Thus, the turbines continue turning on both the rise and fall of wave levels in the collector chamber. The turbine drives the generator which converts this power into electricity. The system has been developed after 20 years of collaborative academic research, and 10 years after Queen's University Belfast (QUB) installed a small research wave-energy station on Islay in 1990. The successful operation of this plant led to the Limpet project.

Established in 1992 by Allan Thomson and Professor Alan Wells, inventor of the Wells turbine, Wavegen has pioneered the research, development and manufacture of wave power systems. The power station has secured a 15-year agreement with the major public electricity suppliers in Scotland. But the development of Limpet has much wider implications.

Oceans cover about three quarters of earth's surface and represent a vast natural energy resource in the form of waves. The World Energy Council estimates the energy that could be harvested from these oceans is the equivalent of twice the planet's electricity production.

The Limpet system is designed to operate right on the shoreline. Alternatively, units may be incorporated in rubble mounds or breakwaters to provide self-financing coastal protection schemes, providing power or potable water to communities.

The new power station in Scotland opens the door for wave power to make a serious contribution to energy supplies and help to reduce emissions of climate-changing greenhouse gases. The European Union is funding research and demonstration activities to bring renewable energy source into the energy market.

John Madeley is with London Press Service. For more

Power System Data Communication Architecture at BC Hydro

By Emile Struyk, P.Eng. and Harry Lee, P.Eng.

BC Hydro is a provincially-owned Crown corporation providing generation, transmission and distribution service to 1.5 million customers over 74,000 km of transmission and distribution lines. Generation consists of approximately 10,000 MW of hydro and 1,000 MW of gas-fired thermal generation. The BC Hydro system can be characterized as having a major load centre connected to remote generation over long series compensated EHV transmission lines.

The System Control Centre in Burnaby, BC is responsible for automatic generation control and reliability of the main 500 KV grid. The four Area Control Centres located throughout the province are responsible for the operation and maintenance procedures on the transmission, subtransmission and distribution networks in their respective areas. Only two generating plants are staffed on a 7x24 basis; all other facilities are either not attended at all or not attended for most of the week. There are about 150 Remote Terminal Units (RTU) and another 150 older remote supervisory and telemetry systems. All generating plants and major substations have separate RTUs and/or remote supervisory and telemetry systems reporting to both the System and Area Control Centres.

Almost all RTUs and older remote supervisory and telemetry systems connect to the control centres over dedicated telecommunication circuits on a one-on-one basis usually over telecommunication media owned by BC Hydro. BC Hydro has an extensive microwave telecommunication network for protective relaying, remote supervisory control and for operational voice requirements. There are also many power line carrier telecommunication links. Both the microwave and the power line carrier equipment are moving to digital technology. Some stations are not accessible by the telephone common carrier. Distribution feeder poletop RTUs use point-to-multi-point cellular radio communications.

All major stations contain digital protective relaying, digital fault recorders, sequence of events recorders or machine condition monitoring equipment which have remote dial-up access to enable operating, maintenance and planning engineers to access this equipment. Each type of equipment has its own proprietary protocol. Both corporate and third party telecommunication media are used. This arrangement is depicted in Figure 1 Typical Present Control and Data Connections. The preferred design practice for local and remote control projects is to use a LAN based local control scheme instead of the electromechanical scheme shown in the figure. The LAN uses a proprietary protocol. About 10 per cent of all stations have some form of LAN for control and/or metering.

Drivers for a Power System Data Communication Architecture (PSDCA)

The need for better utilization of power system facilities has increased significantly in the last decade and will continue, as the electric market becomes more complex and competitive. More real-time data from substations and generating plants is required to support SCADA and EMS in utility control centres. There has been a significant increase in interest by planning, operating, equipment and maintenance personnel for non real-time event and archived data. This wide interest demonstrated the need for a co-ordinated approach to accessing data by the data users. Hence, the development of a PSDCA got underway.

The need to develop PSDCA for BC Hydro was also driven by the expected growth in the use of Intelligent Electronic Devices (IEDs) with remote access capability. Moreover, there was a desire for:

- Better security methods for intranet applications than the simple passwords usually offered by manufacturers for their own devices
- Efficient use of telecommunication bandwidth — a single WAN connection to a substation can support many IEDs

Continued on page 16

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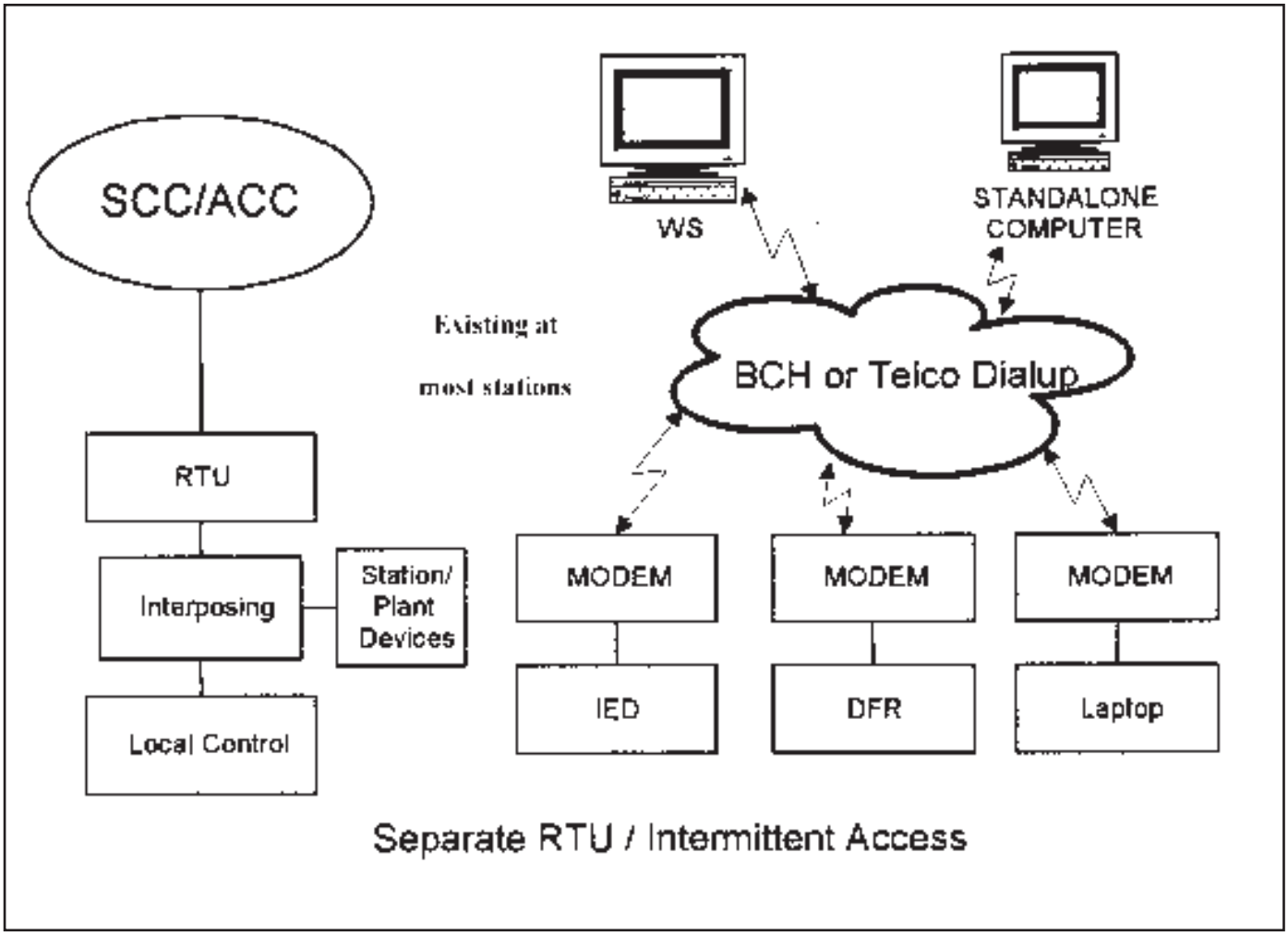

Figure 1: Typical Present Control and Data Communication Architecture (PSDCA)

Continued from page 15

- Avoiding the need for additional telecommunication links
- Corporate wide access — provide easier access to station IEDs for users who are already connected to the corporate IT WAN
- Taking advantage of network communication capability in IEDs
- Taking advantage of common standard protocols

The Study Team and Process

A team representing stakeholders in Transmission & Distribution, Power Supply (Generation) and other corporate groups was formed to develop a communication architecture to allow access to power system data. A smaller design team was charged with doing most of the detailed work in developing the architecture.

The team built on earlier efforts which identified the needs of all corporate users for power system data. A draft PSDCA report was issued in the summer of 2000.

Objectives for the New Data Communication Architecture

The design team has set the following additional goals for the architecture:

- Be comprised of commercially available components (COTS)
- Permit immediate application at new stations and allow evolutionary steps toward the goal architecture at existing stations
- Not compromise the present reliability and availability of the protection, control and SCADA functions
- Separate access to Power Supply (generation) and T&D power system data
- Support the integration of protection and control functions as hardware and software technologies evolve
- Be able to upgrade a station to the PSDCA while dealing with legacy architecture in an economical manner
- Allow flexibility in the deployment of devices for large scale station replacement as well as small scale performance improvements

The Goal Architecture

The PSDCA report made several recommendations with respect to the architecture and its components. The intent was to provide a philosophy and a vision rather than a detailed design and implementation plan. The vision is to be reviewed by 2006.

A detailed description of the proposed architecture is given below, followed by brief highlights of BC Hydro's vision for the main architecture components — LAN, RTU, communication links, etc.

The Proposed Architecture

The proposed data communication architecture accommodates the needs of two different groups of users: control centres and power system data users. The control centres require real-time data which is secure and highly available. Power system data users do not require the data in real time nor do they have the same high availability requirements.

A major feature of the architecture is

Continued on page 19

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Continued from page 16

the physical separation of the control centre and power system data links. The former will continue to be over dedicated SCADA links back to the control centre. The second will be provided over the corporate WAN. This reflects the belief that the corporate WAN may not match the present reliability offered by the SCADA control system. See Figure 2 Goal Architecture Overview.

Under the proposed architecture, there is one station LAN based on an open standard protocol such as Utility Communication Architecture Version 2.0 (UCA 2.0). This station LAN will handle all real-time and non real-time data between the IEDs, RTU and other station equipment except for hardwired signalling between protective relays.

The RTU handles all data and control signals between the station and the control centres for realtime operation of the power system. Major substations and all generating stations will still have separate RTUs to System and Area Control Centres.

The SCADA protocol will be the Distributed Network Protocol Version 3. (DNP 3.0). Station IEDs include digital protection relays, metering devices, monitoring systems and dedicated controllers. With a standard LAN protocol, such as UCA 2.0, it should be possible to connect devices from different manufacturers. The HMI can be connected directly to the LAN, to a computer or to a programmable logic controller and will be the means for local control.

