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THE ELECTRICITY FORUM

June 2007
Volume 19, No. 5

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ELECTRICITY TODAY

in this issue

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CYBER SECURITY AS IMPORTANT AS A GOOD CHAIN LINK FENCE

Don Horne

Cyber security. Protecting substations, transmission and distribution corridors and other utility assets now goes beyond chain link fence, security cameras and locked doors.

Now potential threats are coming literally in the ether – the Ethernet.

Verano's recent rebranding announcement (they are now Industrial Defender) underlines the shift in priorities for many utilities, as they begin devoting larger portions of their operating budgets to installing or upgrading their cyber security systems.

Industrial Defender marks the commitment of what was once Verano to the identification, mitigation and prevention of cyber-threats to power, water, energy, transportation and chemical industries. Critical infrastructure cyber security is becoming as important as maintaining transmission cable integrity to ensure a fully functioning network.

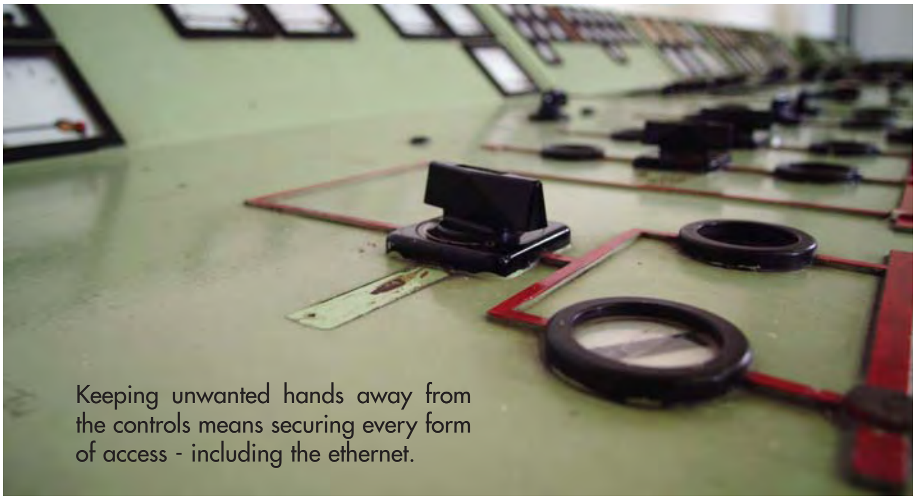
An August 2006 shutdown at the Browns Ferry Unit 3 nuclear facility in northern Alabama came under closer scrutiny from two leading Democratic Congressmen, who sent a letter to the chairman of the U.S. Nuclear Regulatory Commission (NRC) calling for an investigation into the nation's nuclear cybersecurity.

The letter, sent in mid-May, described the 2006 shutdown as a cyber security incident.

The northern Alabama Unit 3 facility was manually shut down following the loss of both of the recirculation pumps (two nuclear generating units are located at Browns Ferry).

According to the letter, the plant personnel determined that the cause of the failure was due to "excessive traffic" on the computer network. As a corrective measure, a firewall was placed on the plant's integrated computer system network.

The NRC followed regulations and decided not to investigate the failure as a cybersecurity incident because the failing system was a "non-safety" system and the licensee (the nuclear plant in question) had determined that the incident did not involve an external cyber attack on the system.



Keeping unwanted hands away from the controls means securing every form of access - including the ethernet.

But the two Democrats, Committee on Homeland Security chairman Bennie G. Thompson, D-Miss., and Subcommittee on Emerging Threats, Cybersecurity, and Science and Technology chairman James R. Langevin D-R.I. had "deep reservations" about the decision not to investigate the incident, adding that the Browns Ferry shutdown revealed that non-safety system can affect plant safety.

And there remains doubts as to whether there was any hacking of the system.

"Conversations between the Homeland Security Committee staff and NRC representatives suggest that it is possible that this incident could have come from outside the plant," reads the letter. "Unless and until the cause of the excessive network load can be explained, there is no way for either the licensee or the NRC to know that this was not an external distributed denial-of-service attack. Without a thorough, independent review of the logs and associated data, the assumption that this incident is not an outside attack is unjustifiable."

The congressmen have requested a further investigation of the source of the "data storm" by the NRC.

As detailed in the Industrial Defender story in this issue, there is a an excellent example of the California man now facing charges of sabotage when he attempted to access the Cal-ISO computer network (after being denied access, he instead pushed an emergency shut-off that created a small blackout and crashed computers used to communicate with the power market).

Viewed as an unsuccessful attempt to sabotage the system, it nonetheless required 20 computer technicians working seven hours to restore the systems.

Utilities are faced with the mammoth task of updating and upgrading a massive infrastructure consisting of lines, towers and equipment that, in some cases, is more than twice the age of the young men and women working on them. New SCADA and computer communication networks also carry hefty pricetags, so paying that much more to ensure their safety and security can be viewed as a luxury.

But as we've seen with frightening regularity each and every night on the news, there are those people out there who are ready, willing and able to spread terror and chaos – and where better than through the very system that keeps the wheels of commerce turning?

don@electricityforum.com

ELECTRICIANS HONOR LAST SURVIVING IWO JIMA FLAG RAISER

Charles Lindberg, the last surviving flag raiser from the WWII battle of Iwo Jima, was honored for his forty years of service as a Minnesota IBEW electrician at a school dedication in Minneapolis recently.

The International Brotherhood of Electrical Workers (IBEW) held a dedication ceremony for one of its most prestigious alumni, Charles Lindberg, where the Minneapolis JATC 292 Electrical Training Center will be renamed in his honor.

Lindberg is the last living war veteran who was part of the team that raised the American flag on the summit of Mount Suribachi during the WWII battle of Iwo Jima.

A second flag raising occurred four hours later and was captured in Joe Rosenthal's iconic Pulitzer Prize winning photo.

"I am proud to be a member of IBEW. In my forty years as a Minnesota electrician, the IBEW has always been fair and dependable," Lindberg said, "And we always got the job done right."

A F-16 flyover, color guard presentation and performance from the St. Michael High School marching band kicked-off the ceremonies to officially rename the local JATC training center to the Charles "Chuck" W. Lindberg JATC 292 Electrical Training Center.

RELAY'S EVENT REPORTS OFFER POWERFUL DATA FOR DIAGNOSING POWER SYSTEM PROBLEMS

By Ed Sullivan

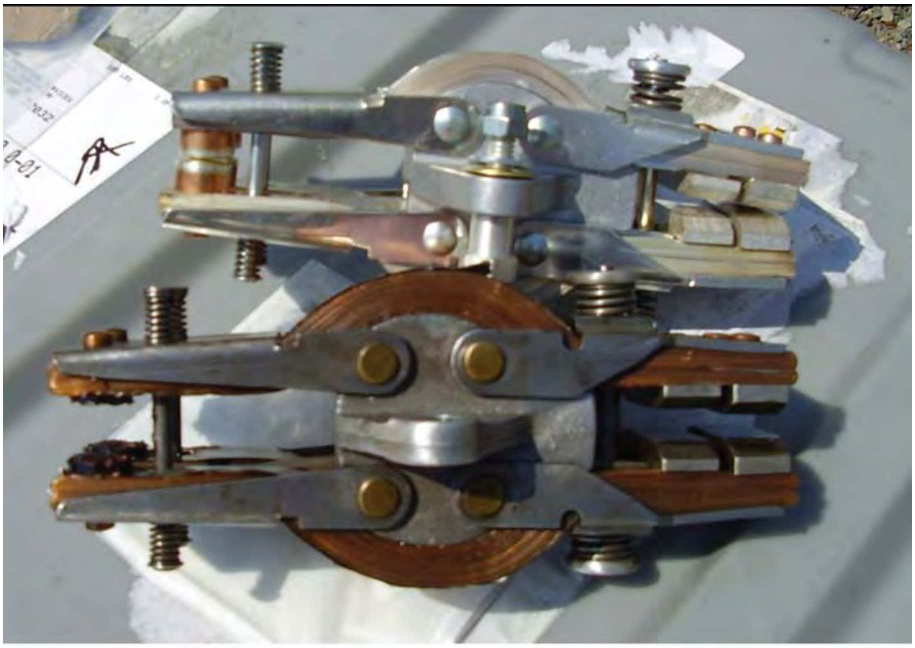
Today's microprocessor-based relays collect and save event reports during faults and other problematic conditions.

Event reports are very useful in determining fault resistance and explain otherwise inexplicable events. They also aid in testing and troubleshooting relay settings and protection schemes that protect costly equipment critical to consumer and industrial services.

The importance of event report records was demonstrated at the city of Conway (Corporation), Arkansas, 20 miles north of Little Rock. Conway's city-owned power system includes two feeders out of its substation, one supplying an industrial customer, and the other supplying the balance of the small city's business and residential customers.

"The industrial customer had detected what they considered a voltage problem," said Emery Perry, a Schweitzer Engineering Laboratories (SEL) field application technician called in to consult on the situation. "Yet when technicians from the Conway Electric Department went to inspect the substation, they noticed that there was no trip on the breaker. However, the technicians at Conway Electric had received training on SEL equipment, enabling them to take full advantage of the event report records in the SEL relays. The technicians decided to check the event history in the SEL relays to learn if there were any relevant event reports on the feeder in question."

