ISSUE 6, 2001

HV Engineering, Operations, Construction & Maintenance

ELECTRICITY TODAY

Power Generation, Transmission & Distribution, Utilization

CANADIAN ELECTRICITY FORUM

POWER DELIVERY AUTOMATION

ATCO Electric Studies
the Feasibility of Distribution Automation

TRANSFORMER TESTING

Frequency Response Analysis for
Diagnostic Testing of Power Transformers

GROUNDING ISSUES

Site Protection Through Proper Grounding,
Bonding and Design Practices

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METERING TECHNOLOGY

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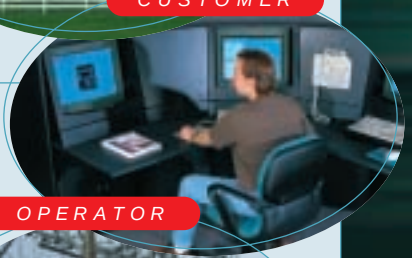

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EDITORIAL

Increase Your Energy Efficiency and Reduce Your Energy Costs Through Robust Electricity Metering, Monitoring and Management

I have been writing a lot recently about electricity deregulation and the need to enhance customer metering, monitoring and management of electricity. The fact is that electricity deregulation is bringing higher electricity prices. Because of this, the pressure to lower energy costs, increase productivity and profitability, improve system reliability, ensure power quality and reduce maintenance costs has increased the need for on-line, real-time electricity metering, monitoring and management.

Electricity is a necessary expense for all companies. Whether you operate a foundry, steel mill, petrochemical company, hospital or grocery store, you can't run your business without electricity. But what do you do when electricity costs go up? Are your customers willing to pay ten to fifteen percent more for your product? Clearly not. The solution is to manage your electricity costs.

Failure to properly meter, monitor and manage electricity can significantly impact the bottom line of any organization. Electrical engineering and maintenance personnel have long been interested in metering and monitoring electrical systems to help them take advantage of better management techniques.

The need to understand and implement electricity management techniques has received a great deal of attention in recent years because of three major factors:

- Increasing pressure to reduce operational costs. Since electricity costs are a significant portion of most facilities' costs, scrutiny is greater than ever.
- More complex utility rate structures and price fluctuations in the electricity marketplace resulting from utility deregulation.
- Increasing attention to power quality and reliability issues at all levels of facilities.

Among the benefits electricity monitoring can offer organizations are reduced maintenance costs, anticipation of potential failures and improved overall productivity. A robust electricity metering and monitoring system can also be helpful for tracking historical use trends and curbing electricity demand based on predetermined load-shedding criteria.

As well, getting the best price for electricity means knowing not only how much energy a facility consumes, but precisely when that energy is used and what equipment is using it - allowing for the development of load shifting and peak-load shaving strategies. Having this information will also help personnel negotiate favourable terms with utilities or electricity retailers.

To address these critical issues, The Canadian Electricity Forum is organizing three important Canadian forums titled: "Electricity Metering, Monitoring and Management: How To Increase Electricity Efficiency and Reduce Costs".;

These forums, are planned for this Fall in:

Toronto, Oct 1-2, 2001
Edmonton, Oct 2-3, 2001
Vancouver, Oct 4-5, 2001

At these forums, we are going to introduce power consumers to cutting edge hardware and software technologies and techniques available.

These forums will bring together representatives from electric utilities and large electricity consumers, Measurement Canada, metering manufacturers and software providers in an effort to show how a robust electricity metering and monitoring system can reduce electricity costs for large electricity consuming companies, increase plant efficiency and productivity, and reduce overall utility system demand. A robust electricity metering and monitoring system can also be helpful for tracking historical use trends and curbing electricity demand based on predetermined load-shedding criteria.

Delegates will have an excellent opportunity to ask specific questions and exchange ideas relating to their own unique situations. These forums are designed to be an interactive, problem-solving, learning environment for delegates of all disciplines.

Companies involved in these forums include: Power Measurement Limited, E2MS Inc. (PML Partner), Measurement Canada, Response Power Inc., Toronto Hydro Energy Services Inc., AltaSteel Ltd., Willis Energy, University of British Columbia (Utilities), B.C. Hydro, and Siemens Canada.

For detailed program content for our MM&M forums, link to www.electricityforum.com/forums.htm

Hope to see you at one of these forums.

Randy Hurst
Publisher
rwh@istar.ca

NEWS

International Energy Leaders Meeting in Newfoundland

Industry leaders representing the electricity, gas, oil, nuclear and coal sectors from Canada and the United States are meeting in St. John's, Newfoundland to discuss developments in eastern North America's offshore resources, North American energy policy and evolving energy industry technologies.

The three-day conference is being hosted by the Energy Council of Canada and has been successful in drawing energy leaders from as far away as Switzerland.

Philip G. Hughes, Chair of the Energy Council of Canada and President and Chief Executive Officer of Newfoundland Power Inc., says the three day conference is guaranteed to stimulate discussion on challenges facing the energy industry and innovative technologies that are required to move our country into the future.

"Canada has the ability to become a world leader in energy development," says Hughes. "What we are challenged with over the next few days is shaping the pathway which will help bring us to this goal."

A key topic of the Forum will be addressing the importance of developing an integrated continental energy strategy for North America. "The Energy Council of Canada recognizes the timeliness and importance of the development of a new energy strategy by Canada's major trading partner, the United States," explains Hughes. "We believe that both countries have a strong common interest in ensuring the availability of secure energy supplies at stable, reasonable prices to serve our closely linked economies."

Hughes says that energy supplies from Canada are secure, Canadian energy markets are increasingly open and competitive, and Canada has access to new energy sources required to meet the growing energy needs of the United States. "Consequently, now is the time for Canada to play a valuable role in developing an integrated energy strategy for the benefit of consumers in our North American countries," says Hughes.

U.S. Congress Struggles Over Energy Plan

As the Bush administration fans out to sell its energy program in town hall meetings across the US, the American Congress set out Tuesday to write its own plan.

A key committee in the US House of Representatives fended off efforts to block oil exploration in the Alaskan National Wildlife Refuge. But US President Bush's plan to drill for oil there still appears to face a tough test in the full House and almost certain defeat in the Senate.

Another House committee wrestled inconclusively with proposals to increase mileage standards for sport utility vehicles and small trucks. Republicans and Democrats clashed over how high the fuel-efficiency requirement should be and how gradually the higher standards should be phased in.