A Data Acquisition System (DAS) collects, processes and stores data from the station IEDs. The DAS is the common storage for most station data that are of interest to support personnel and may be located at the station or at a more centralized location.

A key feature of the goal architecture is the use of the Virtual Private Network (VPN) or similar technology to ensure secure remote access to the DAS and to station IEDs. The use of VPN will allow the secure flow of power system data over both the corporate telecommunications facilities and third party telecommunication networks. VPN uses authentication and encryption techniques to ensure security of data access.

The one LAN concept adopted in this architecture was a change from the draft recommendation that specified two LANs. The basis for this change appears later in the section titled “One LAN or Two LANs”.

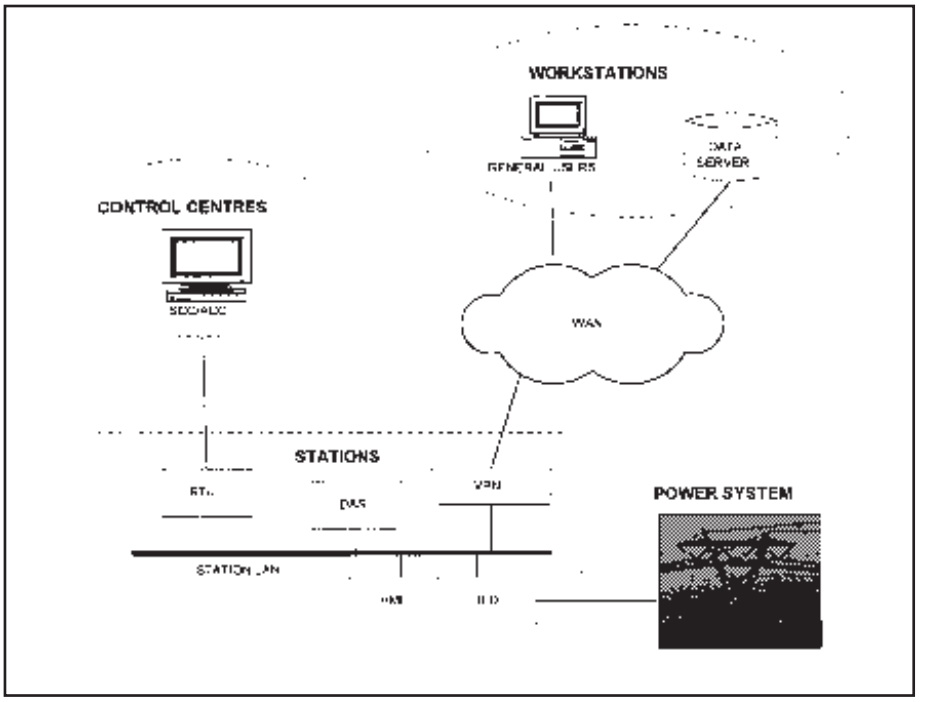

Figure 2: Goal Architecture Overview

Station LAN

The station LAN is to handle remote access of both real-time control data and non-real-time data. The real-time data supports both the local Human Machine Interface (HMI) control and the remote SCADA including all control, alarming and analog metering functions.

Signalling between protective relays will still be hardwired. UCA’s GOOSE messaging will not be implemented during the five year horizon for PSDCA.

The LAN connects IEDs, terminal servers and the Data Acquisition Systems

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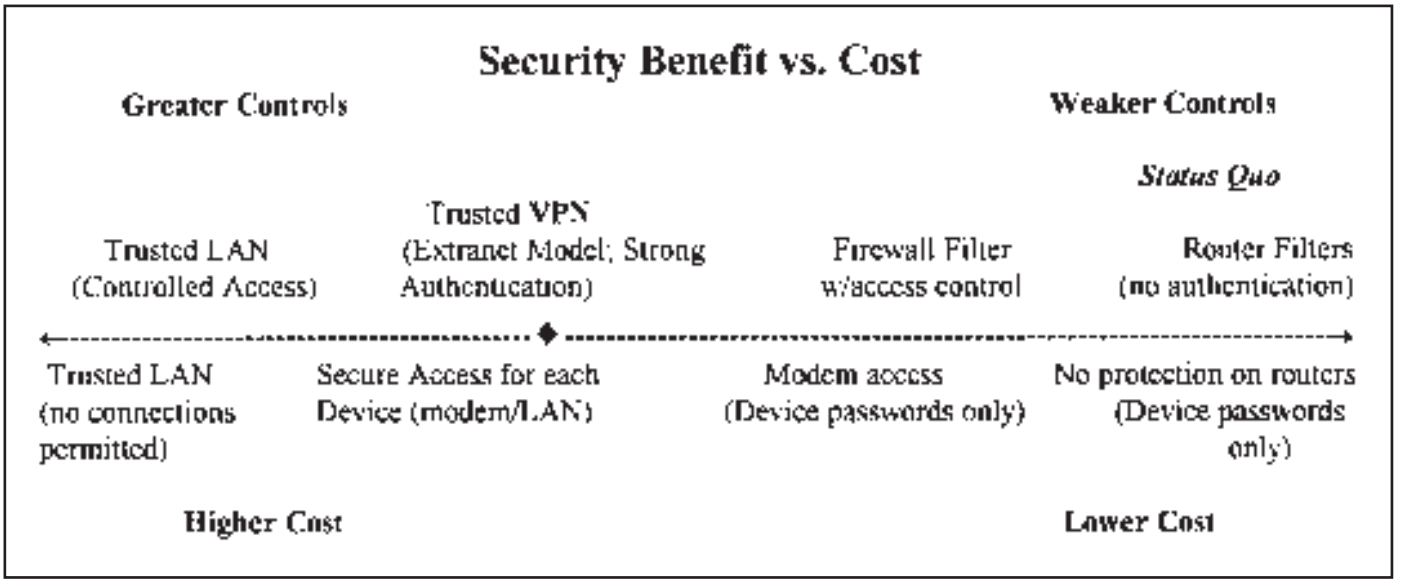

Figure 3: Security Benefit vs. Cost

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(DAS) to a secure gateway which uses the VPN technology to allow remote access only to authorized users. The LAN is to use an open standard protocol such as UCA 2.0 over ethernet. Deterministic behaviour and performance were not considered to be issues for a modem ethernet installation.

For stations equipped with a corporate business WAN, the LAN will have a continuous connection to corporate users via the VPN gateway. Regular corporate business traffic would be blocked from the LAN by the VPN. For other stations, the LAN would connect to the corporate business WAN using VPN type technology over BC Hydro and third party telecommunication facilities. The Virtual Private Network (VPN) technology is described below.

Remote Terminal Units (RTU)

Ultimately, the RTUs will probably become a protocol converter and data processor or filter between the station LAN and the SCADA master. During the transition from the present electromechanical based designs, the RTUs would take many forms as the remote control evolved from hardwired inputs and outputs to LAN-based signals to IEDs. RTUs can be single, dual or even triple ported with each port having its own unique database. Major stations will have two RTUs, each reporting to a different control centre.

SCADA Communication Links

New RTUs will use the DNP 3.0 protocol for communication to the SCADA master while the existing RTUs will continue to use BC Hydro's version of the L&G 8979 protocol. RTUs will continue to have separate dedicated 4-wire data links operating at less than 9600 bps. Except for small distribution stations or fairly expensive telecommunication links, there is no intent to consider sharing a communication link with the PSD LAN access.

Station Intelligent Electronic Devices (LED)

The goal architecture assumes an increased and extensive usage of IEDs. IEDs will be installed under various upgrade initiatives and station projects. IEDs are capable of providing protection relaying, real-time metering, stored event logs and some control capability. RTUs, programmable logic controllers, Data Acquisition Systems and communication processors are needed to collect, filter and consolidate the data of interest from the IEDs for the various users.

This processing is necessary to prevent congestion on the station LAN and the communication links. Programmable logic controllers will also be required to handle inputs and outputs and control logic which cannot be found in the IEDs. One example is substation synchronizing. Terminal servers are necessary to connect low speed RS232 type signals to the ethernet LAN as well as perform the necessary protocol conversion to legacy equipment.

Data Acquisition System (DAS)

The goal architecture supports a Data Acquisition System at the station, regional or central level. The DAS automatically collects raw data from the IEDs and other sources at the station, processes it to some extent and makes the data available to users. The focus of the DAS is the acquisition of data rather than the long-term storage of data. The DAS could be a separate computer or a station programmable logic controller that also has control capability.

Data Storage

The choice of what data is stored at the station, at the region or at a central site is dependent on the amount of data, the need for access, the number of users, the frequency of access and the telecommunication facilities that are available. Some data, such as digital fault recorder data, would be stored in the IED, i.e. the fault recorder.

It is expected that most non-real-time data would be available in station or in central data archiving systems. For ad-hoc queries, authorized users would access to the individual IED directly over the VPN rather than accessing a central database. Long term archiving of data would be done at a central location rather than at the station.

Virtual Private Network (VPN)

A key focus of the new architecture was the secure access by authorized corporate users to the station IED power system data. The goal architecture proposed the use of Virtual Private Network (VPN) over both the corporate telecommunication facilities and over third party public networks. A description of VPN appears below.

One LAN or Two LANs

In parallel and independent from the PSDCA effort, BC Hydro was perusing a Distribution Protection/Control/Monitoring initiative to upgrade a large number of distribution substations to a modem design in order to maximize the benefit of modem technology. This initiative used the draft Goal Architecture in its Request For Information from vendors. The draft architecture included two LANs in the station: one used for control and real-time data and the second used for non-real-time power system data. The responses were somewhat unexpected. The two LAN concept was interpreted in two different ways: one way requiring two physical ethernet ports on each IED connected to both LANs, and the other allowing one physical port in the IED and connection to the two LANs by means of data concentrators or multi-plexers. The PSDCA Team was requested to clarify the goal architecture.

The main issue, and perhaps the only real issue, from the team's point of view, was security of access. The concern was the intentional unauthorized attempt to access the station equipment or an inadvertent problem caused by someone with a legitimate reason to access only certain station IEDs. After some discussion within the team and with WAN and VPN experts, the goal architecture was revised to consist of a single station LAN with remote non-real-time access controlled by a security mechanism such as Virtual Private Network augmented with management procedures. The rest of the draft Goal Architecture remained unaltered.