The SEL event report and Sequential Events Recorder (SER) capability of advanced relays enabled protection engineers to gain a better understanding of faults and disturbances on transmission line systems through analysis of event reports. This analysis frequently leads to better line parameters, more accurate fault locating for complex faults, and improved understanding of electric power system operations.



The old bridge contact is shown in the lower portion of this on-site photo. The contacts at both ends are severely worn. The new bridge contact at the top of the photo clearly shows what the contacts should look like.

The technicians found that existing event reports seemed to indicate a voltage issue. So they consulted Perry to confirm what was evidently an unusual problem. "From the oscillograph readings, it appeared that the problem could be in the source—and in this case the source was a transformer," Perry said.

The Conway Electric Department uses SEL-351S-7 and SEL-351S-6 Protection and Breaker Control Relays and SEL-551 Overcurrent/Reclosing Relays in its distribution substations. The SEL-351S-7 Relay is used on the feeder main, with the SEL-551 as backup. The SEL-351S-6 Relays provide feeder protection as well as reclosing.

Perry said the event records showed a decrease in C-phase current (IC) and C-phase voltage (VC), while A-phase and B-phase currents increased. "This occurred on two feeders. I suggested testing their transformer, which was a tap changer. When we inspected it, we found that the rotary tap changer contacts were severely worn.

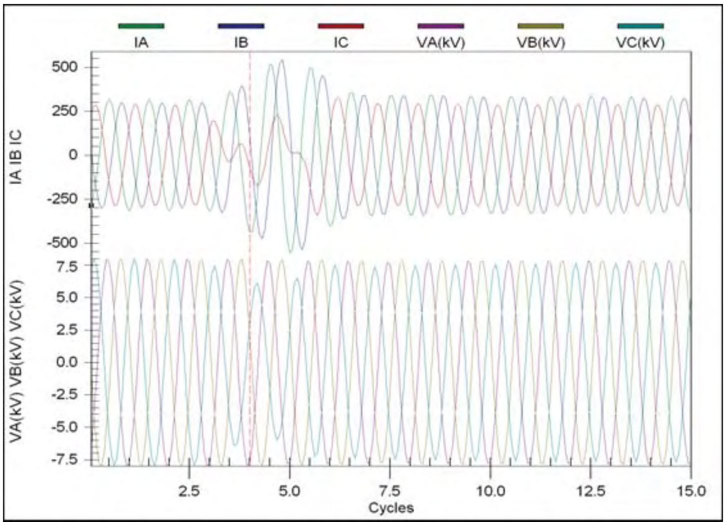
"What was causing the problem was that the C-phase on the utility transformer was opening up, and the industrial customer was in single phase," he added. "It wasn't a complete opening; actually, the moving contacts in the transformer were arcing. That's why the event report oscillograph showed the collapsed C-phase voltage and the collapsed C-phase current, just as if you were removing the voltage off of the load C-phase. There was a three-phase system within the industrial facility that was actually single phasing, which could cause equipment damage. And of course, the arcing of the transformer caused damage to the contacts."

Although transformers are generally among the most dependable components in an electrical system (failure rates are estimated at a minimal 76 failures per 10,000 years of transformer life), when failures occur, they can result in costly outages, considerable downtime, and expensive replacements.

"In this case, I would say that early analyses of the event record helped prevent a possible transformer fire and a sustained power outage, and also possible damage to the industrial plant equipment from a continued single-phasing condition," Perry said.

Each time a relay generates a standard event report; it also generates a corresponding event summary. This is a concise description of an event that includes such information as relay/terminal identification; event type, date, and time; fault location; and more. Event summaries can be viewed using the front-panel LCD or front-panel serial port of the SEL-351S. The date and time of each transition are available in event reports, downloadable to any PC. The chronology helps technicians determine the order and cause of events so that comprehensive troubleshooting is facilitated. With an appropriate setting, the relay will automatically send an event summary in ASCII text to one or more serial ports each time an event report is triggered.

In addition to storing event summaries and full-length event reports, the relays can track the pickup and dropout of protection elements, control inputs, and contact outputs.



Event reports are useful in determining fault resistance and explaining otherwise inexplicable events. This oscillograph generated by SEL's ACSELERATOR Analytic Assistant Software shows a problem with a three-phase voltage and current.

VERANO NOW INDUSTRIAL DEFENDER - BUT THE FOCUS REMAINS ON CYBER SECURITY

By Don Horne

A rose by any other name would smell as sweet, and Verano is hoping that their new name will continue their sweet success.

As of May 15, Verano Incorporated consolidated under the name Industrial Defender Inc., underlining its focus on cyber security.

"We have 15 years experience in the industry," says Todd Nicholson, CMO with Industrial Defender. "Our focus has been critical infrastructure cyber-security since 2002, identifying, mitigating and preventing cyber-threats to Power, Water, Energy, Transportation and Chemical Industries."

Headquartered in Mansfield, Massachusetts, Industrial Defender has offices throughout the United States, and in Canada, England, Belgium and Singapore.

Nicholson, who joined the company in January of this year, sees risk assessment and mitigation for utilities as a booming market that shows no signs of letting up.

"Security has been lacking as a priority for utilities. The total IT expenditures industrywide is $43 billion - that's less than half a per cent spent on cyber security," says Nicholson.

"For electric utilities, there are very tangible threats out there," he adds. "Utilities have public safety to consider; there are lives at stake when it comes to providing power."

The incidence of cyber attack and intrusion (whether intentional or accidental) have increased dramatically over the past few years. More than 310,000 incidents have occurred between 1998-2003, compared to just over 10,000 from 1993-1997.

"Judging by the current state of things, cyber threats are increasing exponentially."

A classic example of things going wrong in a hurry was the 2003 blackout.

"50 million customers went without power, affecting residences and businesses," says Nicholson. "When a control system propagates the problem, things can happen very quickly."

The 2003 blackout was estimated to have had an economic impact worth $6 billion.

A unique example of attempted sabotage occurred recently in California, where an alleged saboteur gained access to a California data center and attempted to take out the state's power grid.

The Federal Bureau of Investigation (FBI), arrested a 32-year-old man and charged him with the federal crime of attempted destruction of an electrical facility.

The story goes that on April 15, the California Independent System Operator Corporation (CAL-ISO) contacted the FBI to report a disruption that occurred to the CAL-ISO computer systems. CAL-ISO, through surveillance cameras and employee security access codes, identified the alleged saboteur as an employee of contractor Science Applications International, to be responsible for the disruption.

The person in question was able to enter the building and high-security rooms — allowed in by electronic card readers and a handprint scanner — even though his employer had warned days earlier that he should be denied access to the facility.

According to the FBI affidavit, the alleged saboteur had earlier in the day tried and failed to log on to access the Cal-ISO computer network. That's when he went to the facility and around midnight broke a glass seal and pushed an emergency electricity shut-off button. That act blacked-out the Cal-ISO building in Folsom, a Sacramento suburb and crashed computers used to communicate with the power market. Twenty computer technicians worked for seven hours to restore the systems.

The act caused no blackouts but could have disrupted the western United States' power grid had it happened during hours of peak demand for electricity, such as a summer afternoon.

Cal-ISO is now investigating its security procedures and SAI is reexamining its personnel screening methods.

According to the FBI, the man under arrest became upset after a dispute with SAI. If found guilty, could be looking at a maximum five-year prison sentence and a $5,000 fine.

For some observers, this latest act is one of myriad examples of how security threats from within are way more prevalent and destructive than threats from outside:

• A teenage hacker recently shut down a major shipping port in Houston, halting all inbound and outbound traffic;

• In 2003, the Davis-Besse nuclear plant's safety monitoring system was shut down for more than five hours by the Slammer Worm. Fortunately the nuclear units were offline, however, if they had been operational, there would have existed the possibility of compromising public safety.

With more than 60 process control/SCADA security assessments and more than 1,100 Industrial Defender deployments in this environment, Industrial Defender can rightfully claim to be the expert in protecting these types of critical infrastructure systems. In addition, 150 process control and SCADA networks in 21 countries are co-managed by CMSS (Industrial Defender Co-Managed Security Services). CMSS is the industry's first and only outsourced cyber risk management and monitoring service designed for the real-time process control and SCADA environments. Organizations such as Avista Utilities, City of Boca Raton, Constellation Energy, Drax, DuPont, PPL Generation LLC, RWE and Tri-State Generation and Transmission Association trust Industrial Defender to protect their real-time control environments, along with organizations globally, including:

- One in five power plants in the United Kingdom;

- The largest single power plant in Western Europe;

- The longest and most advanced metro line in Europe, estimated to carry more than 90-million passengers annually;

- Network power to more than 1.6 million customers in Australia;

- One of the largest chemical companies in the world.

"We're working like gangbusters to keep up with the demand," says Nicholson. "Especially with the new NERC compliance regulations coming. We've conducted more than 60 assessments just in this area. I believe we're the industry leader."

"The sun never sets on Industrial Defender," said Brian M. Ahern, President and CEO, Industrial Defender, Inc. "We provide global 24 x 7 x 365 Defense in-Depth protection through our Security Operations Center (SOC). Our team has the specific process control system/SCADA design experience combined with extensive security expertise needed to help our customers bridge the knowledge gap between enterprise IT and real-time operations staff. As a result, we can educate each group to arrive at a unified and integrated solution that reduces risk and maximizes uptime."