Meanwhile the Senate, matching an earlier House decree, unanimously agreed to block new oil drilling under the Great Lakes in 2002 and 2003. House and Senate Republicans generally have embraced President Bush's energy policy, with its emphasis on increasing fuel production and its late-blooming attention to conservation and alternative fuels. But Tuesday's developments illustrate that Congress is likely to devise its own policy — one that reflects the public's fading sense of urgency about energy, lawmakers' political needs back home and the partisan split between the Republican-controlled House and the Democratic-controlled Senate.

Gasoline prices have dropped after spiking in the spring and fears of electricity blackouts, such as those in California, have subsided. That has called into question the Bush administration's earlier assertions that the country was in an energy crisis. But Republicans and Democrats alike say a long-term energy policy is crucial to curb American reliance on foreign oil and volatile energy costs.

"Just because gasoline prices have dipped slightly doesn't mean that we don't have to have an energy policy for our country," said Sen. Kay Bailey Hutchison, R-Texas. "We cannot continue to ignore the bigger picture; that we do not have sufficient supply, we don't have distribution systems and we don't have . . . a real energy policy for energy self-sufficiency in our country for the long term. "

While the debate is under way, energy companies and corporate trade associations are pushing Bush's plan in a burst of radio, television and print ads. They tout expanded domestic oil and gas production, more pipelines and new power grids. One prominent group, the Alliance for Energy and Economic Growth, includes some of the biggest donors to the Republican Party.

Against that backdrop, the House Resources Committee on Tuesday defeated 29-19 an amendment by Rep. Edward Markey, D-Mass., that would have barred oil and gas exploration in the Arctic National Wildlife Refuge. Drilling in the refuge is one of the Bush energy plan's key components.

The House legislation would open 1.5 million acres there to exploration, but would require assurances that any oil extraction would have no "significant adverse effect" on the environment. Opening the refuge is the most controversial aspect of the Bush plan, and even if it survives the House, it does not appear likely to pass the closely divided Senate. "It's a unique national wonder that should be preserved," Markey said, noting that the refuge is a destination of migratory birds and herds of caribou and that the legislation would end its "pristine, wilderness condition."

That prompted a sharp retort from Rep. Don Young, R-Alaska, who argued that oil exploration would be unobtrusive in such a large expanse. "My biggest challenge today is not crying or laughing," he said, then asked Markey if he had ever been to the refuge. "He's never been there and doesn't know what he's talking about," Young said.

At the same time a block away, the House Energy and Commerce Committee was writing its "Energy Advancement and Conservation Act." But the panel put off the mileage standards for SUVs and light trucks, one of its most contentious issues, until Wednesday.

Committee Chairman W.J. "Billy" Tauzin, R-La., and Rep. John Dingell, D-Mich., offered a bipartisan compromise on the mileage standards that would require automakers to make SUVs that consume 5 billion gallons less fuel in model years 2004 through 2010.

Markey is seeking tougher standards that would require SUVs to improve to 40 miles per gallon by 2017. SUVs currently must meet a fleet-average standard of 20.7 miles per gallon. The average fleet standard for automobiles is 27.5 miles per gallon.

"There are some who would like us to go much further," Tauzin said. "Others would prefer that we not legislate in this area at all. I think we have found the right balance." ET

For more news visit www.electricityforum.com

POWER DELIVERY AUTOMATION

ATCO Electric Studies the Feasiblity of Distribution Automation

By Larry Dakin

Distribution Automation (DA) is a set of technologies that enables an electric utility to remotely monitor, coordinate and operate distribution components in a real-time mode from remote locations.

General Strategy

The corporate objective of ATCO Electric is to balance long-term distribution costs with reliability and availability. How will DA contribute in maintaining or improving the reliability indices of the distribution system?

What are some of the business issues seen today:

- Operational flexibility has to increase. (i.e. do more with less field and support staff).
- Industry migration to performance based rates.
- Coordination of operational requirements with Independent Power Producers.
- Need more comprehensive outage data.
- Improve system operations by utilizing all monitoring, visibility and control systems.
- Centralizing the function of the Distribution Operator in charge to a centralized location.

The technology of Faulted Circuit Indicators (FCI) has improved in recent years, and now remote alarming is readily available. It seems evident that this procedure will make a major contribution to reducing outage duration, even before considering remote alarming.

Increase Worker Productivity

There is a need to strive for higher manpower efficiency in today's world. We are expected to do more with less. Although DA may not reduce the total manpower requirement, our goal should be to better utilize the existing work force.

- Efficiency is gained by remote control of some down stream feeder devices. Even though this results in manpower and cost savings it will not be enough to pay back the Rate of Return of DA.
- DA will reduce the manpower required to do field monitoring for engineering.
- DA will allow more monitoring and control of the distribution system which will make it easier to maintain acceptable levels of service.
- DA will change the level of technical expertise required in field operations as there will be a greater requirement for electrical and communication technicians.

Improve Service Reliability

In the new deregulated world reliability is an important part of our business and customers are becoming more demanding. There is a requirement to meet or exceed the average reliability indices if we intend to be the preferred supplier. It is expected that future rate structures will be subject to performance based rates. Some of our present practices during an outage tend to extend the outage time to all customers, as there appears to be a trend to fix the problem and then restore power to all customers. We need to change this philosophy to isolating the problem and restoring power to as many customers as soon as possible and then fixing the problem.

- DA will reduce outage duration and allow better use of existing equipment.
- DA will also improve the ability for engineers to gather and analyze the data.
- An additional benefit is the ability to do distribution load curtailment on a more precise scale. This could be based on a frequency loadshed or could be peak shaving.

Initially the best payback in reliability is to focus on feeders that have historically shown poor results and are heavily loaded and serve a significant number of customers. Another prime target is feeders with alternate sources and normally open switches.

The financial impact of outages on customers is a concern. Some recent studies have quantified customer losses due to outages at about $10 per kWh not served. This cost may not be "hard" enough to dominate an internal business case, however customers will use such reliability numbers when selecting their energy supplier. As the preferred supplier it is important to retain existing loads and franchises.

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Reduce Electrical Losses

Due to the inductive nature of long rural lines, there is a significant opportunity to reduce electric losses and improve the poor power factor of much of the connected loads with centralized VAR Dispatch. Voltage control on feeders will also be improved. Reducing electrical losses makes good business sense and it is recommended that a program be commenced with or without DA functionality. There are a variety of concerns and questions as to the economical benefits of reducing the electrical losses.