Implementation Strategies

For the next five years, the following strategies will be followed:

- Station LAN will be implemented or expanded whenever it can be technically or strategically justified
- Continued use of the existing MODBUS Plus LAN until a new UCA 2.0 based LAN is viable
- Continued evolution of the protection and control design rather than freezing a particular design for several years
- Co-existence of new and existing LAN protocols, i.e. both UCA 2.0 and MODBUS Plus. Some stations will require a protocol converter to connect to the existing LAN
- Procure RTUs with UCA 2.0 capability as well as hard-

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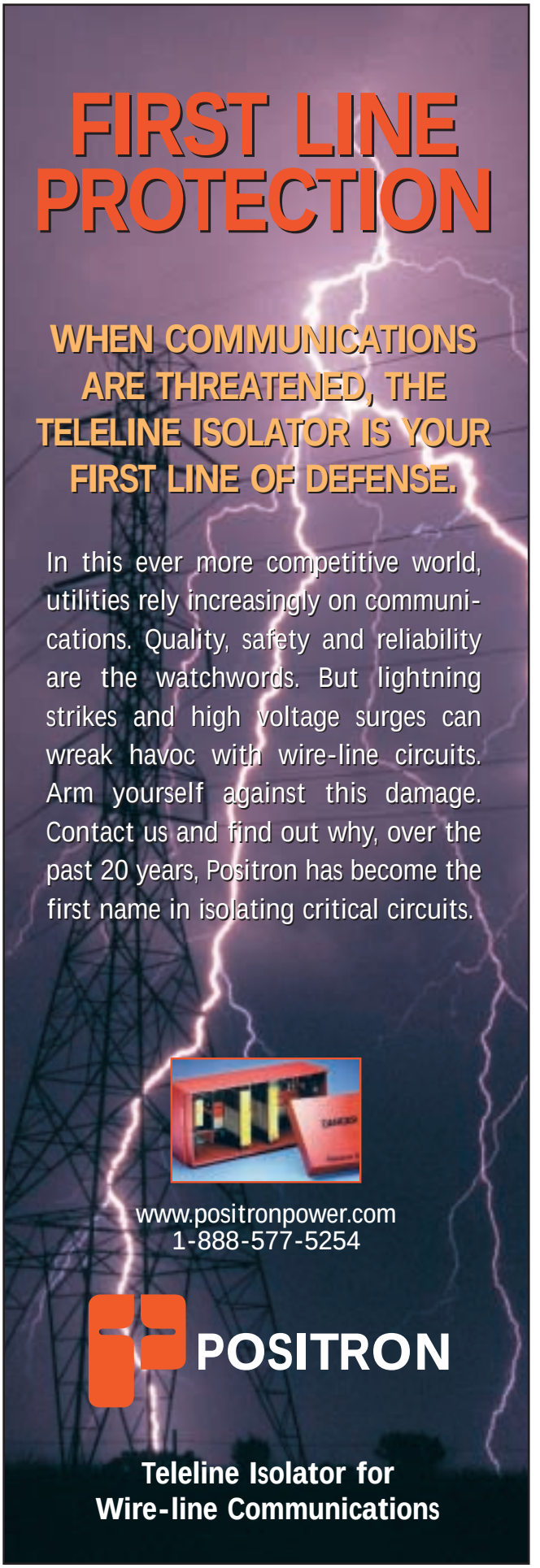

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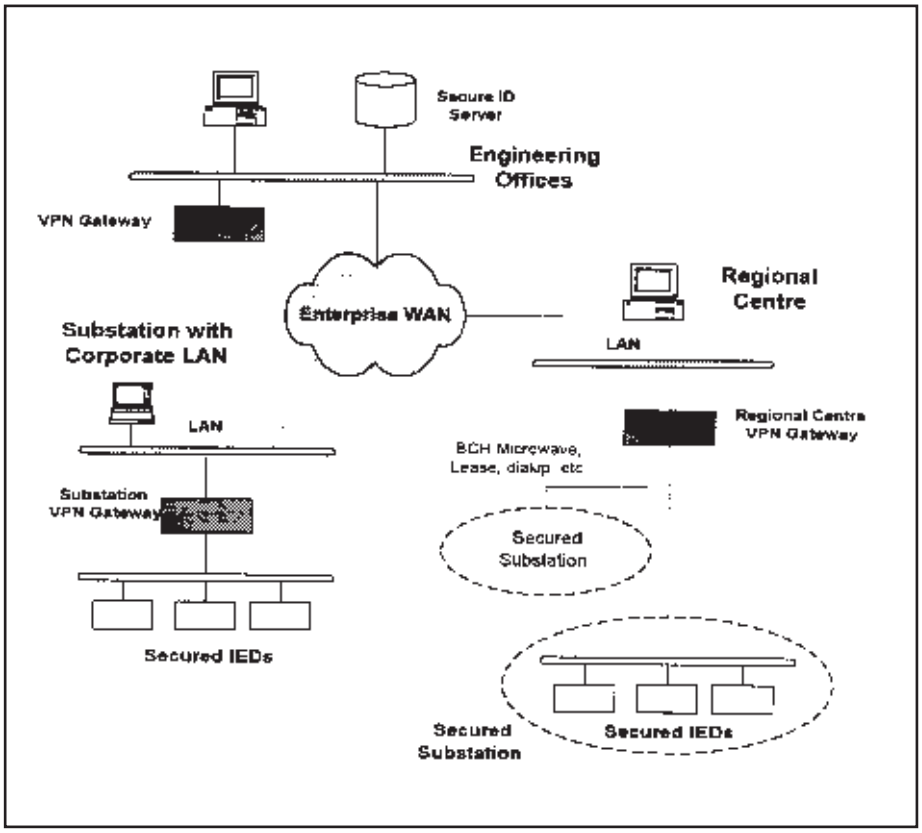

Figure 4: PSDCA - Typical VPN Deployment

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wired I/O

- Use DNP 3.0 for new station RTUs reporting to the control centre
- Use DNP 3.0 for all distribution feeder RTUs and switchgear communications
- The installation of WAN and DAS for substations will be initiated
- The installation of VPN connections will be expedited

The above strategy could result in about 45 more stations having some form of LAN implementation. Most of the metering additions and replacements will use digital relays or metering IEDs which can be connected to a LAN. The number of distribution feeder RTUs or switches could be about 100. The number of PSD LAN installations could exceed 50 over the next five years.

Progress To Date

The following projects or initiatives are underway:

- Development of a DNP 3.0 interface for the present SCADA/EMS system continues
- Proactive rollout of digital metering using LAN-based designs
- Upgrade to digital protective relays which have metering and control capabilities
- Procurement of RTUs with LAN capability continues
- Deployment of the new Distribution Protection, Control and Monitoring initiative using the Goal Architecture is in planning stage
- Scoping and estimating of the WAN and DAS for substations has started

Security and Virtual Private Network (VPN)

The security of protection, control and SCADA systems against electronic threats such as hackers, saboteurs and inadvertent actions is a key concern in the new data communication architecture. Much of the existing protection, control and monitoring equipment has simple methods for securing access such as single or two-level passwords. The complexity of providing robust secure access is generally beyond the scope of most embedded equipment designs and, as a result, most manufacturers have left it to the power companies to provide the necessary levels of security.

A network architecture that incorporates industry standards for PSDCA provides an opportunity to use existing network security systems. Some of the benefits of the Virtual Private Network

(VPN) are:

- Standard off-the-shelf solutions available from manufacturers
- Proven technology for securing networks
- Provides a transparent layer of security for IEDs
- Security can be made very robust
- Single user logon can provide access to multiple IEDs

VPN is used to connect branch offices together over the public telecommunication networks. It is also used to provide a single user broadband access to their company's Intranet. VPN gateways encrypt the trusted data and encapsulate this information within the public network's communications protocol, thus forming a virtual private data "tunnel" crossing the public network.

Other technologies are available for secure network access. Figure 3 Security Benefit vs Cost, gives an idea how VPN compares with other network security technologies.

The successful implementation of the PSDCA for corporate users relies heavily on the availability of the communications infrastructure. Over the next 5 years, the power system data network will be designed to make use of both corporate and third party facilities. For substations and generating stations served by the corporate business network, it would be convenient to install a VPN gateway at the station with all the IEDs on one side and the corporate network on the other. The VPN gateway provides the necessary logical separation between the two networks. Only a small number of stations could be handled in this fashion since these stations typically need to be reporting headquarters to justify a corporate business connection.

The majority of BC Hydro substations are not served by the corporate business network. These stations are typically unmanned. These stations will require the installation of networking infrastructure equipment such as communication lines, routers, hubs, etc. This network will probably be physically separate from the corporate business traffic to ensure a high level of security. A VPN gateway will not be required in these stations.

The communication links to these stations could terminate in a regional headquarters where the VPN gateway would interconnect to the corporate business network as shown in Figure 4. The communication links to these stations will include microwave, power line carrier, fibre, leased circuits, dial-up lines and possibly radio links.

Associated with the rollout of the VPN technology, the following guidelines or constraints will be addressed:

- Management of the VPN on a 7x24 basis: need to check the activity logs
- Authentication of authorized users
- Ensure "view only" ability to certain devices
- Still physically separate control data link
- No software downloads or change of protection relay settings

Conclusion

BC Hydro has developed a Power System Data Communication Architecture, for the next five years, to enable authorized corporate users to access station IEDs for power system data in non real-time without compromising the reliability and availability of the real-time SCADA systems.

Major upgrade initiatives are expanding the use of IEDs and RTUs communicating to control centres using DNP 3.0. Station LANs are being developed with UCA 2.0. The VPN technology will allow secure access to station IED data by corporate users. A pragmatic and evolutionary approach is being taken in deploying the new standards and designs.

The new architecture supports both control centres and corporate users being able to access their own data in a reliable and secure fashion.

Acknowledgements

The authors wish to acknowledge the support from manufacturers and utilities that responded to surveys which the PSDCA Team sent out. The responses helped put a high level of confidence in the recommendations and the goal architecture.

Emile Struyk is a Senior Engineer in the Protection and Control Planning department of T&D Engineering, BC Hydro. Harry Lee is a Senior Engineer in the Protection and Control Maintenance department of Transmission and Distribution Engineering of BC Hydro.

This article is based on a paper given at the Western Power Delivery Automation Conference. ET

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PROTECTION AND CONTROL

Integration of Recording Relays Into Disturbance Analysis

By Dave J. Fedirchuk

In the past electromechanical protective relays world, the only way to monitor and assess relay operations was by way of stand alone fault recorders. These fault recorders sometimes had mechanical methods of providing prefault information by way of rotating drums or through some sort of storage medium such as looped magnetic tapes. While somewhat crude by today's standards, these early recorders provided much insight into what took place during faults and system disturbances. As modern microprocessor power evolved in the 1980s, stand-alone recorders were able to use the power of digital data processing to provide the analytical engineer with power system voltage and current waveforms. These waveforms could then be analyzed in the electronic medium before being printed on paper. This, of course, was a tremendous step forward. Development and use of power system analysis tools such as fault, stability and electromagnetic transient programs also became more widespread. During this time the emergence of microprocessor relays occurred.