The Co-Managed Security Service offering is the third and final component of Industrial Defender's new Risk Protection Lifecycle portfolio. The comprehensive platform includes:

Risk Assessment - Industrial Defender Consulting Services: With more than 60 risk assessments for SCADA and process control systems, Industrial Defender's consulting services and security assessments have emerged through the acquisition of PlantData Technologies, Inc. in 2006.

Risk Mitigation - Industrial Defender Technology Suite: With 16 years of SCADA experience, more than 1,100 global security deployments for critical infrastructure systems and more than 3,000 mission critical SCADA deployments, Industrial Defender's technology is a proven tool to mitigate cyber threats, protect critical infrastructure and meet regulatory compliance.

Risk Management - Industrial Defender Co-Managed Security Services (CMSS): Based on the acquisition of eDMZ last year, Industrial Defender provides co-managed security services for more than 150 mission-critical process control networks in 21 countries.

The Three Gorges project is expected to be completed in 2009, 17 years after it was started.

ALSTOM HELPS HARNESS THE YANGTZE

By Donna Guinivan

Hydro generators from Alstom are turning water-power into electrical energy in the largest hydropower project ever built, the Three Gorges in China.

Filling the energy gap has led to the largest hydropower plant in the world, the Three Gorges on the Yangtze River, China. Alstom is supplying almost half the turbines and generators for the project.

The project's greatest challenge was its sheer size. Compare the width of the Three Gorges at 2.4 kilometers (1.5 miles) to that of a typical dam, which is around 100 meters (328 feet) and you begin to appreciate the scale of the undertaking.

The main part of a hydro turbine is its runner, where the water flow is converted to mechanical energy. "The external diameter of the runner for the Three Gorges was 23 percent larger than any other we had produced before," says Jacques Brémond, Mechanical Engineering Supervisor at the Alstom Turbine Technology Center. "It was a massive 10.6 meters (35 feet) in diameter with a height of 5 meters (17 feet)." It was impossible to produce the runners in the Alstom workshop in Grenoble. When completed, they needed to be transported over the town's bridge, but a single runner's weight of 425 tons was greater than the bridge's 300-ton weight limit.

Consequently, the runners were manufactured in a specially constructed workshop in La Ciotat in the south of France. The runners were transported by sea to Shanghai and then transferred from oceangoing vessels to riverboats. It takes six of these just to carry the draft tube elbow.

Alstom is based at the foot of the Alps, in Grenoble, France, where hydropower was born. Casimir Brenier started work on hydraulic turbines in 1854 to convert the power of flowing water into electrical energy.

Today, the company he founded is a subsidiary of Alstom Power and the global Technology Center for its hydropower business.

"The US still has the largest hydropower capacity, but Asia, led by China, is the fastest growing market," says Brémond. "In Europe and North America, power generation

The project's greatest challenge was its sheer size. The Three Gorges is 2.4 kilometers wide.

exceeds the demands of the population, while in China and India increased capacity is desperately needed."

Alstom started working with Trelleborg, using its Orkot bearings, nearly 10 years ago.

"We were unable to specify Orkot bearings on the left bank of the Three Gorges," says Brémond. "We had little experience of the product at that stage and the customer requested that we design in a known solution." To support their product, Trelleborg provided details of two independent tests on Orkot specifically for this application. "Based on these reports, we were increasingly confident about the performance of Orkot and decided to trial it in the wicket gate lower bushes during refurbishment of a Francis turbine in the Liu Jia Xia dam in China. After a few more tests in application, the product seemed successful and was first fitted in full scale on turbines supplied to the Alqueva Hydro Power Plant, Portugal commissioned in 2004," says Brémond.

Orkot bearings are "fish friendly". Most metal bearings need grease to make them work properly and during operation this lubricant goes into the water. Orkot material has excellent friction characteristics, which means no grease is required.

"After this experience, when specifying equipment for the right bank of the Three Gorges, we persuaded the customer that Orkot would be a good alternative. "The technical support we receive from Trelleborg, along with the product itself, is its greatest strength. That is why we are going to continue developing Orkot solutions for hydro generators with Trelleborg in the future."

HOW THE RUNNER WORKS

In a gravity dam, the water flows down from a reservoir into a hydro turbine. It enters the runner from one side via a spiral case, which distributes the water around the turbine. A distributor with adjustable wicket gates in the turbine controls the flow of water circulating in it. The energy of the water (head and flow) transforms into mechanical energy (torque and rotational speed). This then converts to electrical energy within the generator connected to the same shaft as the turbine.

Once the water has been through the runner, it goes down a draft tube back into the river.

CHINA'S LARGEST CONSTRUCTION SINCE THE GREAT WALL

There were three main reasons for building the Three Gorges dam.

- The first was to regulate the flow of the Yangtze. Its notorious floods have claimed an estimated one million lives in the past one hundred years.

- The second reason was to make the river navigable into the center of China.

- The third reason for the dam was to generate power. The hydropower plant is expected to create as much electricity as 18 nuclear power plants. It will provide an estimated one-ninth of the nation's energy and replace 40 to 50 million tons of raw coal combustion each year.

AN EXCITING MOMENT

"Ten years ago the only products we supplied to Alstom were Orkot Wear Rings," says Olivier Calemard, an account manager for Alstom at Busak+Shamban France, a part of Trelleborg Sealing Solutions.

"When I first arrived at Alstom with my 'plastic' bearing they laughed a little. It was so light compared to the metal ones they used; they could not believe it would be strong enough to do a good job."

Getting Alstom's business was an uphill battle, but Calemard is certainly not one to give up.

"We had to prove that Orkot could stand up to the task," Calemard says. "Alstom would not risk specifying an unreliable component. The cost of replacement of a failed bearing is huge. It took time and lots of independent research and test data to convince them to use the product. Now, however, it is regularly used in the majority of their installations." Orkot bearings are developed and produced at the Busak+Shamban associated manufacturing company Trelleborg Sealing Systems Rotherham. They are also manufactured at Trelleborg Sealing Solutions Eugene for the American market.

Due to the scale of the Three Gorges, the two sites worked together to fill the order and shared technology. "We do benchmarking of processes across the two sites," says Barry Davies, General Manager of Trelleborg Sealing Systems Rotherham. "This is to ensure product consistency. Working on a project like Three Gorges brings this requirement right to the forefront."

IMPROVING MV SWITCHGEAR OPERATOR SAFETY

By Paul Shiel – ESB Networks, Ireland, Darren Jones, EA Technology Ltd

Figure 1 – ABB RGB 12 Ring Main Unit

Partial discharge activity results in the deterioration and degradation of insulation systems in a range of high- and medium-voltage equipment and if left unchecked, will eventually lead to breakdown, flashover and disruptive failure of the equipment. Operating MV equipment with active partial discharge increases the risk of failure occurring at the time of switching leading to increased risk to the operator.

Experienced operators will assess the general condition of switchgear prior to operation to the best of their ability by looking for obvious signs of distress. Basic checks would include an assessment of any unusual sounds or smells and a visual inspection of the external physical condition of the equipment. There is often pressure on the operator to complete the switching and this fact, combined with the subjective nature of the operator's condition assessment, can lead to operation of equipment in an unknown or even potentially dangerous condition.

An understanding and identification of the processes involved in the degradation of a range of insulation types has enabled the development of instruments capable of non-intrusively detecting partial discharge activity. The instruments are designed to assess insulation condition by detecting the presence of partial discharge activity in any high- or medium-voltage equipment while the equipment is energized and in normal service.

This article will describe how ESB Networks, the power utility company of Ireland, has introduced an easy to use instrument to aid their field engineers with the management of a range of different types of switchgear.

INTRODUCTION

ESB Networks is the owner and operator of the electricity network in the Republic of Ireland and as the licensed Distribution System Operator, they are responsible for maintaining all the sub-transmission, medium- and low-voltage electricity network infrastructure in the country. This includes all overhead electricity lines, poles, substations, and underground cables that are used to bring power to Ireland's 1.7 million domestic, commercial and industrial customers.

In 2002 two unrelated but serious incidents occurred that brought safe working practices to the top of the ESB Networks agenda. The first involved an ABB RGB 12 ring main unit which catastrophically failed 30 minutes after being switched. Subsequent investigation indicated insulation failure as the root cause therefore all 250 substations equipped with ABB RGB12s were placed under operational restriction requiring switching operations only be carried out after the unit had been made dead by switching further up the line. Due to the strategic location of the ABB RGB12s on ESB's Network (in some instances, RGB12s were supplying other RGB12s in a "tee off" arrangement) this restriction caused severe disruption to customers' supplies. This situation led ESB Networks to engage EA Technology to assist in developing an operational protocol to help remove the restriction and reduce the disruption.