- How do we gather enough load and voltage data to have adequate design criteria?
- Are the details in our models close enough to the physical layout of the feeder?
- What are the variables under which the compensation has to react?
- How do we validate the actual savings in terms of demand, energy and reductions in the revenue requirement?
- How do we find the long-term resources to make sure the compensation continually performs and to recognize when it has to be adjusted or removed?
- What is the impact to capacitors and harmonics?

We have a number of feeders where a common application to improve the power factor would be very efficient.

Reduce / Defer / Eliminate Capital Investment

The cost of adding DA can be very substantial depending on what, when and how it is implemented. Low cost can be achieved by using existing equipment and minimizing instal-

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a combined reduction in the Operation and Maintenance costs. DA can also lower the amount of capital improvements, which will have a positive effect on revenue requirements.

- The largest single cost of DA is adding SCADA and control of the distribution system at each appropriate substation. Normally, this has been a Transmission Substation cost.
- Adding DA to equipment on the distribution feeders will vary with desired operational benefits. This could range from $2,000.00 to $10,000.00. If equipment is not DA ready there could be an additional retrofit cost to upgrade.
- The use of a submaster device will keep communication costs reasonable if there are multiple controllers and remote terminal units in an area serving a number of automated substation functions.
- DA will provide improved monitoring so line performances will be maximized prior to costly upgrade solutions. Future upgrades will benefit from this experience, as results will be clarified by real time data.

Engineering and Procurement of DA Ready Equipment

All new procurement and engineering requirements for all distribution equipment will include some functionality to be DA ready.

- All new line switching devices installed on the critical sections of feeders will be capable of remote control or at least be easily adaptable.
- ATCO Electric will attempt to utilize as many standard systems as possible so that interfacing and integrating becomes much more practical. New systems and existing programs must be compatible in order for data and results to be shared.
- Communications protocol DNP 3.0 will become the ATCO Electric Standard and be included in all new equipment.

Observations and Recommendations

ATCO Electric is not proceeding with a company wide Distribution Automation project at this time.

- ATCO Electric will continue to work towards the implementation of Distribution Automation justified on a project by project basis.
- Initiate some short term and long term steady state monitoring of voltage and amperage.
- Standardize operating practices and philosophies around sectionalizing and coordination of service restoration.
- Continue to improve on how we report and manage outage data.
- Develop and apply an application philosophy for drive-by fault indicators.
- Distribution Automation will not reduce outage frequency so the root cause of outages should be managed first.
- The Automatic Meter Reading system used by ATCO Electric is not a viable option as a Distribution Automation communications carrier.
- Continue to look at system improvements to improve system reliability prior to Distribution Automation.
- ATCO Electric will continue to proceed or accelerate the installation of SCADA for distribution breakers in all substations.

Larry Dakin is with Distribution Operations at ATCO Electric. This article is based on a paper from the Western Power Delivery Automation Conference. ET

METERING TECHNOLOGY

Territory-wide AMR Yields Big Results for Rural Electric Cooperative

By Don Snell and Becky Lorentz

Automatic meter reading (AMR) is more than a method to obtain a meter read; it's a vital tool for significantly improving customer service in the eyes of the consumer. In fact, the positive impact that AMR has on customer service is one of the top three reasons for installing AMR, according to the Chartwell AMR Report 2000.

Providing superior customer service is a key element for successful companies in the evolving utility industry. Advancing technologies, combined with consumers' expectations to pay less for fast and convenient services, drive utility leaders to constantly improve programs and customer relationships.

Consumers want to be in control and make their own decisions about their utility needs. Choice is becoming more important than loyalty to the product or company. The industry is facing a new business model in the customer-choice environment, and utilities are finding that AMR is the practical solution for excellent customer service — and the key to consumer retention.

AMR affects customer service in a number of ways. It provides accurate and timely meter reads, speeds the resolution of billing issues and improves the reliability of services. In the end, AMR builds trust and loyalty.

Billing supervisors, line maintenance crews, system engineers, customer service representatives — just about all utility management — are discovering new ways to utilize data from some AMR systems to give better customer service, maintain the system, and cut line loss.

Good Customer Service Leads to New Business

Data collected through meter reads provides more than just a kWh total. Minnesota Valley Cooperative Light & Power Association, which serves 5,000 members in southern Minnesota, implemented a power-line carrier AMR system with a focus on customer services. The territory-wide deployment of the Turtle® system also allows the cooperative to address several critical business issues.

The system, developed by Pequot Lakes Minnesota based Hunt Technologies, Inc., has improved members' quality of life because it eliminates the need for self-reads, which can be strenuous in a harsh northern climate. Members' high regard of the AMR program has increased loyalty and reduced the risks of losing members to competitive electric providers.

This loyalty allows Minnesota Valley to generate additional revenue through new services. Faced with a stagnant membership growth rate, cooperative leaders have found that business diversification combined with exceptional customer service is the key to building the utility's business. New offerings such as heating systems, monitoring services, cellular phone plans and loans are a growing part of the cooperative's business model.

The impact that AMR has on Minnesota Valley's operations — and bottom line — is dramatic. Since deploying the system, the cost of reading single- and three-phase meters has decreased significantly. Other benefits include:

- High-bill complaints have decreased from 20 calls per month to two.
- Site visits have decreased from 10 per month to approximately 4 per year.
- Cooperative employees no longer need to spend time reviewing billing variance reports.

All of these benefits add up to saved revenue for electric utilities, which typically measure the success of an AMR system by how fast it pays for itself through savings in labor costs, vehicle expenses, more accurate billing, and improved cash flow. The actual break even point on an AMR investment varies significantly between utilities, but industry average is about seven years.

Minnesota Valley has streamlined processes in ways that would have been impossible without AMR. Overall, AMR decreases operating expenses by about $38,060 a year.

Don Snell is with Minnesota Valley Cooperative Light & Power Association and Becky Lorentz is with Hunt Technologies, Inc. ET

METERING TECHNOLOGY

Submetering: Increased Interest in a Low-Cost Technology

By Don Millstein

The problems of rising electricity costs, increasing power consumption and supply unpredictability in the U.S. are sending palpable warning signals to Canada. According to a May 2001 update to the second edition of the Retail Energy Deregulation Index 2001 (RED Index), Canada already suffers from constrained power supply in the Pacific Northwest.[1]

Additionally, provinces are keeping a wary eye on California's rolling blackouts and skyrocketing electricity prices while grappling with their own experiments in restructuring. Alberta's electricity prices quadrupled last year and Ontario is determined to avoid a similar fate. On the bright side, the unstable energy environment in California provides countries like Canada with not only a valuable lesson on avoiding deregulation pitfalls but also on effectively implementing cost-saving options.