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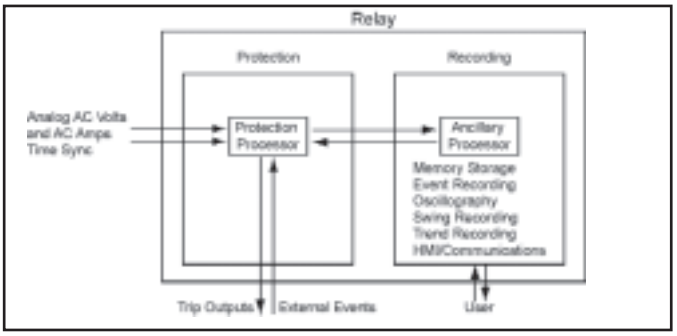

Figure 1 Recording Relay Infrastructure Example

To address power system reliability issues, the North American Electric Reliability Council (NERC) has been charged with the responsibility to see that this is achieved. It is not in the scope of this article to look at the pros and cons of NERC, other than to say that there exists some expectations by this group for power utilities to demonstrate knowledge of what their systems look like and what their performance is like during a particular type of fault or system disturbance condition.

Time Frames Associated with Power System Operation

Various events happen within various time frames. Some of these events are categorized below:

TIME FRAME	EVENT	EXAMPLE
microseconds	switching surges	breaker restrikes
milliseconds	harmonics	variable speed drives
cycles	fault clearing	relay/breaker operation
seconds	load flow changes	governor/exciter response
minutes	system stability	reaction to dispatch actions
hours	load variation	new generation schedules
days	NERC reports	system disturbance
months/years	system modeling	fault, load flow and stability

Today's Microelectronics World in the Utility Field

While it is true that many pieces of equipment are still protected by electromechanical relays, it cannot be denied that the digital world has arrived in the power industry. Processors such as the Digital Signal Processor (DSP) have a tremendous ability to perform mathematical computations for data processing and for performing protective functions. Digital technologies today are able to provide both a protection as well as a recording function in one box as a robust and technically feasible solution (See Figure 1).

Recording relays have the ability to cover recording time frames from milliseconds to hours with a sampling speed of about 100 samples per cycle. As well, this sampling rate can be averaged down to cover the power swing time domain. This

permits issues related to harmonics, faults, load flow and stability to be covered as well. There is no reason to believe that this direction will not continue as station integration of all IEDs produces technically sound and efficient solutions.

Benefits of Using Fault Recording Digital Relays

Some of the benefits of fault recording relays are:

- Cost, minimizing external connections and hardware.
- Voltage and current recorded waveforms are the same as those used by the relay's protection.
- Relay functions that operate are all part of the fault record itself. That is, fault record events are analyzed by the same software as the analog volts and amp channels.
- Relay settings at the time of the fault are easily attached to the fault record to help produce a more complete fault database.

SOME QUESTIONS ABOUT THE USE OF RECORDING RELAYS

1. What happens to the recording if the relay fails during the fault?

This question is answered with another question — what happens to protection if a relay fails? Good protective relaying design practices dictate that backup relaying needs to be provided for protection purposes. Should backup recording be such a foreign concept then? If overlapping zones of protection are used, overlapping zones of recording is certainly available. Figure 2 illustrates an example of a line distance relay covering six zones forward and reverse from its location using more or less conventional relaying logic. Since protection logic is used to initiate recording, recording can also be initiated for any fault in the 6 distance zones. In addition, protection redundancies at these busses should also provide backup protection and redundant recording.

Overlapping Recording Zones

For a fault that may occur at Bus D, the recording relay at Bus C will see the fault by using its overreaching distance functions zones 2 and 3 (21-2 and 21-3) see Figure 2). Normally these zones of protection would have time delays applied to them for backup tripping protection. These relays could however be programmed to collect fault recordings immediately upon the detection of a fault into zone 2 or 3 and in this manner make fault recordings available for faults that occur at adjacent Bus D. In a similar manner, zones 3 and 4 provide recordings for faults at Bus A, B or E.

2. What happens if the relay gets burdened with recording that slow down its protective function?

Make no mistake, a recording relay's function must be to provide protection first, and recording second. Intelligent recording relay design can use one processor such as a DSP to provide protection, then hand off recording to another on microprocessor, thus leaving protection unaffected for any system condition.

3. Data rates for relay functions are typically in the range of 4 to 16 samples per cycle. Where does good quality fault recording come from?

Again, processors such as DSPs can be made to sample analog voltage and current quantities at rates of say 100 samples per cycle, then average down this rate as required for relay algorithm

Continued on page 26

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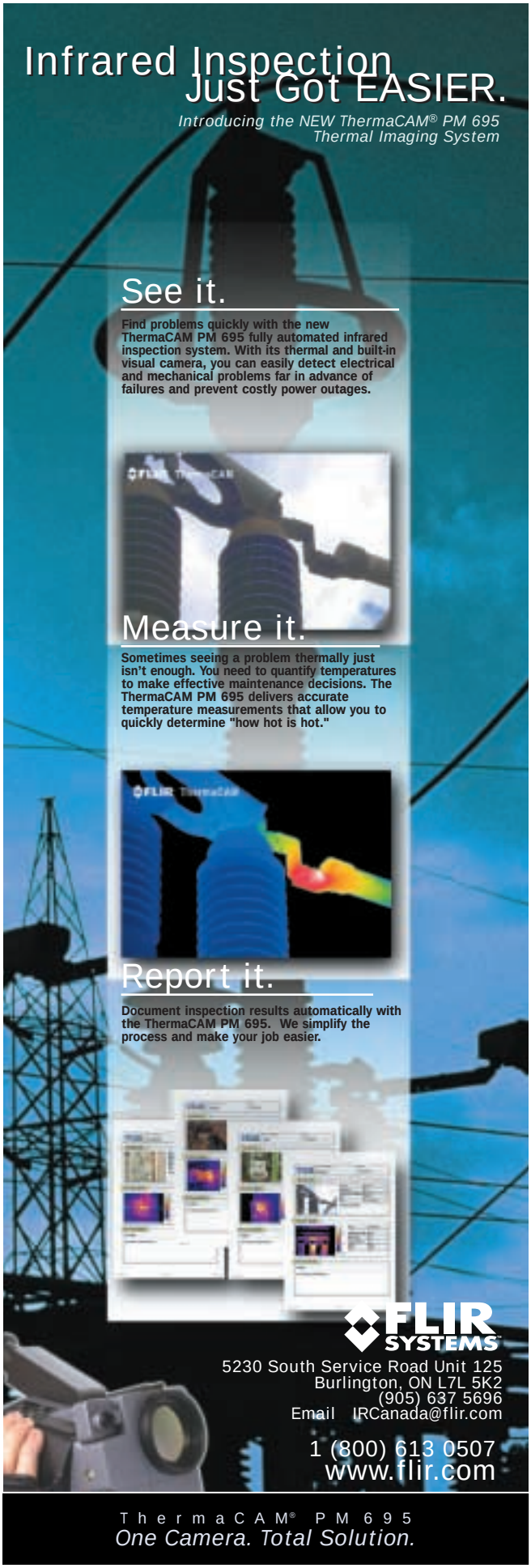

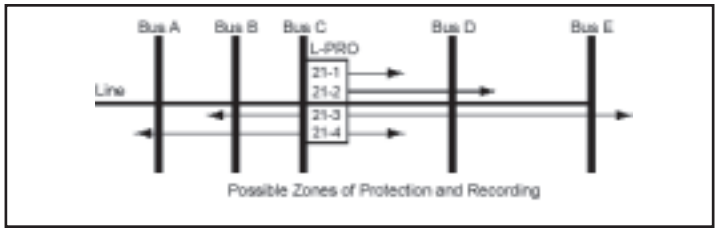

Figure 2 Possible Zones of Recording and Protection

Continued from page 25

needs — the NERC standard for recording relays is 64 s/c. Advances in memory technologies have made data storage in the relays possible.

4. What about Time Synchronization?

Most relays as well as stand-alone disturbance fault recorders are able to accept time signals such as IRIG-B to ensure accurate time resolution between events. Failure to do this with data collected by other IEDs can lead to a chicken and egg situation. Fortunately, IRIG-B is getting better and less costly for station applications.

Other Disturbance Data Sources

The presence of and the ability to collect disturbance data from recording relays is of course not the only data source. Other data sources include:

- Stand alone fault and disturbance recorders
- SCADA and RTUs
- Other relays and IEDs such as meters, controllers and special protection devices.

A Data Management Model

With all the IEDs on a power system, the first question one may ask is "Where is the information that I need?" This may seem obvious, but past experience shows that either the relevant information is buried in a heap of data or possibly failed to reach its destination for some reason. (Mr. Murphy had a theory on this!) In the building of a data management model, a healthy component of this theory can be used to improve this model.

Basic data management model questions that need to be asked:

- Who needs the information?
- How soon is the information required?
- What type of information is needed for each user?
- Where is the information needed?
- When is the information needed?

Other issues that need input in the model are:

- Where should the data be stored?
- What is the fallback position if data is not received?
- What to do with redundant data?
- How can data be integrated into a useful form?
- How is the data formatted?

A first attempt at a data integration model is shown in Figure 3. In this model, recording relays (e.g. L-PRO, T-PRO, F-PRO and B-PRO), recorders (e.g. TESLA) and other IEDs in the field col-

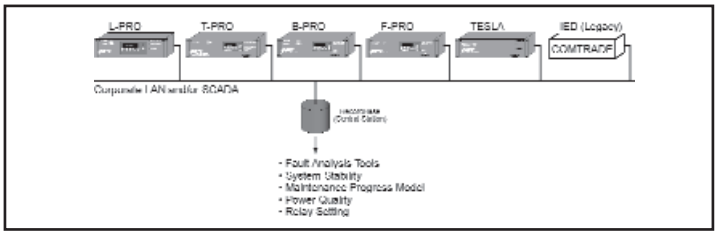

Figure 3 Data Integration Model

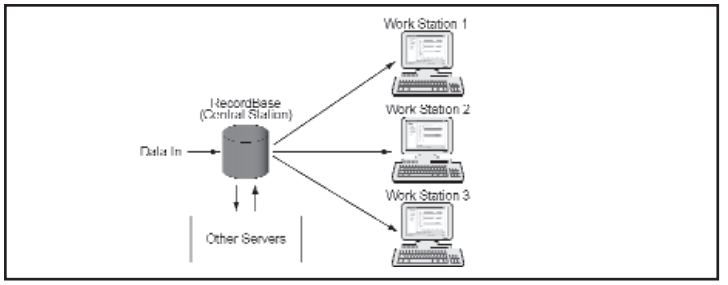

Figure 4 Central Station Makeup Example

lect data then report this data to a common Central Station (e.g. RecordBase) and/or their own collection systems.

The data from the various IEDs may be sent in the same or different formats. In order to place the data into the Central Station in a meaningful fashion, this data needs to be converted to a standard format such as COMTRADE.