The solution was based on the fact that insulation breakdown was identified as the cause of failure. It was reasoned that as the main cause of insulation failure within high-voltage plant and equipment is partial discharge activity, it was

Figure 2 – Damage caused by Surface Partial Discharge Activity

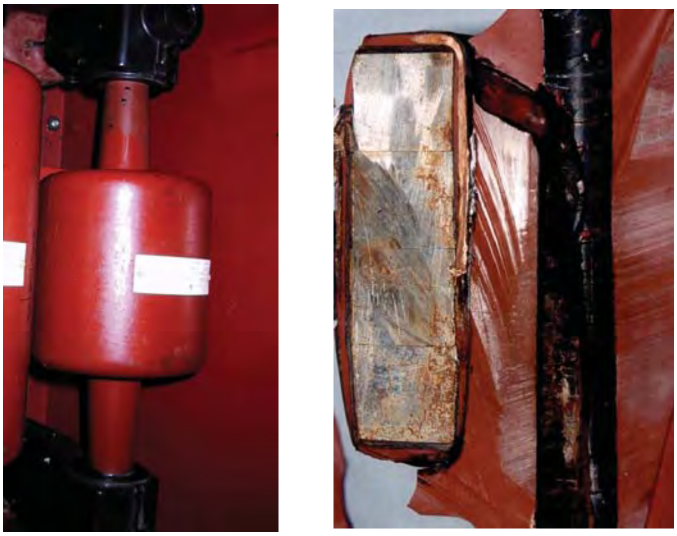


Figure 3 – Internal Partial Discharge

almost certainly occurring prior to failure. It was proposed that the use of a field-based detection instrument could have detected the partial discharge activity prior to failure and a series of field tests were commissioned to investigate the remaining population of ABB RGB12s.

PARTIAL DISCHARGE

Quoting directly from IEEE standard 1291-1993 (Guide for Partial Discharge Measurement in Power Switchgear):

"PD measurements are an ideal method for evaluating switchgear apparatus with non-self-restoring insulation. During a temporary over-voltage, during a high-voltage test, or under transient voltage conditions during operation, partial discharges may occur on insulation of this type, which includes gas, liquid, and solid materials. If these partial discharges are sustained due to poor materials, design, and/or foreign inclusions in the insulation, degradation and possible failure of the insulation structure may occur."

In practice, partial discharge in high-voltage insulation can be considered to take two forms, surface partial discharge and internal partial discharge. When surface partial discharge is present, tracking occurs across the surface of the insulation which is exacerbated by airborne contamination and moisture. Surface partial discharge leads to erosion of the insulation as illustrated in figure 2.

Internal partial discharge occurs within the bulk of insulation materials and is caused by age, poor materials or poor quality manufacturing processes. The current transformer illustrated in figure 3 was known to be exhibiting internal partial discharge. When it was removed and sectioned, the damage was seen to be at the top and is illustrated in the figure on the left.

If allowed to continue unchecked, either mechanism will lead to failure of the insulation system under normal working stress resulting in catastrophic failure of the equipment.

SURFACE PARTIAL DISCHARGE

Surface discharges are best detected using an ultrasonic detection instrument. However, there must be an uninterrupted air path between the discharge site and the instrument to allow the sound pressure waves to be detected externally. Surface discharges tend to occur between the particles of a contaminant, producing heat, light, smoke, sound, electromagnetic radiation and ozone and nitrogen gasses. In the early stages of this type of degradation process, and if an air path from the discharge site to the outside of the equipment is present, the high frequency sound waves generated by the partial discharge activity are readily detected using sensitive ultrasonic detection equipment in the 40kHz range. Often moisture combines with the NOx gasses to produce Nitric Acid that attacks the surrounding metalwork and leads to severe corrosion of the equipment. Insulation surfaces affected by such an acid attack produce an ideal surface for tracking to occur leading to the creepage distance of the insulator being compromised. Tracking is the result of carbonization of the surface of insulation brought on in the early stages by the breakdown of contaminates.

INTERNAL PARTIAL DISCHARGE

Within all insulation material, however manufactured, microscopic voids or cracks are present. When in use, the insulation has one end connected to high voltage and the other to ground, causing these voids and cracks to charge up and discharge with the 60Hz cycle like small capacitors.

Eventually, because the breakdown strength of air is less than that of the surrounding insulation, the air breaks down with a (very small) arc and a partial discharge occurs. These arcs produce heat, light, smoke, sound and electromagnetic radiation but as the void is buried within the insulation material, only the electromagnetic radiation is detectable externally.

This discharge action also erodes the voids making them bigger and as they get bigger, the discharge energy dissipated with each discharge increases in magnitude. During this process carbonization of the inner surface of the void occurs which progressively builds up to make the void conductive and increasing the electrical stress on the next void. This causes the process to be repeated throughout the insulation system leading to enough conductive voids in the insulation to cause it to fail even under normal working voltages and particularly following transient over-voltages caused, for example, by switching operations.

The electromagnetic pulses produced by internal partial discharges are conducted away in every direction by the surrounding metalwork. This charge in motion gives rise to an electric current which, when it impinges on the impedance of the metal casing, leads to a very high frequency voltage pulse. These high frequency voltage pulses (between 0.1mV and a few volts) escape through joints in the metalwork and pass from the inner to the outer surface of the equipment and then down to ground. The voltage pulse will stay on the surface of the steelwork as their high frequency leads to a skin effect. These pulses were first observed at EA Technology in 1974 by Dr John Reeves and were termed Transient Earth Voltages (TEVs).

They were given this description because they literally only last for a very short time and are traveling down to earth (ground). It was found after extensive trials that these TEV signals are directly proportional to the magnitude of any active partial discharge activity and the condition of the insulation for switchgear of the same type and model, measured at the same point. This produced a very powerful comparative field based technique for non-invasively checking the condition of switches of the same type and manufacture whilst the equipment is live and in service.

When new switchgear is tested for partial discharge under factory conditions, very expensive bench top test equipment is used and the reading is expressed in pico-coulombs (pC), a value obtained by direct measurement with the switchgear out of service. Once the switchgear or other equipment has been installed and in service for some time, pico-coulomb readings from direct measurements become relatively meaningless as the individual service history (fault operations, maintenance history) of each item of high-voltage equipment will lead to variations in their individual insulation systems. Furthermore, whilst partial discharge measurements on new switchgear are a very reliable indication of the build quality as it leaves the factory, it is older switchgear that is at more risk from failure due to partial discharge.

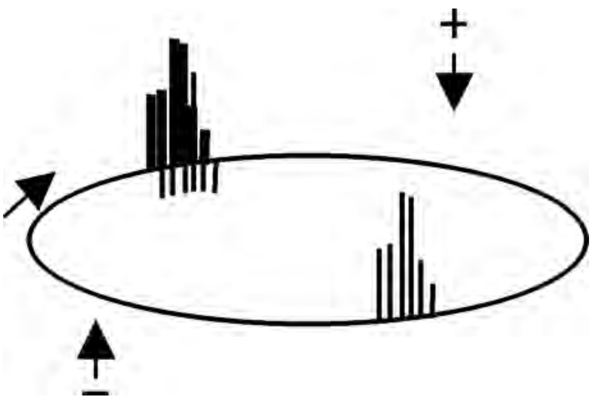


Figure 4 - Lissajous Figure of Internal Discharge in a Solid Dielectric Cavity
ref IEEE std 1291 – 1993

INTERPRETATION OF TEV MEASUREMENTS

The pulses that are being measured on the outside of the equipment are represented in the Lissojous Figures contained in Annex A of IEEE std 1291 – 1993, an example of which is shown in figure 4.

It can be seen from the figures contained in Annex A of IEEE std 1291 – 1993 that for each type of activity the pulses shown have two distinct features, the size (or magnitude) of the individual pulse and the number of pulses per cycle. In all instances the underlying feature is that as the partial discharge activity increases over time, the magnitude and number of pulses per cycle increases. The method of interpreting the TEV readings as measured by the instruments described earlier relies on being able to combine two aspects in the manner shown in figure 5.

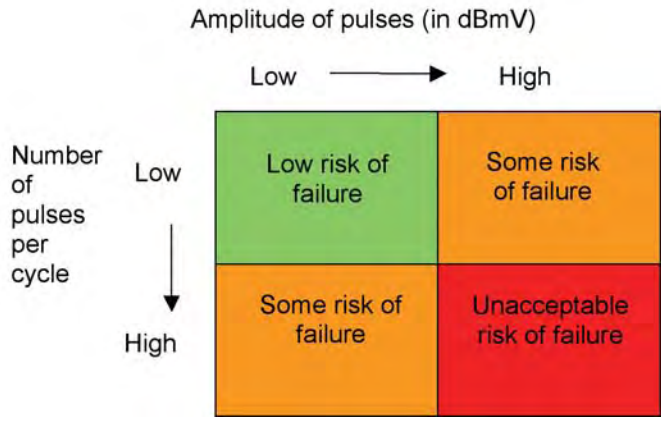


Figure 5 – Analysis of Transient Earth Voltages (TEV's)

As is illustrated, a low number and low magnitude of pulses means that there is little risk of insulation failure, either a low number of high magnitude pulses or a high number of low magnitude pulses means that the risk of insulation failure is increasing and more regular testing should be undertaken. Finally, a high number of high magnitude pulses means that the risk of failure may be unacceptable and intervention is required at the earliest opportunity.

EA Technology began making partial discharge measurements of switchgear using TEV Detection Instruments in 1983. Since that time, EA Technology has assembled, with the cooperation of all the UK power utilities, a database of partial discharge survey results with over 100,000 entries covering many different manufacturers and types of high-voltage switchgear and associated equipment. When a survey is undertaken, the TEV readings (in dBmV) are compared with the database results, if the level of partial discharge is within the top 5% of the database values for comparative equipment (of the same voltage level, insulation type and design) then it is deemed to be in the 'red' quadrant of figure 5. If the readings are in the top 25% of the database values then the equipment is deemed to be in the 'amber' quadrant, below this level the equipment is deemed to be in the 'green' quadrant.