Energy Probe, a Canadian consumer and environmental advocacy group, estimates that Ontario's electricity prices will rise at least 20 per cent in two years and utility experts expect electricity bills in Ontario to more than double.[2] Predictions like these are causing Canadian businesses to rethink how they manage their energy usage, especially when considering the U.S. energy situation.

This emphasis on energy conservation to lower electricity bills has led to a surge in interest in submetering technology.

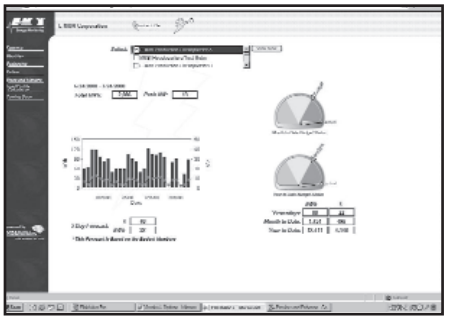

Figure 1: Above is an example of an online metering service which gives the user graphical and statistical reports including: load profiling, multi-site aggregation, budgeting and forecasting.

Although it has existed for some time, submetering technology is drawing renewed attention from energy-conscious regions. In June 2001, for instance, California sponsored a program to install more than 3,400 meters in Los Angeles businesses to help with the areas' energy crisis. Indeed, utility and facility managers, building engineers,

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Figure 2: About 50 per cent of the Bank of America Center at 555 California Street in downtown San Francisco is now electrically submetered, capturing an annual energy cost savings of over $1 million.

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Electricity is a necessary expense for all companies. Whether you operate a foundry, steel mill, petrochemical company, hospital or grocery store, you can't run your business without electricity. But what do you do when electricity costs go up? Are your customers willing to pay ten to fifteen percent more for your product? Clearly not. The solution is to manage your electricity costs.

Failure to properly meter, monitor and manage electricity can significantly impact the bottom line of any organization. Electrical engineering and maintenance personnel have long been interested in metering and monitoring electrical systems to help them take advantage of better management techniques.

Three Important Reasons To Attend This Forum:
The need to understand and implement electricity management techniques has received a great deal of attention in recent years because of three major factors:

- Rising pressure to reduce operational costs. Since electricity costs are a significant portion of most facilities' costs, scrutiny is greater than ever.
- More complex utility rate structures and price fluctuations in the electricity marketplace resulting from utility deregulation.
- Increasing attention to power quality and reliability issues at all levels of facilities.

Today, the pressure to lower energy costs, improve system reliability, ensure power quality and reduce maintenance costs has increased the need for on-line, real-time electricity metering, monitoring and management.

Among the benefits electricity monitoring can offer organizations are reduced maintenance costs, anticipation of potential failures and improved overall productivity. A robust electricity metering and monitoring system can also be helpful for tracking historical use trends and curbing electricity demand based on predetermined load-shedding criteria.

As well, getting the best price for electricity means knowing not only how much energy a facility consumes, but precisely when that energy is used and what equipment is using it - allowing for the development of load shifting and peak-load shaving strategies. Having this information will also help personnel negotiate favourable terms with utilities or electricity retailers.

This comprehensive program will update delegates about the latest technologies and techniques available in this area. This forum also offers an excellent opportunity for delegates to ask specific questions and exchange ideas relating to their own applications. This is designed to be an interactive, problem-solving, learning environment for delegates of all disciplines.

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energy consultants and service providers the world over are interested in submeters for being cost-effective, easy to install and for having a proven track record for lowering energy bills. This sophisticated technology succeeds by gathering and delivering real-time energy usage data to facility operators, allowing them to take proactive measures to significantly reduce bottom line costs.

Energy Management

The combination of submetering equipment and software is used to monitor a facility's energy via comprehensive energy profiling - information needed to determine a facility's energy demand and usage levels. The information garnered from tracking electricity usage this way is then used for peak shaving, load shedding, aggregation and other measures, that lead to lowered energy bills. A submetering device provides the energy manager with energy consumption data showing how slices of the "energy pie" are distributed to the various departments, tenants, or processes within the building or facility. From here, submetering lets the consumer define energy usage all the way down to a 15A branch circuit, if necessary. Such precise metering happens from tracking demand (kW) and usage (kWh) to provide aggregate data. With the appropriate software, the user can manipulate and display this raw information on a centralized or remote Windows-based PC operator interface.

Automatic Meter Reading (AMR) capability allows the submetering system to be read anywhere, anytime, and in any weather from the convenience of a computer. Time-of-use graphs and charts give the user the data necessary for real-time pricing, event analysis, Demand Side Management (DSM) programs and Energy Management System (EMS) performance analyses. For added flexibility and convenience, energy managers can choose to access submetering information on-line. A submetering company, for example, can offer a service that helps users track and analyze their electrical consumption and demand by logging on to the Internet. The energy data is acquired from any meter with a pulse output, such as utility meters and submeters. The metering data is collected by a hardware interface and sent via cellular or telephone modem to the server. The information is posted daily to the subscriber's password-protected folder where it may be accessed directly by a PC (Fig. 1). By using this type of service, users can access the following energy profiles over the Internet:

- Statistical analysis of energy consumption
- Energy analysis by: 15, 30, 60 minute intervals
- Daily, M-T-D, Y-T-D
- Weather, Degree Days
- Budgets
- KWH, KW, $

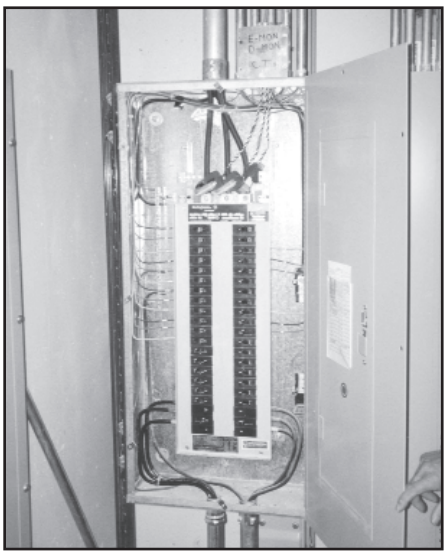

Figure 3: Split core sensors, like those shown in this breakerpanel, allow electronic submeters to be quickly and easily installed without powering down the load or rewiring the panel.