Once this is done, various tasks are performed on this data. Appropriate data is absorbed into the various tasks by different data processors. For example, fault analysis can be performed by an artificial neural network or by a combination of human and software interactions. The results of this activity can either go off to other areas or can be put back into another part of the Central Station database.

In some cases, such as the need for fault location, the information may be required sooner than the Central Station information route can provide.

In these cases, the data from the relays is provided locally and through connection with systems such as SCADA to provide the information to the right people at the right time. This does not preclude the possibility of also sending information such as fault information to the Central Station for further statistical analysis.

Central Station Format

In order to provide enough flexibility in the use of data collected by the Central Station, the Central Station must be structured to allow this to take place quickly and effectively. One Central Station possibility is presented in Figure 4.

This Central Station model allows the data collected from recording relays, recorders and other IEDs to be distributed to various user workstations where data is analyzed or used by other software programs. This model also goes some distance in addressing issues such as backup data storage. In all the models for common data use, time synchronization and the ability to generate standard data forms using standards such as COMTRADE to normalize the information is important. If this cannot be achieved, then the user is forced to use several Central Station programs that make it very difficult to correlate to a given fault or disturbance. This unfortunately still happens today for far too many post-disturbance analysis activities.

Conclusion

As the need to know exactly what happens on power systems is becoming more and more important, any and all sources of fault and disturbance data will be sought and used by power system analysts and system operators. All information available for a particular disturbance will therefore be actively used.

For all faults and disturbances, it is guaranteed that one form of protective relay or another will be involved and assessed. The ability of a recording relay to provide information about the power system during these disturbances is therefore of great value in the analysis process.

Dave J. Fedirchuk is Product Manager at APT Power Technologies (a NxtPhase business). ET

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POWER QUALITY Q&A

Our Expert Offers Answers to Frequently Asked Questions About Power Quality

By David Windley, P.Eng., C.I.M.

Question:

We are purchasing a Variable Frequency Drive (VFD) for a 100 HP load in our plant. Do I have to be concerned with harmonics or other system problems?

Answer:

Yes and No. First of all, you want to be sure that you specified the correct drive. This isn't as easy as it used to be. To make the drives smaller and less costly, many items have been reduced or eliminated from the standard drive. This means that in specifying the drive, the vendor must be made aware of the exact application and take the necessary precautions to achieve a successful installation. Alternatively, an engineer experienced in drives applications should be engaged. The new drives, however, tend to reduce the amount of harmonic content reflected back into the power system resulting in less noticeable effects. Some drives do this better than others. Therefore, initial drive specification is important.

The next step is correct installation practices. Correct grounding (as always) is key to the installation. Insure that the manufacturer's installation recommendations are followed. Try to isolate the drive on a separate bus and always use an isolation transformer or line reactor to prevent the passage of transients and higher level harmonics. Keep the VFD away from buses with sensitive electronic loads. It is always wise to monitor the harmonic levels prior to installation to ensure that you don't already have harmonic problems.

Ensure the drive is installed on a stiff bus. This means one with plenty of capacity and adequately sized feeders. Drive effects will be more noticeable if the feeding transformer or cables are too small or there is poor regulation on the feeding circuit.

Avoid putting VFD's on circuits where power factor correction capacitors are installed. This could lead to some unexpected and undesirable interaction between the capacitors and the drive.

Try to limit the amount of drive load on a single transformer. Typically, if you have more than 50 per cent of the load on a transformer from VFD's, you will experience some problems.

In severe cases, drives can be ordered with an AFE (or active front end) which will modify the waveform through active filtering techniques. However, this is usually done for larger drives, as it generally doubles the cost of the drive.

Attention to the above guidelines will reduce the effects of any potential harmonic or transient problems.

Question:

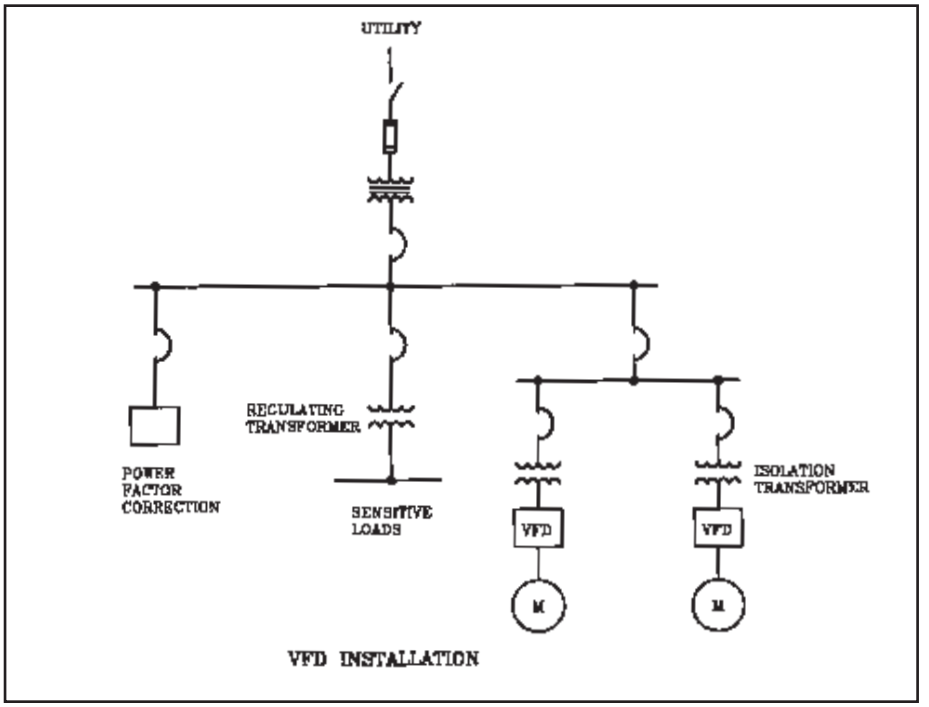
I need an uninterruptable power system (UPS) for a computer system that we are installing. How big does it need to be and are there any installation issues of which I should be aware?

Answer:

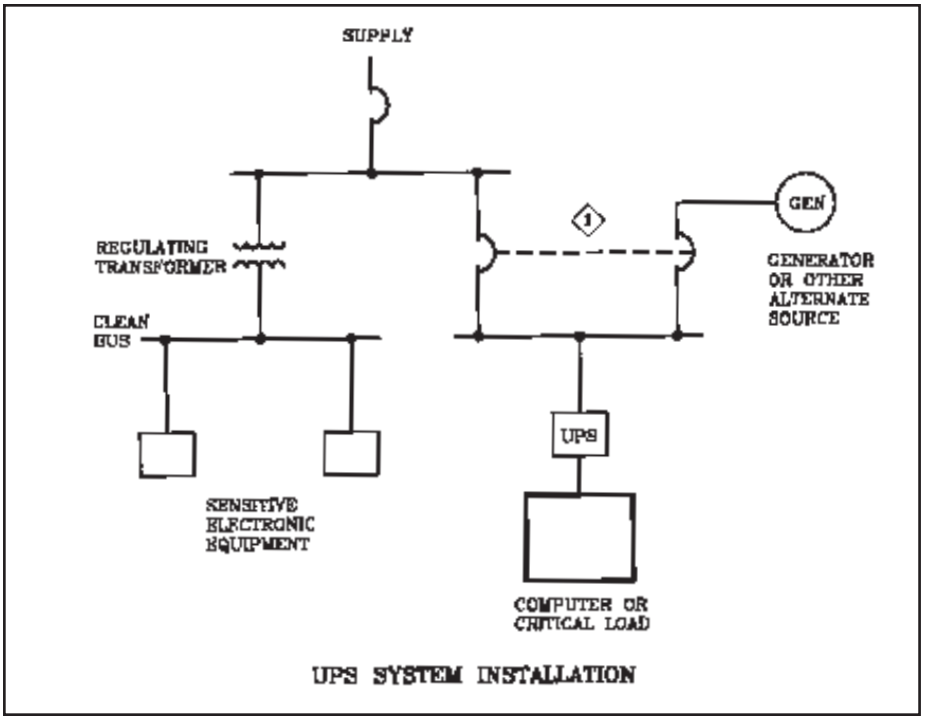
The primary purpose for a UPS system is to ride through short power interruptions and protect the memory and data located within a computer. It can also be used to provide a continuous power source for critical equipment or provide a clean power source for sensitive electronic equipment.

The size of the UPS must be large enough to handle the equipment load and yet be capable of supplying the extra current necessary for equipment starting inrushes. This is generally specified in VA or kVA. Use equipment nameplates or specification data to determine the necessary size. Check with the manufacturer for any inrush requirements. Allow more capacity than you think you need.

When it comes to specifying the battery capacity, consider the length of time it is necessary to keep the equipment running. If life critical equipment is involved, the battery capacity must last until the source is restored or an alternate source is switched on. Normally with a computer, we are looking at keeping the equipment running only long enough to save the necessary data and perform an orderly shutdown. In many



VFD INSTALLATION



UPS SYSTEM INSTALLATION

cases, major plant or facility equipment will also go down, debilitating normal operation anyway.

Battery sets are generally specified in ampere-hours. This is a nominal term and actual performance will depend on the actual load conditions. If in doubt allow extra. This is an important decision as not only the length of time the equipment runs is affected, but as the amount of battery capacity goes up, the cost of the system significantly increases.

One of the installation issues which is not always understood is how the UPS should be connected to the power system. As the UPS involves an AC/DC conversion, it will inherently generate noise and harmonics in its supply. Therefore, we do not want to connect it to an existing clean supply, as it will corrupt it. The best place to install it is in a relatively stable and reliable bus where there are no sensitive electronic devices connected.