EA TECHNOLOGY PARTIAL DISCHARGE INSTRUMENTS

Having discovered a technique for determining the condition of switchgear in service, EA Technology began to develop a range of instruments to detect, locate and measure Transient Earth Voltages in high- and medium-voltage equipment. Over subsequent years, the range of instruments has been further developed and refined into the range we have today. A brief description of function and use is as follows:

UltraTEV Detector – This instrument detects the presence of both Surface and TEV discharges and indicates, using different coloured LEDs, if further investigation is required. This instrument is designed for use by staff with minimal training and is used extensively as a first pass indicator to detect the presence of active partial discharge.

UltraTEV Alarm – Based on the UltraTEV Detector architecture, the UltraTEV Alarm is a series of magnetically clamped nodes which can capacitively detect TEV signals at the positions they are mounted. They also have the ability to detect Surface Discharge using a remote strategically placed magnetically mounted ultrasonic detector. A ‘daisy chain’ power and communications cable runs between them and a central hub. The hub is configured to respond to the partial discharge detected signals from the nodes by applying protocols. An alarm is raised through SCADA, GPRS, or even by a simple light outside the substation indicating partial discharge activity above a certain level is present.

MiniTEV – This instrument is for use by a trained engineer and gives both a TEV reading in dBmV and the number of pulses at that level during the fixed measuring period. By combining the number of pulses with the magnitude of the discharge, a severity level (see figure 5) can be calculated which is useful in developing an understanding of the rate at which the insulation is being damaged. This is compared to readings from other equipment of the same manufacture and model and a decision on further action can be taken.

UltraMET – An instrument that only measures ultrasonic emissions in the 40 kHz band and is intended for surface discharge detection. This instrument complements the MiniTEV and together can determine the levels of discharge detected by the UltraTEV Detector. An optional extra for this instrument is a parabolic collector which allows the instrument to be used for detecting surface discharges on pole mounted equipment and open switchyards.

Partial Discharge Locator – This instrument measures partial discharge magnitude but also features 2 probes which are used to give an accurate location of the active partial discharge. This is achieved by placing the probes a minimum of 24" apart and recording which probe detected the TEV signal first. The Partial Discharge Locator has a time resolution between probes of 2 nano seconds. A short training course in partial discharge detection is required for successful use of this instrument.

Partial Discharge Monitor – With 8 probes and 4 aerials, this instrument monitors discharge activity 24 hours a day for up to 3 months. The Partial Discharge Monitor also features precedence detection circuits which allows the location of any discharge activity to be established and any external interference eliminated. The data can be fully analysed on a standard PC and produce reports on discharge activity, location, and severity.

PDM 100 Multinode –This instrument is designed to be permanently installed in a substation continuously monitoring partial discharges both electromagnetic and ultrasonic, humidity, temperature, backup battery condition, etc. The PDM 100 can read up to 100 probes, perform analysis internally, and is fully web enabled allowing EA Technology to monitor switchgear condition anywhere in the world. The unit also has intelligent alarms that can detect trends from the data and give early warnings of potential problems via the web.

In summary, the range of instruments developed allows reliable and repeatable partial discharge measurements to be made on a range of high voltage equipment. The instruments are designed to be used when the equipment being tested is energised but ensuring the operator is kept in complete safety.

The use of the testing instruments requires no modifications to the equipment being tested and is completely non-intrusive. Unlike traditional insulation testing techniques that use DC test signals from battery based instruments, partial discharge testing allows an assessment to be made under normal everyday service conditions making them far more representative of the insulation condition and therefore much more reliable.

THE ESB NETWORKS EXPERIENCE

As referred to in the Introduction, ESB Networks, the electricity distribution network operator for Ireland, suffered two unrelated but serious incidents that brought safe working practices to the top of the ESB Networks agenda.

One of these incidents involved a cast resin ring main unit which catastrophically failed soon after a manual switching operation had been performed. Subsequent forensic investigation of the failed ring main unit indicated an insulation failure had occurred leading to a flashover and the release of significant fault energy. ESB Networks immediately imposed an operational restriction on all 250 substations equipped with the ABB RGB12 which only allowed operation of the switch 'off-line'.

Because of the customer supply disruption caused and the logistical difficulties in replacing the equipment quickly, ESB Networks approached EA Technology to assist with development of an operational protocol to manage the removal of the restriction.

THE PROTOCOL

The UltraTEV Detector, as described earlier, detects both internal and surface discharge activity and indicates with simple red, amber and green lights the presence or absence of active partial discharge.

This made the instrument ideal for use as a 'safe to operate/not safe to operate' indicator. The protocol required the threshold settings (the level at which the LEDs change colour) within the UltraTEV Detector to accurately and demonstrably indicate when partial discharge was present or absent. It was proposed that a trial be undertaken to test the protocol which would involve non-intrusively testing a selection of ABB RGB 12 units with the UltraTEV Detector.

Further non-intrusive checks would also be carried out using the MiniTEV instrument for internal discharges and a sensitive ultrasonic detection instrument to test for surface discharge. Following the non-intrusive tests, the ABB RGB 12 unit would then be de-energised, racked out and stripped down and subjected to a detailed internal inspection. If the UltraTEV Detector instrument indicated the absence of partial discharge and this was confirmed by the detailed visual inspection, then the restriction could be lifted for that substation.

TESTING

This approach was agreed to by the safety representatives of ESB Networks in November 2003 and later that month tested on a selection of substations in Cork in the south west of Ireland.

Ten substations equipped with ABB RGB 12 units were inspected and in 7 out of 10 substations no detectable partial discharge was found by the UltraTEV Detector or MiniTEV. In the remaining 3 substations, a very low level of ultrasonic activity below the threshold level of the UltraTEV Detector instrument was detected.

The level of ultrasonic and TEV measurements was below the pre-set levels for all of the ten ABB RGB 12 units visited which enabled switching to be undertaken and internal inspections carried out.

The internal inspections revealed evidence of partial discharge activity in the 3 substations identified by the sensitive ultrasonic equipment. The main area affected was the fixed copper cable contacts which exhibited verdigris growth with some resulting acid damage, both contributing to the very early stages of insulation degradation. While the observations were clear evidence of partial discharge activity that could ultimately lead to disruptive failure, the process was at a relatively early stage. While it is difficult to estimate the rate of ongoing degradation, failure would not be expected for any of these switches within the next 12 months. Nevertheless, under the terms of the protocol, the operational restriction remained in place for these 3 units until maintenance or replacement could be carried out. For 7 of the units inspected, the conditions required to remove the restriction (subject to the use of a simple go/no go UltraTEV Detector check prior to operation) were met.

Figure 6 - Magnefix

The testing and inspections carried out indicated that the protocol was viable and provided a basis for practical management of the 250 ABB RGB 12 units. It was also determined that the threshold levels of the UltraTEV Detector were correct, sensitive enough to detect a dangerous level of partial discharge but not over sensitive to lead to an unmanageable number of 'positives'.

OTHER SWITCHES ON THE ESB NETWORK

ESB Networks also have over 5000 10kV Magnefix (figure 6) cast resin ring main units on their network. These ring main units have suffered numerous disruptive failures and the opportunity arose during the Cork trials to survey two of these units. Both units exhibited red lights on the UltraTEV Detector indicating the need for maintenance or replacement leading ESB Networks to consider incorporating the UltraTEV Detector into routine working practices prior to switchgear operation.

This, it was argued, would significantly improve the safety and reliability of operational activities as well as target their on-going replacement programme to best effect. The ESB network also includes some modern SF6 switchgear, oil-filled ring main units and open cubicle substations.

ADOPTION OF THE PROTOCOL ACROSS THE ESB NETWORK

The protocol developed and tested in Cork was adopted nationally and all operational switching and inspection staff were issued with an UltraTEV Detector instrument for use prior to all switching operations. Two versions of the UltraTEV Detector are available, the initial model has a

	Indication	
	Green	Red
Cast Resin	93%	7%
Other	95%	5%

Table 1 – Results of 5000 UltraTEV Detector readings across the ESB Network

Continued on Page 21

ETHERNET IN SUBSTATION AUTOMATION APPLICATIONS - PART I

By Marzio P. Pozzuoli, RuggedCom Inc. – Industrial Strength Networks

INTRODUCTION

Trends in electric utility automation, specifically substation automation, have converged upon a common communications architecture with the goal of having interoperability between a variety of Intelligent Electronic Devices (IEDs) found in the substation. This initiative was begun back in the late 1980s driven by the major North American utilities under the technical auspices of EPRI (Electric Power Research Institute). The resulting standard that emerged is known as the Utility Communications Architecture 2.0 (UCA2.0) and is now becoming an international standard as IEC 61850. This architecture, which is now being adopted worldwide by utilities and IED vendors alike, has as its underlying network technology - Ethernet.

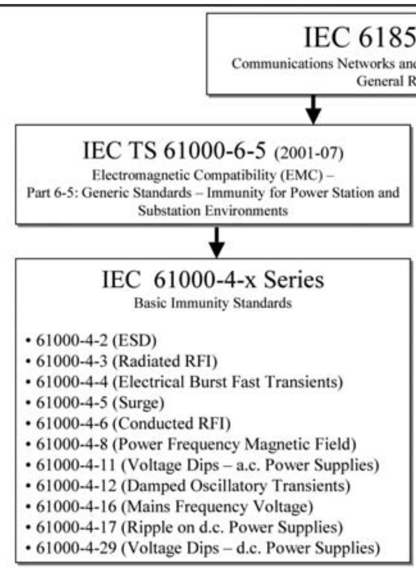


Figure 1: IEC 61850-3 Referenced Standards

This article looks at the key issues and requirements for Ethernet in the substation environment and for substation automation applications requiring real-time performance. Specific topics addressed are: EMI phenomena and atmospheric conditions in substations which can affect network performance, new standards introduced by the IEC and IEEE that establish new EMI and environmental requirements specifically for communications networks (i.e. Ethernet) in substations, critical Layer-2 features of modern Ethernet switching hubs (i.e. switches) which enhance real-time deterministic performance as well as fault tolerant loop architectures and network redundancy.