Figure 4. A multiple meter unit may contain up to eight submeters and a communication interface device that downloads data from the meters and transmits it via modem to the energy manager's PC.

Lowering Energy Bills

Companies like E-MON Corporation, which has customers ranging from multi-tenant apartment buildings, government facilities, sky rises and the personal estate of Microsoft founder Bill Gates, has seen its customers enjoy significant energy savings due to submetering installations (fig. 2). Demand in submetering products is growing concurrently with California's energy crisis and with a global concern for energy conservation. For example, many multi-tenant and multi-building facilities are using electric submeters and Automatic Meter Reading (AMR) equipment for billing and allocation, cost center analysis, energy use verification and demand control and analysis to save energy, and money.

Studies have shown that 7-15 per cent cost savings can be achieved by simply allocating electricity to the proper user. Not only is this method more equitable than lumping various users or departments onto one bill, it gives facility managers a way to view and control how energy is allocated at their sites. If governmental or company incentives are involved, individual energy users are empowered to lower their own usage and reap financial benefits, while skirting penalties for another tenant's or co-worker's poor energy habits. Typical facilities applying submetering for cost allocation measures, include:

- Government facilities
- Hospitals
- Airports
- Schools and universities
- Multifamily dwellings
- Shopping centers
- Industrial facilities
- Commercial Offices

As a system "watchdog," the submetering base informs the user of any changes in energy usage patterns. It can also act as a power quality meter to draw attention to possible anomalies in expected electrical system performance. At the enterprise level, submetering allows facility managers to accurately assess energy usage by specific areas to highlight energy efficiency opportunities and to implement electrical demand "shedding" or "rolling". In plant floor settings, submetering allows engineers to precisely evaluate the performance of individual machinery and processes, as well as to identify inefficiencies and opportunities to increase productivity.

Additionally, besides allocating or dividing and properly allotting energy costs according to usage, submeters can be used for aggregation, or combining loads from various sites to negotiate rates with energy providers. Savings on such aggregated demand can average up

to 20 per cent — especially in applications where loads are diverse (where peak demand is generated at different times) as in hospitals, schools, and manufacturing plants that may have more than one location.

Ease of Installation

Submeters are installed after the master meter in a building or facility. Besides being low-cost, submeters are safe since electricians don't even need to power down the load to install. Additionally, the meters facilitate electricity monitoring without doing major changes inside a commercial or residential building (Fig. 3.). Indeed, installation is simply a matter of hooking three current sensors around the electrical feeds being measured. And, the meter can be mounted anywhere.

In this way, the contractor can quickly turn a very profitable installation in a fraction of the time needed to install an older style socket-based meter. All told, the time and cost to install an electronic submeter typically runs less than 25 per cent of having the utility install a dedicated meter on the same circuit.

Contemporary electronic submeters eliminate the need for meter pans and current transformer (CT) cabinets, and are much easier and flexible to install. Their compact size allows installation in areas too cramped for previous metering methods (Fig. 4).

It's not uncommon to install 40 or more electronic submeters in the same amount of space occupied by fewer than half a dozen electromechanical type submeters. Since feedthrough wiring is not required, subpanels aren't necessary for proper monitoring. In fact, multiple meters can be used to monitor individual circuits in a breaker panel without having to rewire the panel.

The Bottom Line

Applied in a diversity of applications, submeters are allowing buildings, institutions and utilities to realize savings of up to tens of thousands of dollars per month, depending on the type of facility being profiled. The reason? Advanced metering equipment puts knowledge and control in the hands of facility operators. By comparing historical energy usage with current trends, these managers can identify energy savings opportunities guaranteeing the largest payback.

Because data and budget numbers play a major role in determining the best energy conservation measures to undertake, the information gathered from PC and web-based software and meters is an invaluable resource.

Submeters are a cost-effective, tried-and-true method for lowering energy costs — in a time when energy savings can mean business survival.

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Don Millstein is the president of E-MON Corporation. ET

TRANSFORMERS

Frequency Response Analysis for Diagnostic Testing of Power Transformers

By Simon Ryder

Frequency Response Analysis, generally known within the industry as FRA, is a powerful diagnostic test technique. FRA consists of measuring the impedance of transformer windings over a wide range of frequencies and comparing the results of these measurements to a reference set. Differences may indicate damage to the transformer, which can be investigated further using other techniques or by an internal examination.

Fundamentals

FRA essentially consists of measuring the impedance of transformer windings over a wide range of frequencies and comparing the results of these measurements with a reference set. There are two ways of injecting the wide range of frequencies necessary: either inject an impulse into the winding or make a frequency sweep using a sinusoidal signal. The former is sometimes known as the impulse response method and the latter as the swept frequency method. Both methods are currently used within the industry.

The shorter measurement time of the impulse response method offers an advantage over the swept frequency method.

However, the swept frequency method offers the following advantages over the impulse response method:

- Better signal to noise ratio.
- Equal, or near equal, accuracy and precision across the whole measurement range.
- Less measuring equipment is required.
- Wider range of frequencies are injected.

The impulse response method is similar to an earlier test method known as low voltage impulse measurement, or LVI (see [1] and [2] for more information on this method, which is not often used any more).

So far as is known, the swept frequency method was invented by Dick and Erven between 1975 and 1977. The first description of the method to appear in the literature is [3]. Important recent publications on this subject have been made by Vaessen and Hanique [4], Lapworth and Jarman [5] and Noonan [6].

Measurement Method

The swept frequency method for FRA requires the use of a network analyzer to generate the signal, take the measurements and manipulate the results. The basic measurement circuit used is shown in figure 1.

The tested impedance, in this case the transformer winding, is ZT. The standardized test impedance, in this case the impedance of the measurement cables, is ZS. The injected signal is S, the reference measurement signal is R and the test measurement signal is T.

Figure 2 shows engineers performing measurements on a test transformer as part of a research program.

The network analyzer is controlled by a laptop computer. This reduces the probability of human error and speeds measurement. The network analyzer and the laptop computer are earthed using an isolating transformer, the screen of which is connected to the same earth as the transformer tank. Screened measurement cables are used, and these are earthed at both ends. This reduces the influence of the cables at high frequencies (above 500kHz).