David is the President of Wintek Engineering. You can forward your questions or comments to him at wintek@wintek-eng.com. Some of these questions will be addressed in future issues of Electricity Today . ET

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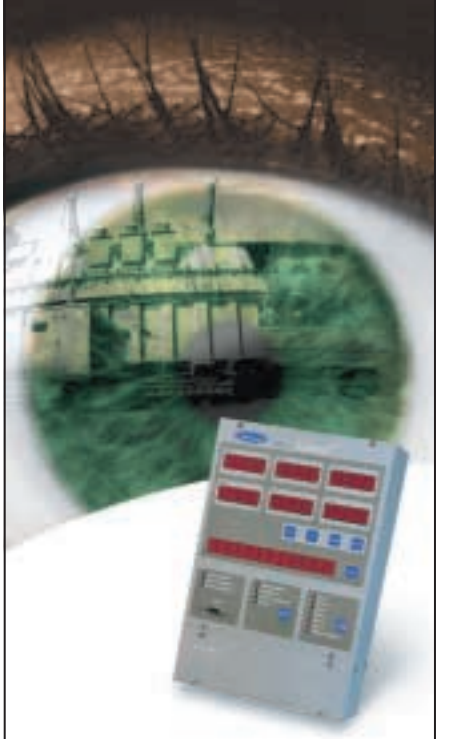

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TRANSFORMER DESIGN

The Transformer:

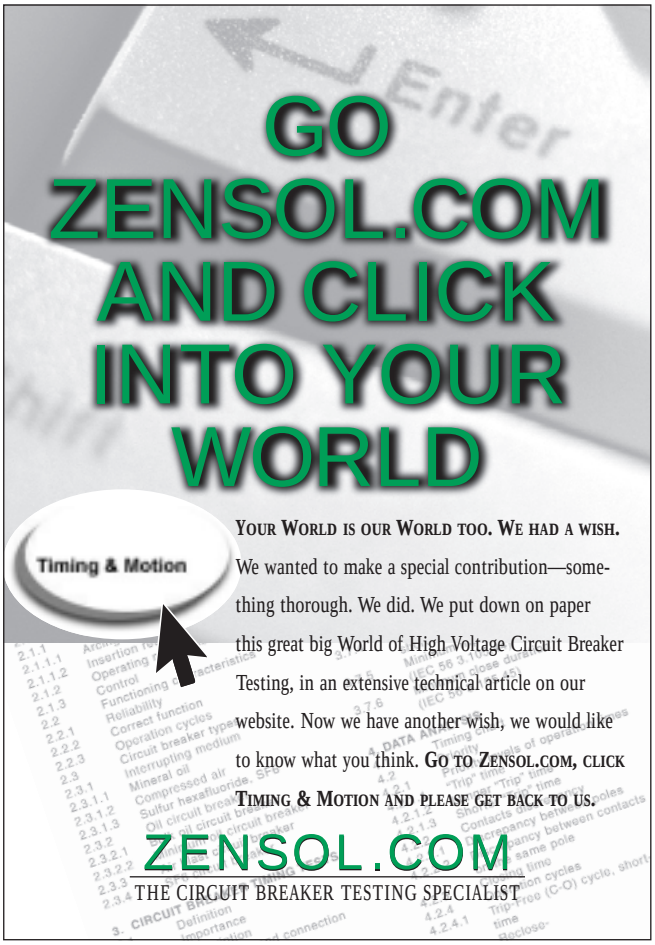
A Tried and Tested Product, But With Scope for Development

By Anders Lindroth

The transformer is a product that is more than one hundred years old. Many of the basic functions and solutions remain the same after all these years, in spite of the fact that transformers have undergone a comprehensive development process. One could therefore assume that most things that could be done have already been done; but still there is extensive ongoing R&D being conducted at a highly theoretical level. This research is looking at new materials for insulation, methods for condition monitoring and diagnostics, noise elimination, environmental impact and the possibilities of using superconductive materials.

Intensive search for New insulation Materials

The oil and cellulose material known as pressboard has been used in the insulation of transformers for one hundred years. Experience has shown that it works well, and over the years both the material and the methods have been refined.



Pressboard has, however, one obvious disadvantage: its good electrical properties drastically deteriorate if the material is damp. This means it must be dry. There must be a drying process during the production of the transformer, and during the erection work in the field — the ingress of air must be limited to the absolute minimum, especially if the air is damp.

To avoid difficulties caused by sensitivity to moisture, we are researching other materials. To merely carry out tests with some plastic material and maintain that it works well in the lab, is not the way forward. The strength of pressboard is that we know that it can actually function over a long period of time — 50 years is nothing unusual. To be sure that any new material will function for such a long time, there are two alternatives: either we must test the material over a very long period; or, amass a sufficient amount of theoretical knowledge to assure us that the new material really will function for the required number of years.

Naturally our primary aim is to increase our theoretical understanding of what happens inside a transformer. One route, for example, is to increase our understanding of the physical processes that occur in connection with a flashover, and how this is influenced by the materials present.

A new material should have the following properties:

- It must be resistant to electrical breakdown.
- Electrical flash-over must not slide along the materials surface (which it can do with pressboard).
- It must be homogeneous.
- The material must be mechanically stable.
- It must not be affected by or affect the oil.

In order to verify all these properties, it is also necessary to construct full-scale models.

Right now we are in the process of constructing a full-scale model with a new material. There remain, however, many questions that we have to find answers to. The knowledge gained from working with pressboard, e.g. when it comes to dimensioning, is to a large extent empirical and can therefore not be directly applied to other materials.

Condition Monitoring Helps the Customers Make Decisions

The material that could eventually be used to replace pressboard is unlikely to be any cheaper to buy. It could, on the other hand, contribute to lowering total costs if you can dispense with drying, and perhaps the dimensioning can be changed. In addition, better aging properties can hopefully prolong active life.

An important means for our customers to save money is to make the right investments at the right point in time — and thereby of course also avoid making unnecessary investments.

In general, it is estimated that a transformer will last for 25 years. At the same time, we know that some last for 50 years

and more. In this respect it is of interest to develop techniques for condition monitoring and diagnostics.

Privatization and deregulation of the power industry in many countries has changed the demands placed on the equipment. When everything was under the control of national power companies, the demands on the reliability of individual components were less. Then, problems at one location could be compensated for by taking power from somewhere else until the problem had been remedied. A smaller power producer who has undertaken to supply power to a major industry has no such options. Cuts in power supply cannot be compensated for and therefore must not occur.

Traditionally, the condition monitoring of power transformers takes place through keeping a check on temperature and oil levels, along with regular maintenance of the tap changer. In addition, oil samples are often taken once a year for gas analysis, to check that no problems are in the process of developing. Increased demands on non-stop supply also mean demands for early warning of incipient problems.

To meet these demands, we are now developing a gas detector for online use, which can detect several gases. We are also developing a detector that can trace partial discharge, which can be the first sign of a fault developing. To handle all the information provided by condition monitoring, a data collection unit with an accompanying communications system is also being developed, to enable information from different installations to be collected in a central control room.

When an indication comes in that something is not as it should be, it's a matter of being able to make the right diagnosis. This is going to demand considerably more advanced, and therefore more costly, equipment; it will not be possible to install this in the field, but it should be possible to take it out to the site if necessary.

A detailed gas analysis can give information about what is happening, but not where it is happening. Partial discharges emit sounds in a range of frequencies which can normally not be detected by the human ear. This is utilised so that, with the help of special microphones, placed in a certain way, the distance and direction of the sound can be located.

Over and above the information obtained through measurements, diagnostics is to a very large extent built on experience. In order to make all our collected experience available, we have started to incorporate it into knowledge-based diagnostic systems.

As a part of the general heightened environmental awareness, demand for quieter installations has increased. There are two ways of tackling the problem of unwanted noise. You can either muffle the existing noise or eliminate the cause.

If you want to deaden noise the simplest way is to case it in. A more advanced method of suppressing noise is to record and analyze the noise and then transmit the same noise, but offset in phase, so that the sound waves eliminate each other.

It is best however, in most cases, to start by tackling the problem at source, primarily through increasing our understanding of sound generation. In addition, the noise generated is often amplified by resonance phenomena. Such phenomena can be eliminated through construction, if dimensions that give resonance with the sounds that are generated are avoided.

So, that we can get a perspective on our products' environmental impact and prepare ourselves for possible future demands from the authorities and the world around, we have started to work with life cycle analysis. Such analyses indicate there is one factor in the transformer that exceeds all others by a very large margin. That is the energy loss during operation.

Superconductors and High-Voltage Direct Current in the Future

Suppose that one of our transformers has an efficiency of 99.7 per cent. If you work out how much energy this loss of 0.3 per cent corresponds to per year, and subsequently during the entire lifetime of the transformer, then we are talking about huge amounts of energy. The transformer's total environmental impact, then, is largely governed by the environmental impact of the electrical power producing installations.

The biggest contribution we can make to helping the environment is to improve the transformers' efficiency, which is a matter we are addressing.

If one wants to look further into the future, then there could be more dramatic innovations. One of them, of course, is the use of superconductive materials. Superconductors could give us smaller transformers and transformers able to effectively handle high frequencies at a low voltage.

This development has, however, not proceeded as rapidly as many hoped when the first discoveries were made. While it has been possible to discover materials that are superconductive at "high" temperatures i.e. temperatures over -70 degrees C, these materials are extremely expensive.

But there are still possible advantages to be gained with superconductors, so we are continuing to work with these materials. We have constructed one prototype and are about to start constructing a second.

There are signs that the transformers of the future will be of a totally different type than today. Some believe that alternating current will turn out to be a parenthesis in history, albeit a long one. If the energy of the future is to come from solar power stations in the Sahara, one might as well keep it as direct current. Already now it is cheaper to transport energy long distances as high-voltage direct current, and for most uses direct current is as good as alternating current. In those cases where alternating current is necessary, for example in motors, 50 Hz is in any case seldom ideal.

It will take a few decades before the time comes to scrap alternating current. Until then, we will continue to develop the management of it just as far as it is possible to go.

Anders Lindroth is General Manager, Transformer Technology Division, ABB, Ludvika, Sweden. ET

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TRANSFORMER DESIGN

The Performance Advantages of Circular Windings

By Subhas Sarkar, MSEE, P.Eng., Sr. Member IEEE

Staying at the leading edge of technology in the transformer industry requires a complete understanding of the major advantages of circular windings over rectangular windings. To develop a proper evaluation of why circular windings are better than rectangular windings, Virginia Transformer Corporation has examined the nature of forces generated in windings and how each of these two types of windings copes with these forces. Circular windings can be a major asset to transformer owners when they are developing specifications for transformers above 5000 KVA. The following simplistic explanation can help to educate transformer purchasers as to the advantages.

Under the short circuit, the rectangular coil design transformer will undergo substantial geometry changes in the coil shape leading to coil/insulation damage because it wants to become circular. The impedance change is up to 7.5 per cent. The circular coil on the other hand remains circular, the natural shape and suffers no change in geometry and impedance.