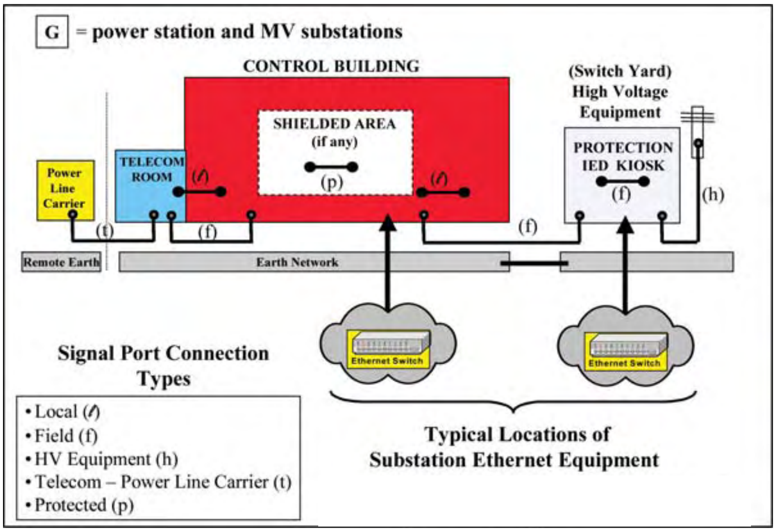


Figure 2: MV Substation Location and Signal Port Connection Types

EMI IMMUNITY REQUIREMENTS

The proliferation of Ethernet capable IEDs used for substation automation has increased markedly in the past several years. There are currently nine vendors of protective relaying devices alone offering Ethernet communications with their IEDs. Vendors of meters, RTUs and PLCs used for substation automation, also mirror this trend. A key requirement of most substations IEDs such as protection relays is that they must operate properly (i.e. not 'misoperate') under the influence of a variety of EMI phenomena commonly found in the substation. Standards such as IEEE C37.90.x and IEC 60255 define a variety of type withstands tests designed to simulate EMI phenomena such as inductive load switching, lightening strikes, electrostatic discharges from human contact, radio frequency interference due to personnel using portable radio handsets, ground potential rise resulting from high current fault conditions within the substation and a variety of other EMI phenomena commonly encountered in the substation. This will also be true of the substation LAN equipment (i.e. the Ethernet switches). Often the Ethernet switches will be installed in the

Continued on Page 22

MV Switchgear
Continued from Page 19

green/amber/red LED indication system with an alternative green/red LED indication system. ESB Networks chose to deploy the later version and over 400 instruments were issued between May 2004 and March 2005.

EXPERIENCE AFTER 12 MONTHS

During 2005/6, over 5,000 inspections have been carried out using the UltraTEV Detector on the ESB network. These results are split into 2 basic areas, 'cast resin', which account for 70% of the tests, and 'others', which include a range of equipment including, for example, terminations on SF6 switchgear, oil-filled ring main units and open cubicle substations. The results were as described in table 1.

This result demonstrated to ESB Networks that their network is, in fact, in a good condition and as the 'positive' results are targeted for maintenance or replacement, the number of red lights will reduce. ESB Networks indicated that they were satisfied with the results as it has achieved its main objectives of ensuring that operational staff are not unknowingly being exposed to dangerous situations and that defective equipment can be quickly targeted for removal or refurbishment. The use of the UltraTEV Detector instrument has resulted in an increase in ESB Networks confidence in the continued safety of their staff and the integrity of their asset base.

SUMMARY

The development and subsequent availability of the UltraTEV Detector was instrumental in allowing ESB Networks to resolve and safely manage the removal of an operational restriction on 250 substations that contain ABB RGB 12 switchgear.

The disruption to ESB Networks customers was also minimized, and the protocol developed between ESB Networks and EA Technology has now been adopted nationally to include all switchgear. ESB Networks are satisfied with the results of the first year which have exhibited the following clear benefits:

- Clearly identifies switches that must not be operated whilst 'live'
- Improves operator safety
- Network cleared of operational restrictions
- Clear indication of the condition of the network
- No failures of cast resin switchgear since protocol adopted
- Accurate targeting of maintenance and replacement resources
- Cost effective

Paul Shiel BE MIEI MSc., joined ESB Networks in 1980. It was under Paul's tenure of this position the UltraTEV Detector was introduced into Standard Work Practices.

Darren Jones BEng (Hons.) CEng., joined EA Technology in 2001 after seven years at ABB and then spent several years as the co-ordinator of the substation equipment module of EA Technology's Strategic Technology Programme.

Continued from Page 20

UTILITY IEC 61850-3 (61000-6-5) Communications Networks and Systems In Substations (Jan 2002)				
TEST	Description		Test Levels	Severity Levels
IEC 61000-4-2	ESD	Enclosure Contact	+/- 6kV	3
		Enclosure Air	+/- 8kV	3
IEC 61000-4-3	Radiated RFI	Enclosure ports	10 V/m	3
IEC 61000-4-4	Burst (Fast Transient)	Signal ports	+/- 4kV @ 2.5kHz	x
		D.C. Power ports	+/- 4kV	4
		A.C. Power ports	+/- 4kV	4
		Earth ground ports[3]	+/- 4kV	4
IEC 61000-4-5	Surge	Signal ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
		D.C. Power ports	+/- 2kV line-to-earth, +/- 1kV line-to-line	3
		A.C. Power ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
IEC 61000-4-6	Induced (Conducted) RFI	Signal ports	10V	3
		D.C Power ports	10V	3
		A.C. Power ports	10V	3
		Earth ground ports[3]	10V	3
IEC 61000-4-8	Magnetic Field	Enclosure ports	40 A/m continuous, 1000 A/m for 1 s	N/A
IEC 61000-4-29	Voltage Dips & Interrupts	D.C. Power ports	30% for 0.1s, 60% for 0.1s, 100% for 0.05s	N/A
		A.C. Power ports	30% for 1 period, 60% for 50 periods	N/A
IEC 61000-4-11			100% for 5 periods, 100% for 50 periods[2]	N/A
IEC 61000-4-12	Damped Oscillatory	Signal ports	2.5kV common, 1kV differential mode @ 1MH:	3
		D.C. Power ports	2.5kV common, 1kV differential mode @ 1MH:	3
		A.C. Power ports	2.5kV common, 1kV differential mode @ 1MH:	3
IEC 61000-4-16	Mains Frequency Voltage	Signal ports	30V Continous, 300V for 1s	4
		D.C. Power ports	30V Continous, 300V for 1s	4
IEC 61000-4-17	Ripple on D.C. Power Supply	D.C. Power ports	10%	3

Table 1: Typical EMI Immunity Type Test Profile for Network Equipment Located in the Protection IED Kiosk of Figure 2

same compartment or even on the same rack as protective relaying IEDs. Therefore, it has become necessary that the Ethernet equipment become "substation hardened", from an EMI immunity perspective, to the same level as protective relaying IEDs.

IEC 61850-3 COMMUNICATIONS NETWORKS AND SYSTEMS IN SUBSTATIONS

In recognition of the above requirements, the IEC (International Electrotechnical Commission) issued a new standard in January 2002 entitled: IEC 61850-3 Communications Networks and Systems in Substations – Part 3: General Requirements. Section 5.7 of the standard outlines the EMI immunity requirements for communications equipment installed in substations. In general, it sets a higher standard than the immunity requirements for equipment in industrial environments stating that: "The general immunity requirements for the industrial environment are considered not sufficient for substations. Therefore, dedicated requirements are defined in IEC 61000-6-5…"

The IEC 61000-6-5: "Generic Standards – Immunity for power station and substation environments" outlines the EMI immunity requirements. The details of these requirements and type test procedures are given in the parts of the IEC 61000-4-x series. Figure 1 shows the relationship between IEC 61850-3, IEC 61000-6-5, the IEC 61000-4-x series and other referenced standards.

IEC 61000-6-5 defines port categories. A 'port' is defined as a "particular interface of the specified equipment with the external electromagnetic environment".

There are five port categories defined:

1. Enclosure Port (typically the device enclosure)
2. Signal Port (a connection to local, field, high voltage, or telecom equipment)
3. Low Voltage a.c. Input Power and Output Power Ports
4. Low Voltage d.c. Input Power and Output Power Ports
5. Functional Earth Port

In addition to 'port' definitions IEC 61000-6-5 also defines categories of locations:

G = power stations and MV substations
H = HV substations
P = "protected" areas if any

Also defined are Signal Port connections:

L = local connections
f = field connections
h = connections to HV equipment

t = telecom

p = connections within a protected area if any

Figure 2 shows a typical substation defined in terms of Locations and Signal Port connections. Specific IEC 61000-4-x Tests and corresponding test levels are assigned to each port type (e.g. enclosure, power, signal) based on device location (e.g. H = HV Substations, G = Power Stations or MV substations) and signal port connection types (e.g. local, field, HV, telecom, protection) in the case of signal port types. Table 1 lists the resultant type test profile and corresponding test levels for network equipment located in the Protection Kiosk in MV substation shown in Figure 2.