Advice

The author offers the following advice for making good FRA measurements:

- Always use the same frequency range. Start at about 5Hz, continue to about 10MHz.
- To cover the necessary range, you will have to make more than one sweep with the analyser. If the analyser supports logarithmic frequency sweeps, use this function to reduce the number of sweeps made.
- Set the resolution bandwidth to about 10 per cent of the measured frequency.
- Use the shortest cables available. If you intend to make measurements on transformers of radically different sizes, have more than one set of cables.
- Make sure the cable joints are not touching before starting any measurements.
- Make sure the cables are reasonably straight and not knotted together. Keep the measurement cables away from the power lead.
- Make sure that the transformer is completely disconnected at every terminal before making the measurements. Even very short lengths of external connection can have a strong effect on the results.

Results

Results of FRA measurements are conventionally displayed in modulus-argument form. The modulus is usually referred to as the gain or the amplitude and the argument as the phase.

The amplitude is presented in decibels, on a 50Ω base. (The 50Ω base is because 50Ω co-axial cables are conventionally used for FRA measurements).

The amplitude k is defined by:
[5.1] $k = 20\lg(T/R)$
using the same notation as in figure 1.

Similarly the phase ϕ is defined as:
[5.2] $\phi = \angle(T/R)$
using the same notation as in figure 1.

The author uses the gain in assessing the results of FRA measurements, rather than the phase. The gain contains almost all of the useful information in the measurements, and it is not usually necessary to consider the phase as well.

Comparison Methods

As was stated before, FRA essentially consists of measuring the impedance of the transformer windings over a wide range of frequencies and comparing the results of these measurements with a reference set. The reference measurement will ideally have been made previously on the same winding in the

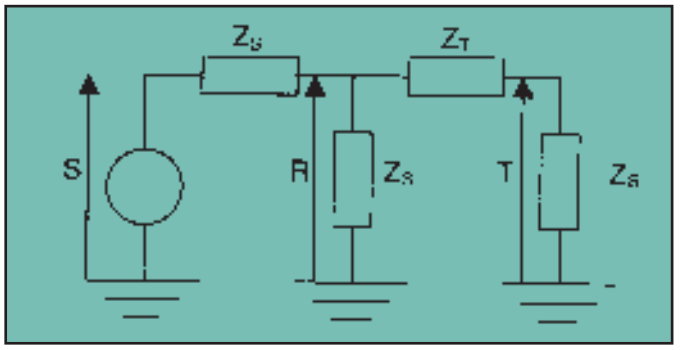

Figure 1: Basic Measurement Circuit

Figure 2: Performing measurements on a test transformer

same transformer. If no measurements from the same winding are available, they can be obtained from another phase, which is known or assumed to be undamaged, or from a sister transformer. Different phases of the same transformer are usually more alike than different transformers of the same design, so it is preferable to use a reference measurement on an undamaged phase of the same transformer. There is no such thing as a 'typical ' measurement, so measurements made on 'similar ' transformers cannot be used as a basis for comparison.

The comparison is usually made by eye. Some work has already been done on more advanced methods of comparison (see reference [7] for information on neural networks or reference [8] for a statistical method). It is likely that more work will be necessary before these methods can be used routinely.

For a comparison by eye, the author plots the results on a log-linear scale, with frequency on the logarithmic abscissa and gain as the linear ordinate. A useful scale for the abscissa is from 10Hz to 1MHz, a larger scale does not add much useful information. Any particularly interesting parts of the curve can be viewed in more detail using one or two decade band plots. The range for the ordinate should be chosen so as to fit the measurements on the curve as clearly as possible.

Both sets of measurements should be plotted on the same axes. If additional measurements are available, these can be plotted as well. In the author's experience, six is the largest number of sets of measurements which can be assessed at the same time.

In comparing the sets of measurements, the key indicators of damage are:

- Changes to the overall shape of the graph.
- The creation of new resonant frequencies or the elimination of existing resonant frequencies.
- Large shifts in existing resonant frequencies.

It is often useful to note the resonant frequencies in each trace, to see where and how many new resonances have been created or how large the shifts in existing resonances are.

Detectable Faults

As has been stated before, FRA consists of measuring the impedance of transformer windings over a wide range of frequencies. Faults, which change either the winding capacitances or the winding inductances, are detectable. Fault simulation programs made by Bak-Jensen et al [8], by Noonan [6] and by the author and his colleagues (underway, no publications yet) have indicated that the following faults are, or are not, detectable using FRA:

Nature of Fault	**Detectable?**
No core earth	Probably not detectable except under laboratory conditions.
Multiple core earths	Usually not detectable
Foreign object	Not detectable.
Additional turns:	
-on yoke	Detectable.
-on limbs	Detectable.
Short-circuited turns	Detectable.
Mechanical damage:	
-to windings	Detectable.
-to core	Detectable if very severe.
Windings unclamped	Probably not detectable except under laboratory conditions.
Loose turns	Detectable.
"Normal" ageing	Detectable if very severe.

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FRA is the only method known to the author which is capable of reliably detecting faults involving damage to the windings (mechanical damage and loose turns). It is the most reliable method known to the author for detecting faults involving the short-circuiting of existing turns or the creation of new turns (short-circuited turns or additional turns on the limbs or yokes).

Case Studies

A small number of case studies will now be presented to illustrate how FRA may be applied to fault diagnosis, and illustrate the points made earlier on the comparison of sets of measurements.

Case Study 1

This illustrates the normal differences between different phases of the same transformer. The transformer concerned is a 100kVA, 20/0.4kV, three phase, Dyn1, pad mounted distribution transformer. Figure 3 shows three sets of measurements made on the three phases of the LV winding.

There are some differences at low frequency. These are caused by differences in the inductances of the windings at low frequency (the capacitances are substantially the same). At low frequencies the magnetic flux is confined to the core. In the case of B phase the two return paths within the core have the same length and there is a single low frequency resonance. In the case of A and C phases there are two paths having different lengths, which give rise to a double resonance. These occur at slightly different frequencies on the two phases, partly owing to differences in the reluctances of the core joints and partly owing to differences in the state of residual magnetisation.

Case Study 2

This illustrates the effect of residual magnetisation for the same phase of the same transformer. The transformer concerned is the same as for case study 1. Figure 4 shows three sets of measurements made on A phase of the LV winding. These are a baseline measurement (normal residual magnetisation), a measurement made with the core de-magnetised and a measurement made with the core saturated by passing dc through the windings.

There are differences between the three sets of measurements at frequencies up to about 500Hz, or about double the first resonant frequency. Both of the first two resonant frequencies have shifted slightly and there are also some slight changes to the amplitude of the measurements.