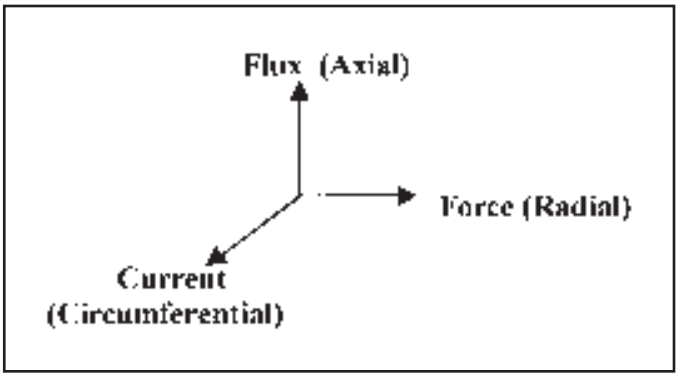

Figure 1: Direction of forces generated due to interaction of Flux and Current

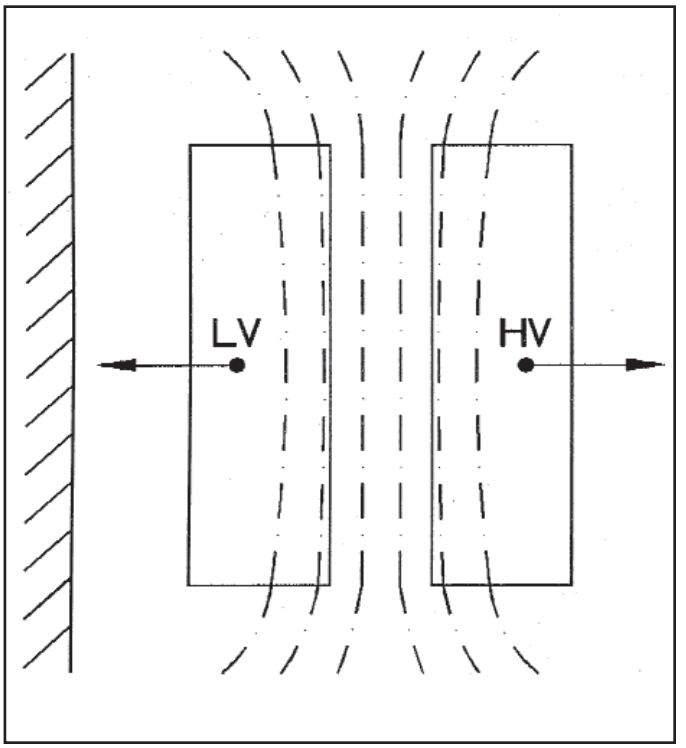

Figure 2: Leakage Flux Pattern and Direction of Forces Acting on HV and LV

How Forces are Generated in Transformer Windings

When the windings of transformer carry current, a leakage flux field is produced between the concentric windings (i.e. high voltage and low voltage windings). The principal component of the leakage flux is axial.

The current carried by the winding conductors (circumferential direction) interact with the leakage flux and produces forces.

Radial Forces

The nature of the leakage flux is such that it is mostly in the axial direction (except in the ends of the windings) and hence the maximum radial force occurs around the mid-height of the coils. Radial forces act outward on the outer winding and inward on the inner winding (Fig 2).

Axial Forces

Near the ends of the windings, a large part of the leakage flux bends towards the core leg and thereby causes a radial component of the flux. The interaction of this radial component of flux with the winding current produces axial forces that tend to compress (or telescope) the winding conductors along the vertical axis.

In short, there are both radial forces and axial forces generated in a transformer winding.

Short-Circuit Conditions Result in Very Large Forces

During the short circuit condition, large amount of currents flow through the windings. The forces generated in a transformer subject to short circuit conditions are magnified many times more compared to those under normal operating conditions.

For example, a transformer with 6 percent of leakage impedance will carry 16 times the rated current during short circuit and this will result in forces more than 250 times those under normal operating conditions. Also, the peak forces are much higher than the RMS forces. As an example, the radial forces in a 10 MVA transformer can exceed 100,000 lbs.

Circular Windings remain Circular under Short-Circuit — No Change in the Geometry

In circular coils any radial forces tend to be distributed uniformly along the circumference of the coil. In circular windings the radial forces are resisted by the strength of the winding conductors, and in some cases the low-voltage wind-

Continued on page 34)

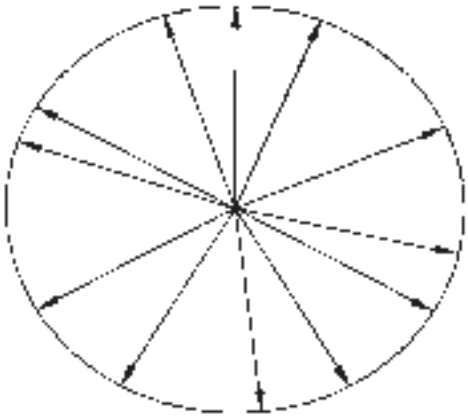

Figure 3

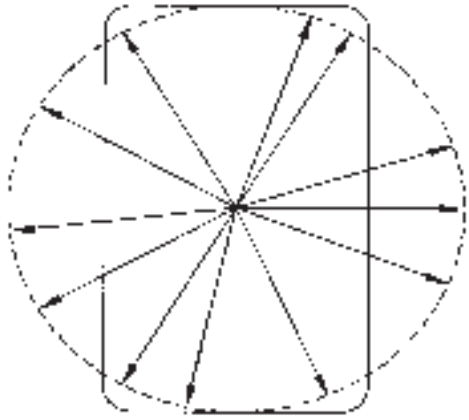

Figure 4

Figure 3 illustrates that a circular winding remains circular and Figure 4 illustrates that a rectangular wire tends to become circular.

Continued from page 33

ing tubes. The axial forces are resisted by the stiffness of the radial spacers and the beam strength of the conductors.

In circular coils the forces are limited to that particular phase coil and are borne by the coil itself, which is suitably designed to withstand the forces on its own strength. There is no change in the performance of the coils. The impedance changes during short circuit test is typically 1 per cent or less.

Rectangular Windings Try to Become Circular

The forces generated in the rectangular coil transformers are very similar to those in circular coil transformers. The radial forces tend to separate the inner winding from the outer winding. The inner winding tries to crush inwards. The outer winding tries to arch or bow away from the flat surfaces of the inner winding and the high-low gap.

Under radial forces, the rectangular windings tend to become circular (see Fig 4). This results in substantial change in geometry and the impedance.

For rectangular coils, the radial forces tend to concentrate at the corners of the coil and cause greater stresses in those regions.

By restraining the outer winding (mechanically) from moving, the forces on the inner winding greatly increased. If the inner winding happens to be a sheet winding, it tries to get displaced towards the corners.

The phase-to-phase gaps between rectangular coils are sometimes packed to restrain movement of coils in that area. Unfortunately, under such arrangement, the forces generated by one coil are passed on to the adjacent phase coil and hence the forces are compounded. The insulation may be damaged (coil failure) due to the mechanical restraint on windings/coils.

Change in High-Low Gap in Rectangular Winding

The short circuit forces in the rectangular windings tend to separate the windings and consequently increase the high-low gap. This increase results in variation of impedance. The standards allow 7Ω per cent variation of impedance after the short circuit test. In other words, a transformer will be deemed 'passed' if the variation is within 7Ω per cent.

In this section we shall show that the actual change in the high-low gap is nearly 20 per cent when the overall change is 7Ω per cent.

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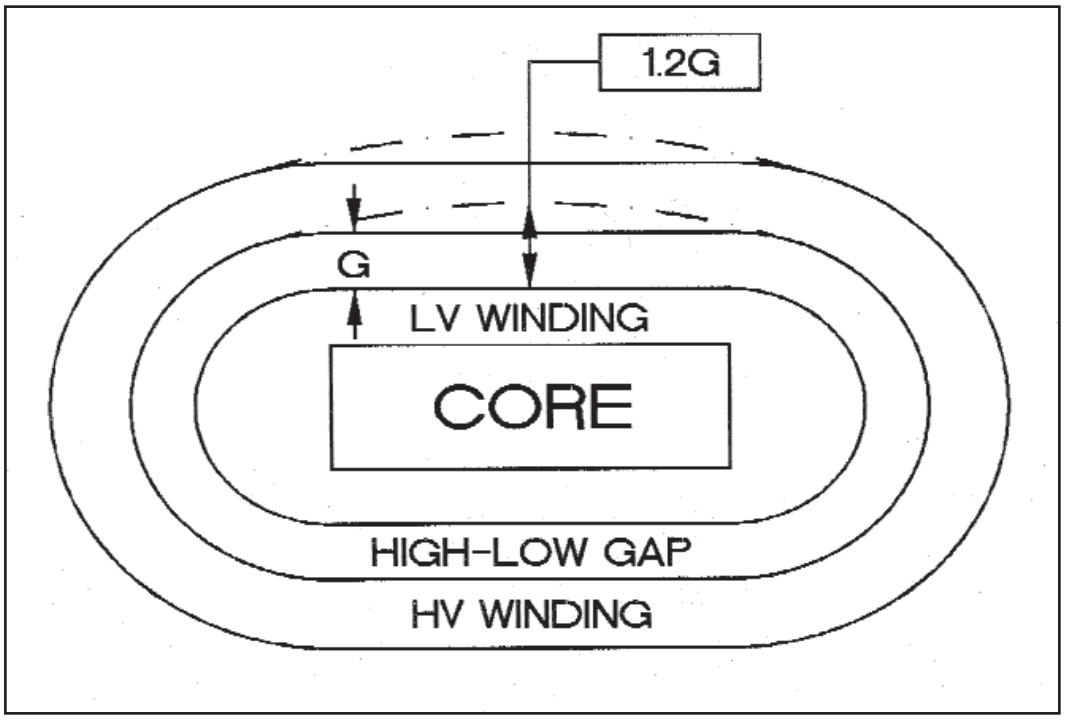

Figure 5: Change in High-Low Gap in Rectangular Windings is Very Large

The ends (front and back) of rectangular windings are somewhat oval in shape and can be expected to undergo lesser change than the flat sides. For this analysis we have assumed 3 percent change in the ends. Also, of the total length of the high-low gap about 60 per cent is on the flat side and 40 per cent is on the ends.

Let us assume that the high-low gap was 'G' before the short circuit test.

Overall change = change in the ends + change in the flat sides (say 'X').

G * 1.075 =(40% of 'G') * 1.03 + (60 % of 'G') * 'X'

Or, 1.075 G = 0.412 G + 0.6 G * X

Solving for 'X', we get:

X = 1.105 (i.e. 10.5% change in High-Low gap).

Further, Figure 5 shows the nature of the deformation of high-low gap which is like an arch, and the highest reflection occurs in the center. Using trigonometry, it can be seen that the deformation in the center of the arch is nearly twice as much as the average change.

In other words, the percentage change in the high-low gap would be as much as 20 per cent (even though the average change may be within 7 Ω per cent).

Summary

Rectangular designs may be fine for distribution applications typically less than 5000 KVA. Ratings above 5000 KVA should be circular.

Rectangular windings tend to become circular under radial forces. This results in conductor movement, risk of failure and change in performance.

If the outer coils of a rectangular winding are restrained from moving, the forces on the inner winding are greatly increased, thereby increasing the risk of conductor movements.

References

(1) J & P Transformer Book, 11th Edition.
(2) IEEE Std C 57.12. 90-1993, Part II, Guide for Short-Circuit Testing of Distribution and Power Transformers.
(3) IEEE Guide C 57.12.125 -1991, Guide for Failure Investigation, documentation and Analysis for Power Transformers and Shunt Reactors. (presently out of circulation).