IEEE P1613 – Draft Standard Environmental Requirements for Communications Devices Installed in Electric Power Substations

TEST	Description		Test Levels	Severity Levels
IEEE C37.90.3	ESD	Enclosure Contact	+/- 8kV	N/A
		Enclosure Air	+/- 15kV	N/A
IEEE C37.90.2	Radiated RFI	Enclosure ports	35 V/m	N/A
IEEE C37.90.1	Fast Transient	Signal ports	+/- 4kV @ 2.5kHz	N/A
		D.C. Power ports	+/- 4kV	N/A
		A.C. Power ports	+/- 4kV	N/A
		Earth ground ports[3]	+/- 4kV	N/A
IEEE C37.90.1	Oscillatory	Signal ports	2.5kV common mode @ 1MHz	N/A
		D.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A
		A.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A
IEEE C37.90	Dielectric Strength	Signal ports	2kVac	N/A
		D.C. Power ports	2kVac	N/A
		A.C. Power ports	2kVac	N/A

Table 2: P1613 EMI Immunity Requirements based on IEEE C37.90.x Type Tests

ENVIRONMENTAL AND TESTING REQUIREMENTS FOR COMMUNICATIONS NETWORKING DEVICES IN ELECTRIC POWER SUBSTATIONS

The IEEE P1613 standard for networking devices in substations specifically adopts and adapts the EMI immunity type tests applied to protective relaying IEDs as defined by the familiar IEEE C37.90.x standards. Table 2 summarizes the tests and test levels required in accordance with IEEE P1613.

P1613 also defines two different classes of communications devices: Class 1 devices must withstand the type tests defined in Table 2 without sustaining damage or resetting but may incur communications errors during the applications of the type tests. Class 2 devices, however, must meet the same requirements as Class 1 devices with the exception that no communications errors, delays or interruptions occur during the application of the type tests defined in Table 2.

Class 2 network equipment is intended to provide the same level of performance as protective relaying devices during periods of high EMI stress as would be occur during a power system fault.

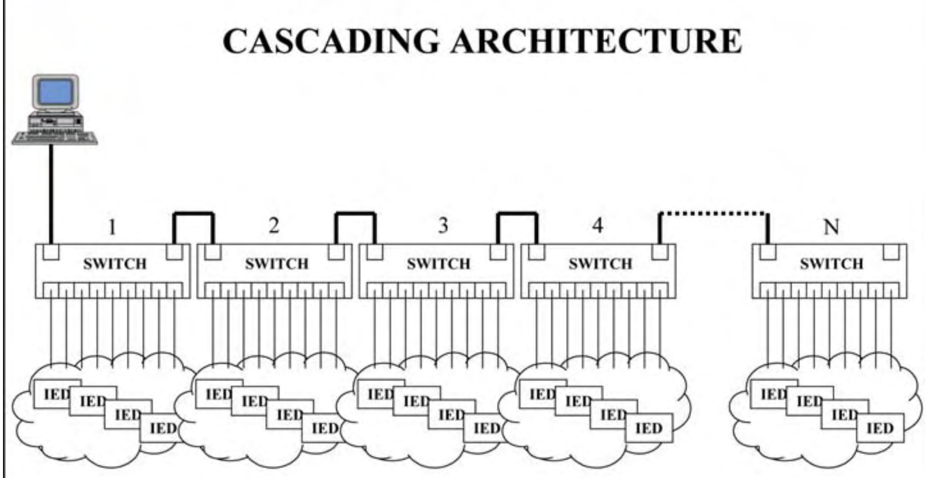


Figure 3: Cascading Network Architecture

ENVIRONMENTAL REQUIREMENTS

Both the IEC 61850-3 standard and the IEEE P1613 standard define atmospheric environmental requirements for network communications devices such as Ethernet switches in substations.

IEC 61850-3 ENVIRONMENTAL REQUIREMENTS

IEC 61850-3 refers to IEC 870-2-2 "Telecontrol equipment and systems – Part 2: Operating conditions – Section 2: Environmental conditions (climatic, mechanical and other non-electrical influences)". IEC 870-2-2 addresses the atmospheric environment which defines four classes of locations:

1. Class A: air-conditioned locations (indoor)
2. Class B: heated and/or cooled enclosed conditions
3. Class C: sheltered locations
4. Class D: outdoor locations

The majority of IEDs in substations will be in "Class C" locations. Class C locations are further sub-divided into four classes: C1, C2, C3 and Cx. Operating temperature ranges for each of the classes are as follows:

1. Class C1: -5 to 45°C
2. Class C2: -25 to 55°C
3. Class C3: -40 to 70°C
4. Class Cx: Special

For IEDs in substations classes C2, C3 or Cx (-40 to 85°C) will be required.

IEEE P1613 ENVIRONMENTAL REQUIREMENTS

IEEE P1613 defines four temperature ranges:

a) -40 °C to +70 °C.

b) –30 °C to +65 °C.

c) –20 °C to +55 °C (the default range if no other range is specified).

d) Range defined by the manufacturer

Furthermore, clause 4 of the standard requires that no fans be used for cooling in the communications networking equipment.

REAL-TIME CONTROL REQUIREMENTS

Modern managed Ethernet switches offer advanced Layer 2 and Layer 3 features that are critical for real-time control and substation automation. These include:

- IEEE 802.3x Full-Duplex operation on all ports ensures that no collisions occur and thereby makes Ethernet much more deterministic. There are absolutely zero collisions in connections that both support IEEE 802.3x Full-Duplex operation. This eliminates one the biggest "bugaboos" about Ethernet and deterministic operation.

- IEEE 802.1p Priority Queuing which allows frames to be tagged with different priority levels in order to ensure that real-time critical traffic always makes it through the network even during high periods of congestion.

- IEEE 802.1Q VLAN which allows for the segregation and grouping of IEDs into virtual LANs in order to isolate real-time IEDs from data collection or less critical IEDs.

- IEEE 802.1w Rapid Spanning Tree Protocol which allows for the creation of fault tolerant ring network architectures that will reconfigure in milliseconds as opposed to tens of seconds as was the case for the original Spanning Tree Protocol 802.1D.

- IGMP Snooping/Multicast Filtering that allows for multicast data frames, such as GOOSE frames, to be filtered and assigned only to those IEDs which request to listen to them.

It is important to note that the above features are based on standards thereby ensuring interoperability amongst different vendors.

NETWORK ARCHITECTURE REQUIREMENTS

There are three basic network architectures (i.e. Cascading, Ring, and Star) that are commonly implemented with Ethernet Switches in substations with numerous variations and hybrids of the three. Each of the three basic architectures offers various performance vs. cost tradeoffs.

CASCADING (OR BUS) ARCHITECTURE

A typical cascading architecture is illustrated in Figure 3. Each switch is connected to the previous switch or next switch in the cascade via one of its ports. These ports are sometimes referred to as uplink ports and are often operating at a higher speed than the ports connected to the IEDs. The maximum number of switches, N, which can be cascaded depends on the worst case delay (latency) which can be tolerated by the system. For example, consider the case where an IED connected to Switch 1 sends a frame to an IED on Switch 4. The frame must

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Automatic Generation Control
Energy Usage & Cost Reporting
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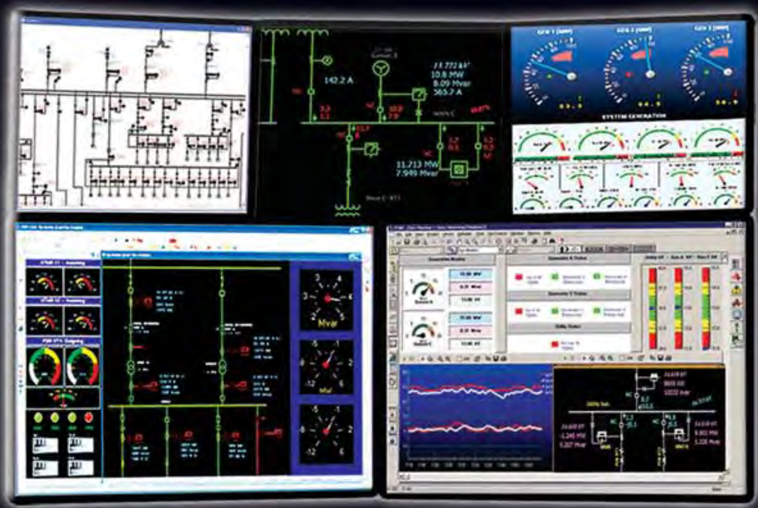