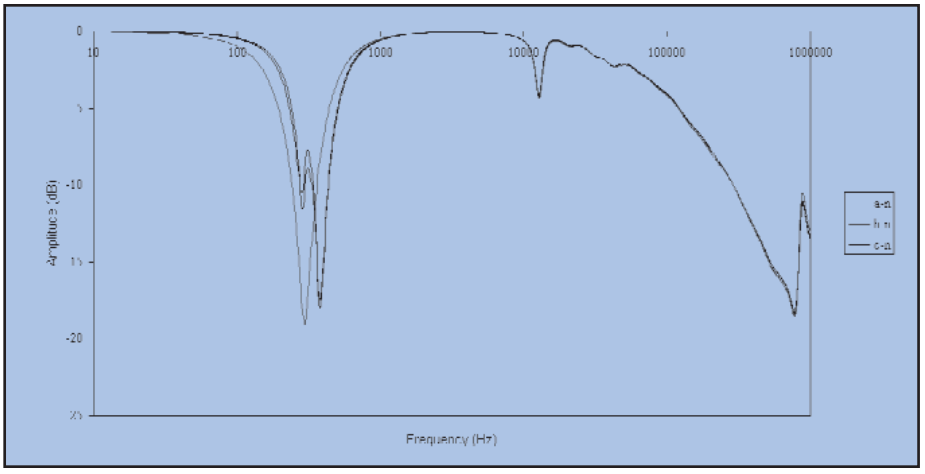

Figure 3: Frequency Response of LV Windings of 100kVA, 0.4/20kV, Three Phase, Dyn 1, Pad-Mounted Distribution Transformer

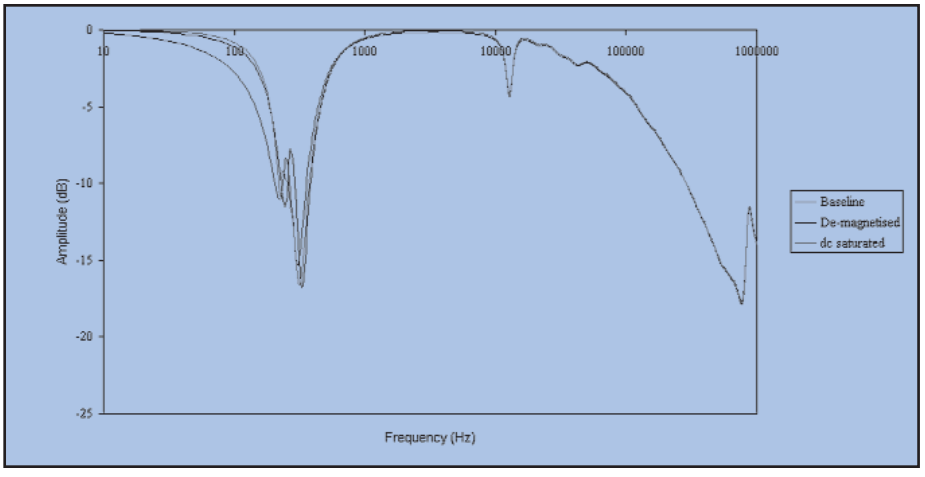

Figure 4: Frequency Response of LV o-n Winding of 100kVA, 0.4/20kV, Three Phase, Dyn 1, Pad-Mounted Distribution Transformer with Different States of Residual Magnetisation

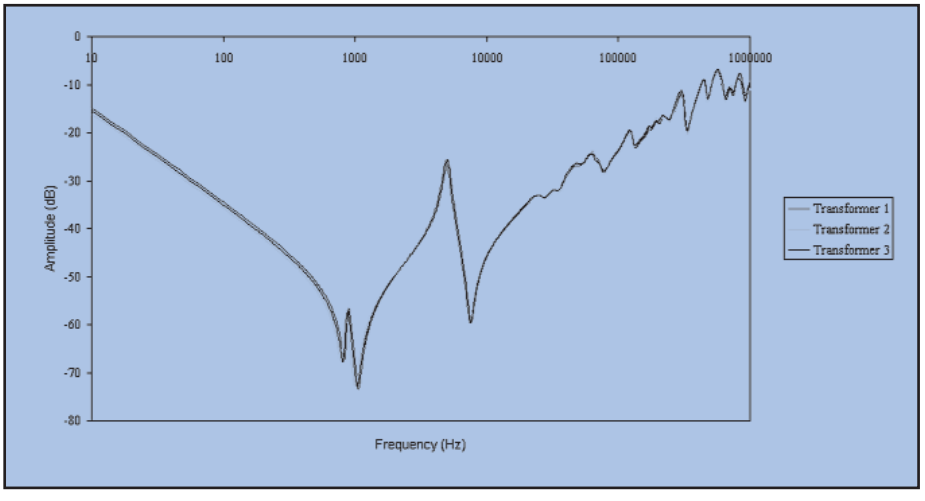

Figure 5: Frequency Response of HV A-N Windings of 36MVA, 62.5/21kV, Three Phase, YNyn0, Substation Transformer

Case Study 3

This illustrates the normal differences between measurements made on different transformers of the same design. The transformer concerned is a 36MVA, 62.5/21kV, three phase, YNyn0, sub-station transformer. Figure 5 shows three sets of measurements made on A phase of the HV winding on

different transformers of the same design.

There are some small differences at low frequencies around the first two resonant frequencies, as before. These differences are partly owing to differences in the reluctances of the core joints and partly owing to differences in the state of residual magnetisation.

Case Study 4

This illustrates the differences which may arise owing to measurement problems. The transformer concerned is a 36MVA, 89.5/21kV, three phase, YNd11 sub-station transformer. Figure 6 shows a good and a bad set of measurements for each phase of the HV winding. The cause of the problems is a badly made connection in the earthing circuit.

It can be seen that the main effect of the bad joint is at higher frequencies. Differences are apparent above 300kHz and by 1MHz the differences are quite large. Note that the bad measurement series shows a lower gain than the good measurement series.

The starting frequency and the changes to the shape of the curve in this example are highly characteristic of this problem.

Case Study 5

This illustrates a serious fault on an operating transformer. The transformer in question was a 70MVA, 227/21kV, three phase, YNyn6, sub-station transformer. The fault in question was a circulating current through an intermittent connection in the HV winding. This had caused localised erosion of the conductor and conductor insulation, arcing under oil and the generation of gas.

The transformer was removed from service following a Bucholz relay alarm, investigatory tests were made and the transformer was finally returned to the manufacturer's facilities for a strip-down and repair. Figure 7 shows a set of measurements for each phase of the HV winding.