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Finding Surplus Electric Power in Traditional Sources

By Dennis Pybus

Not too terribly long ago, electric utilities appeared capable of producing increasing amounts of electrical energy to feed the apparently insatiable demands of North American consumers. Today, the entire question as to whether or not sufficient generation exists to fulfil existing demands is placed in doubt. The prospect of additional generating plants being constructed in time to provide interruption free service for all consumers is questionable. A notable example being that of the State of California, where demand now exceeds generation and a series of 'rolling blackouts' became inevitable.

Emerging Technologies

The burden of providing increased generation is being transferred to the consumer. 'Distributed Power', meaning generation that is relatively small in size and located at its point of use, is no longer merely a buzzword. A couple of new technologies are poised to participate in the burgeoning need for more power. Fuel cells, which produce electricity from natural gas by means of a catalytic process, are one example. Fuel cells typically are sized from about 45 kW up to about 300 kW. Provided that fuel and air are supplied to the unit, electricity is generated instantaneously. The fuel cell is able to cope well with dynamic load changes up to its maximum capacity.

Another example is the so-called micro-turbine, a high-speed miniature gas turbine that converts natural gas, sour gas or even bio-mass waste gas into electrical energy, by driving a generator. Power outputs of these devices are currently in the range of about 25-75 kW. The turbine system does have a couple of shortcomings. First, the time from being provided with a start signal to actually achieving power output may be as long as two minutes. Second, turbines are intolerant of overloads. Even a slight overload will cause the system to shut down to protect itself from over temperature damage.

Both of the new technology solutions are relatively environmentally friendly and adapt themselves well to many residential and small business energy needs. Both systems also produce considerable heat that may be recovered and used in other processes. On a less positive note, volatility in the cost of and

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supply of natural gas, will play a major role in the success of either of these emerging systems.

Finding Surplus Power In Traditional Sources

Other, more traditional untapped sources of electrical power generation, are the standby generator sets that are installed in many commercial and institutional buildings. These machines generally use diesel engines as their prime movers and may use diesel grade oil or natural gas as a fuel source. Other standby units may use large gas turbines as the motive source, running on a wide variety of fuels. In general, emissions from standby generator sets are higher than the emerging alternatives.

At the same time, the power output available from individual diesel generator sets may be much greater, ranging from a few kiloWatts to several megaWatts. Diesel powered units are relatively tolerant of short time overloads. They are capable of accepting full load within some 10 seconds after being commanded to start. Larger gas turbines, as in the case of micro turbines, are essentially incapable of accepting overloads and suffer the same long time to start limitation.

Codes and standards for the construction of new buildings often include a minimum requirement for standby power for life safety reasons. Many end users actually choose to exceed the minimum standard in order that they may continue to carry on business during periods of utility power outages.

The Use of 'Standby' Generators

So it may be, that in the short term, the large and growing installed base of standby diesel generator sets will afford the greatest opportunity to provide the on-site generation needed to supplement essentially fixed utility capabilities. Let us look at some possibilities that would allow for the efficient use of these underutilized machines.

The first and simplest use of a standby generator is to use it to simply shed load by using its associated automatic transfer switch to start the generator and transfer the already connected emergency loads to it. Starting may be programmed on a time-of-day basis or as a function of facility load demand. Using the generator in this way can trim peak demands and lower utility demand charges for the user. This is likely not the most efficient use of the generator because emergency requirements do not usually load the generator to its most efficient capacity. The use of a standard automatic transfer switch will result in a brief (from about 40 milliseconds to as long as 10 seconds) power outage when transferring to and from the engine generator. The actual time of outage is purely dependent on the design of the transfer switch as well as the nature of the loads connected to it.

A second possibility is to use a Closed Transition Transfer Switch (CTTS) instead of the standard, open transition automatic transfer switch (ATS). In Canada, at the present time, the Canadian Electrical Code, Part 1 and the Automatic Transfer Switch Standard CSA C22.2 No. 178, do not permit the use of closed transition devices. Therefore approval will have to be granted by the utility having jurisdiction to connect a CTTS to its network. An alternative is to use a Solid State Transition Transfer Switch (SSTTS). The SSTTS does not physically interconnect utility and emergency power sources and is actually a 'load uninterrupted' device, switching in less than 1/2 cycle. Either of these alternatives will provide transfer without any apparent interruption, provided both sources are live. This

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operation is otherwise known as 'Seamless Transfer' due to the lack of disturbance to electrical loads. Properly designed, no speed adjustment is required to be made at the engine generator, permitting the use of less sophisticated governor controls.

Generator Control Developments — Soft Load Transfer

An automatic transfer switch development known as a 'Soft Load Transfer Switch' (SLTS) can further enhance load shedding operations. An SLTS essentially uses CTTS technology but actively changes the amount of load accepted by the generator. Again, because of present restrictions imposed by Canadian Electrical Codes and Standards, it is essential to secure utility approval prior to beginning construction.

Almost universally, engine generators are incapable of accepting their optimum load in one step. The use of any non-interactive automatic transfer switch will require that the connected load be within the capability of the machine to accept a block load. Therefore, the generator's peak efficiency cannot be realized. An SLTS solves this situation by gradually increasing the load applied to the generator over a pre-determined time. Gradual acceptance of the load over a short interval avoids problems with block loading and permits the machine to operate at its most efficient level.

An SLTS will operate in any one of several modes. 'Islanding Mode' where transfer between sources is conducted in a closed transition soft loading mode. Once the programmed load level is achieved, the SLTS disconnects the load from the utility. It will also operate in 'Base Load Mode' where the optimum load level for a given generator set is determined, the generator is loaded to that point and run in parallel with the utility. The third mode is 'Import/Export Mode' which is similar to the Base Load Mode, with the added ability to maintain optimum loading of the generator set through its ability to import power from, or export power to, the utility.

SLTS Operational Modes

Islanding Mode satisfies the requirements of those utilities, or users, who wish to transfer loads in a seamless fashion, but then operate in isolation until it is time to retransfer. Actual power generation will be dependent on the demand of loads connected to the emergency power system. The soft loading ability operates when transferring in both directions. This avoids any block loading problems with the generator as well as minimizing utility disturbances. Installations that operate in this mode may require a supplemental switching device for use when utility power is lost.

The Base Load Mode offers more efficient use of the engine generator set. By operating the generator continuously in parallel with the utility, all facility loads are connected to the generator, not merely the emergency loads.

This enables the machine to constantly run at its optimum output level, providing a fixed amount of power while demand on the utility rises and falls to accommodate total facility power demand. When the requirement for on site generation ceases to exist, the SLTS disconnects from the generator, which is then shut down. When facility loads may vary below as well as above the most efficient level of generation, Import/Export Mode permits a constant power output from the generator. It allows the utility to supply additional power to the facility during periods of high demand as in the case of the Base Load Mode. More importantly however, with the utility's agreement, during periods of low facility demand, the excess capability of the generator may be exported to the utility. This has two benefits. First, the generator is allowed to operate at its highest efficiency and second, revenue is generated by the sale of excess power. Agreements with specific utilities may determine time periods or peak demand loads that on site generation is used to augment utility power. At other times the SLTS connects loads only to the utility.

As is the situation with any standard automatic transfer switch, during such times that on site generation is not being used, the SLTS functions if an unexpected utility outage occurs. The SLTS will signal the generator to start and then transfer emergency loads to it. Once utility power is restored, the SLTS can again function in any of its operational modes.

All three operating modes are completely compatible with currently available generating systems including fuel cell and micro turbine technology. Seamless transfer is inherent in their design and operation. Protection against inadvertent overloading is especially important with the newly developed generation systems as well as traditional gas turbine generators. In line with modern technology, SLTS units should have the ability to interact with building management systems as well as be remotely controlled. Internet access to these devices readies them for immediate remote controlled action during times of utility initiated power curtailment.

Properly designed SLTS equipment contains all of the necessary protective relaying equipment to safeguard the utility and the owner alike. Attention must be given to possible failure modes such as the loss of either source when operating in parallel. The equipment should be designed to operate and communicate with generator control systems supplied by a variety of engine generator OEMs.

Conclusion

Soft Loading Transfer Switch equipment may well prove to be valuable as a first line of defense against the threat of declining electrical power availability. The technology is worthy of consideration to help solve power shortage problems on existing projects. It should also be given very careful consideration for use in new construction. In all likelihood, a generator is a requirement. Using that generator at its most efficient will provide an attractive payback.

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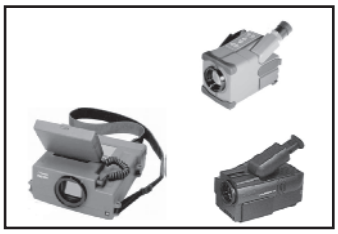

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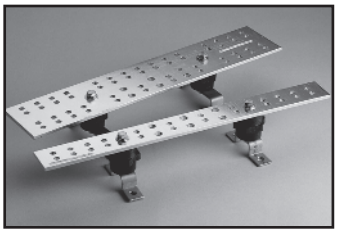

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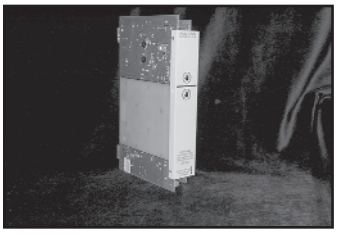

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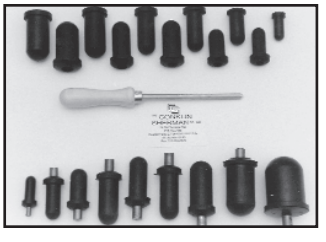

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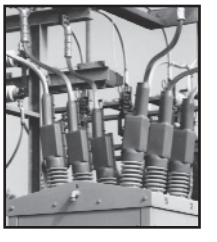

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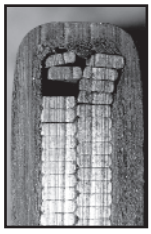

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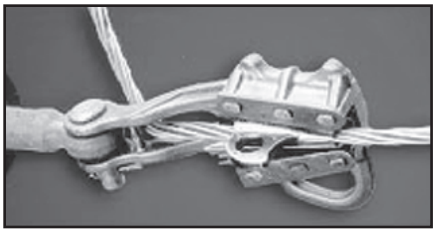

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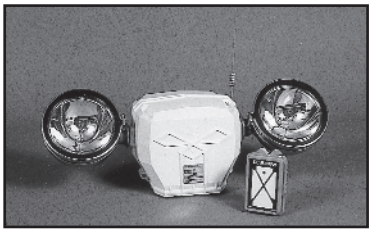

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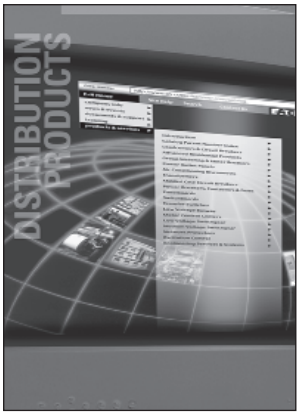

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