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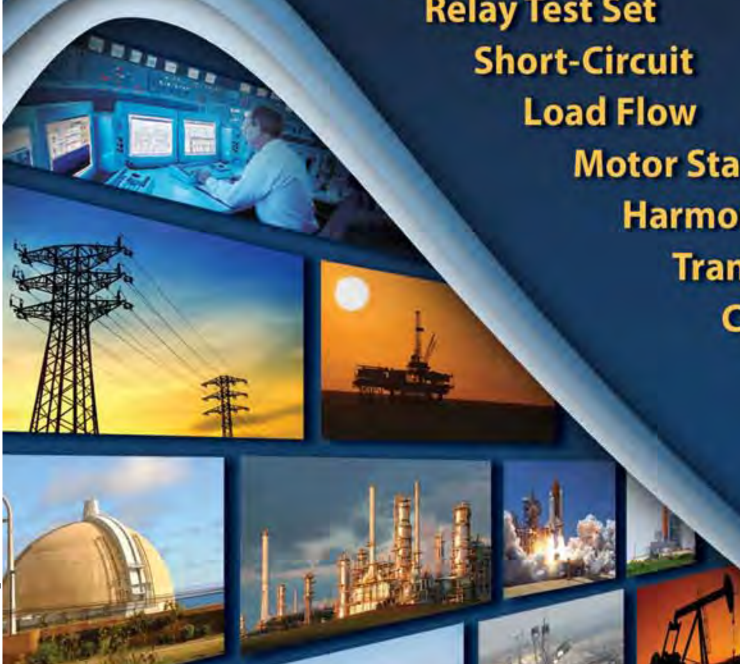

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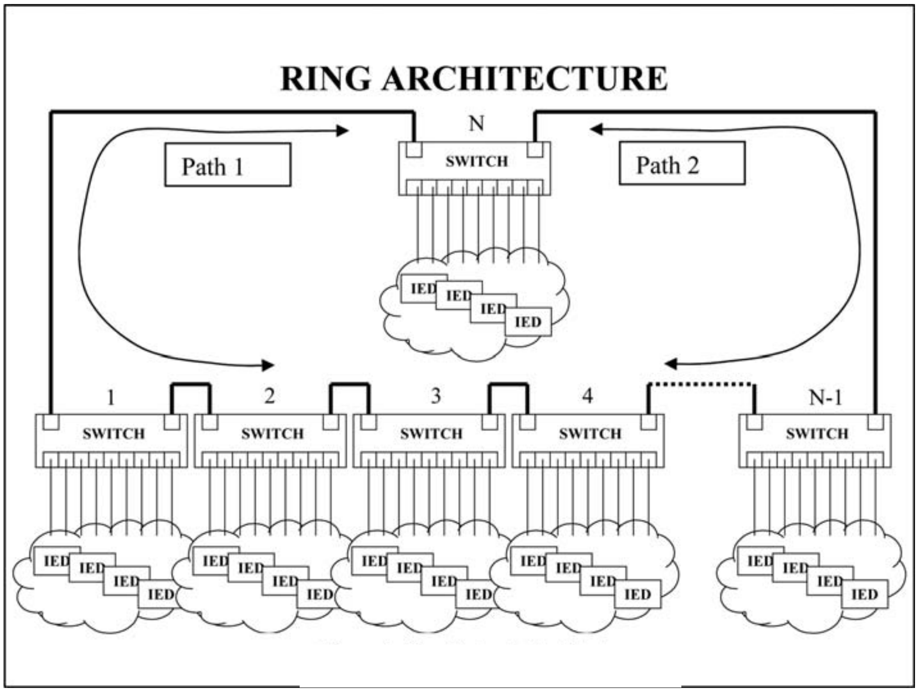

Figure 4a: Ring Network Architecture

endure the retransmission delays of Switch 1, Switch 2, and Switch 3 of the cascade or three 'hops'. Furthermore, it will also be delayed by the internal processing time of each switch; a parameter commonly specified as the Switch Latency. Let's workout this example for a 64 Byte message frame assuming the following:

- Message Frame size = 64 Bytes
- Speed of Uplink ports (i.e. the ports forming the cascade) = 100Mbps
- Internal Switch Latency = 5us (typical for 100Mbps ports)

Therefore:

- The frame transmission time = 64 Bytes * 8Bits/Byte * 1/100Mbps = 5.12 us.
- The total delay from Switch 1 to Switch 4 = (Frame Transmission Time + Internal Switch Latency) * (# of 'Hops') = (5.12us + 5us) * 3 = 30.36us
- The total delay from Switch 1 to Switch N = (5.12us + 5us) * N = N*10.12us

Advantages:

- Cost effective - allows for shorter wiring runs vs. bringing all connections to a central point.

Disadvantages:

- No Redundancy – if one of the cascade connections is lost every IED downstream of that connection is also lost.
- Latency – worst case delays across the cascading backbone have to be considered if the application is very time sensitive.

RING ARCHITECTURE

A typical ring architecture is shown in Figure 4a. It is very similar to the Cascading architecture except that the loop is closed from Switch N back to Switch 1. This provides some level of redundancy if any of the ring connections should fail.

Normally, Ethernet Switches don't like "loops" since messages would circulate indefinitely in a loop and eventually eat up all of the available bandwidth.

However, 'managed' switches (i.e. those with a management processor inside) take into consideration the potential for loops and implement an algorithm called the Spanning Tree Protocol which is defined in the IEEE 802.1D standard.

Spanning Tree allows switches to detect loops and internally block messages from circulating in the loop. As a result, managed switches with Spanning Tree actually logically break the ring by blocking internally. This results in the equivalent of a cascading architecture with the advantage that if one of the links should break, the managed switches in the network will reconfigure themselves to span out via two paths.

Consider the following example:

- Switches 1 to N are physically connected in a ring as shown in Figure 4 and all are managed switches supporting the IEEE 802.1D Spanning Tree protocol.
- Typically, network traffic will flow in accordance with Path 1 as shown in Figure 4. Switch N will block message frames as they come full circle thereby logically preventing a message loop.
- Now, assume a physical break in the Ring occurs, let's say between Switches 3 and 4.
- The switches on the network will now reconfigure themselves via the Spanning Tree Protocol to utilize two paths: Path 1 and Path 2 as shown in Figure 4 thereby maintaining communications with all the switches. If the network had been a simple cascading architecture, the physical break between switches 3 and 4 would have resulted in two isolated network segments.

While Spanning Tree Protocol (IEEE 802.1D) is useful and a must for Ring architectures or in resolving inadvertent message loops, it has one disadvantage when it comes to real-time control. Time! It simply takes too long; anywhere from tens of seconds to minutes depending on the size of the network. In order to address this shortcoming, the IEEE developed Rapid Spanning Tree Protocol (IEEE 802.1w) that allows for sub-second reconfiguration of the network.

Advantages:

- Rings offer redundancy in the form of immunity to physical breaks in the network.
- IEEE 802.1w Rapid Spanning Tree Protocol allows sub-second network reconfiguration.
- Cost effective cabling/wiring allowed. Similar to Cascaded architecture.

Disadvantages:

- Latency – worst case delays across the cascading backbone have to be considered if the application is very time sensitive (similar to Cascading)
- All switches should be Managed Switches. This is not necessarily a disadvantage per se but simply an added complexity. Although, the advantages of Managed Switches often far outweigh the added complexity.

Look in the July/August issue of Electricity Today for the second of this two-part article.

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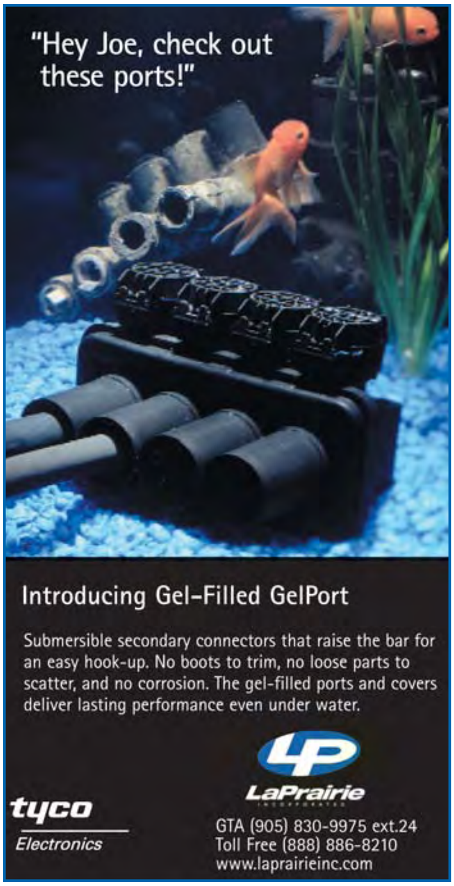

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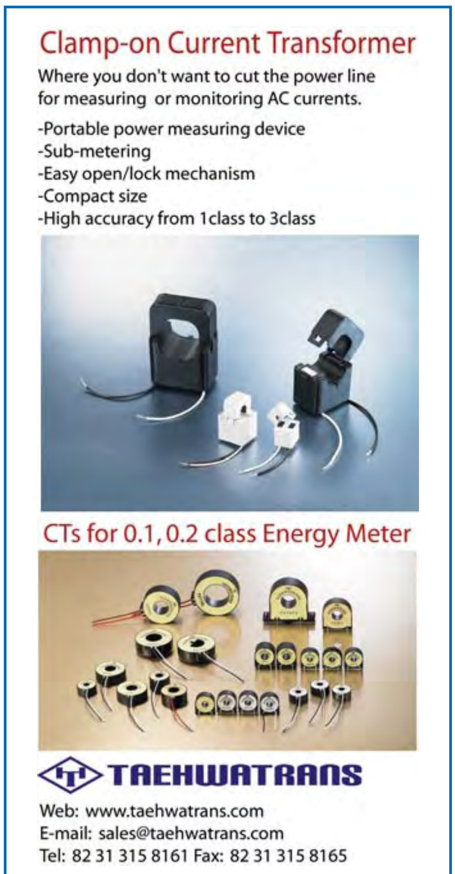

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