Differences between the three phases are apparent at very low frequency (below 20Hz). Differences are also apparent, although less obvious at high frequencies, beginning at about 170kHz and continuing up to 1MHz. B phase seems to be most different from the others (and is believed to have been the phase which was generating the gas which caused the Bucholz relay alarm).

The differences at very low frequency were probably caused by the circulating current loop itself, whilst those at high frequency are probably a result of the consequent damage.

Case Study 6

This illustrates the use of FRA in the decision making process for a failed transformer. (A more detailed account of how FRA was used in this case may be found in [9]). The transformer in question was a 300MVA, 400/225kV, three phase, Yna0+d, autotransformer. The fault in question is still under investigation, but is believed to involve mechanical damage to the C phase series winding caused by a bushing failure. The tank of the transformer had been damaged and the HV bushings destroyed in the failure. Tests were made to determine whether the windings were damaged, to decide whether the transformer should be repaired or scrapped. The tests indicated that the windings had been damaged and so the transformer is to be scrapped. Figure 8 shows a set of measurements for each HV (series and common togeth-

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er) winding.

Important differences are apparent between C phase and the others. Note how the fifth resonance, at about 17kHz, completely disappears from C phase. Note the creation of a new resonance, at about 460kHz, on C phase.

Integration into a Condition Assessment Program

As has been stated before, FRA is the only method known to the author which is capable of reliably detecting faults involving mechanical damage to the windings. It is also the most reliable method known to the author for detecting faults involving the short-circuiting of existing turns or the creation of new turns (short-circuited turns or additional turns on the limbs or yokes).

FRA thus forms a necessary part of any comprehensive condition assessment program. Additional tests and measurements should be used to cover the faults which FRA is not capable of detecting, most importantly normal ageing and partial discharge. By combining FRA with these other tests and measurements a complete picture of the condition of the transformer can be established and informed decisions about life management made.

In [10] Noonan describes the policy of his company (ESBI) in routine monitoring and in condition assessment prior to decision making. He states that his company uses the following program prior to decision making:

- Oil tests (breakdown voltage, moisture content, neutralisation value, colour, resistivity and relative permitivity).
- Oil dissolved gas analysis.
- Oil furan analysis.
- Paper sample degree of polymerisation measurement (where possible or necessary).
- Paper sample moisture content test (where possible or necessary).
- Inter-winding and winding-earth power factor measurements.
- Inter-winding and winding-earth capacitance measurements.
- Bushing main insulation-earth and test tap-earth insulation power factor and capacitance measurements.
- Winding resistance measurement.
- Magnetising current measurement.
- Leakage reactance measurement.
- Polarisation spectrum measurement.
- Infrared thermal vision.
- Frequency response analysis.

A visual inspection of the outside of the transformer and the tapchanger diverter switch is performed at the same time. The operating, maintenance and fault histories of the transformer are reviewed.

The condition of the auxiliaries and

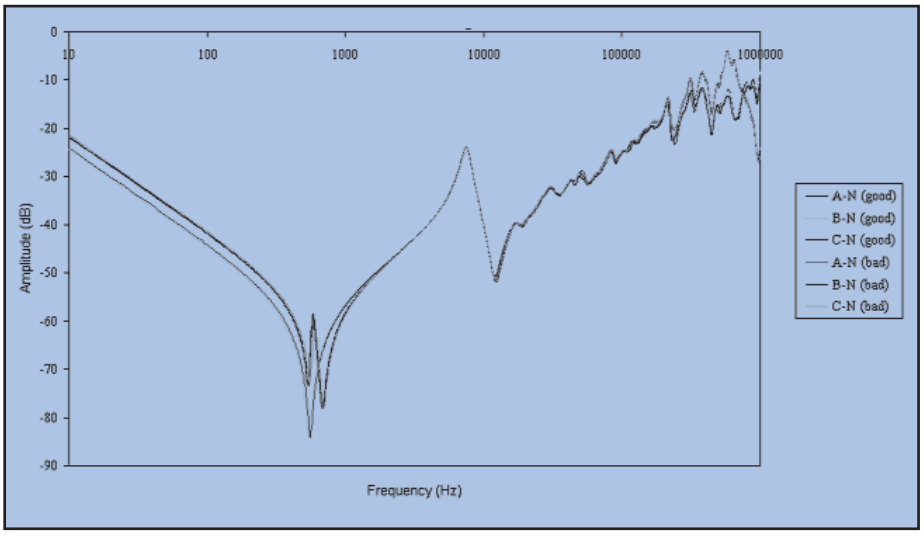

Figure 6: Frequency Response of HV Winding of 36MVA, 62.5/21kV, Three Phase, YNyn0, Substation Transformer Showing Effect of Bad Measurement

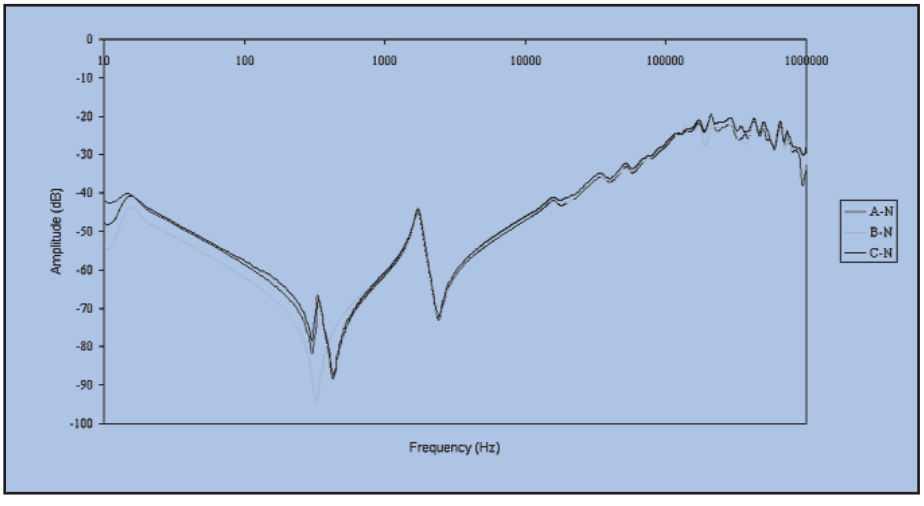

Figure 7: Frequency Response of HV Winding of 70MVA, 227/21kV, Three Phase, YNd11, Substation Transformer with Circulating Current in HV Winding

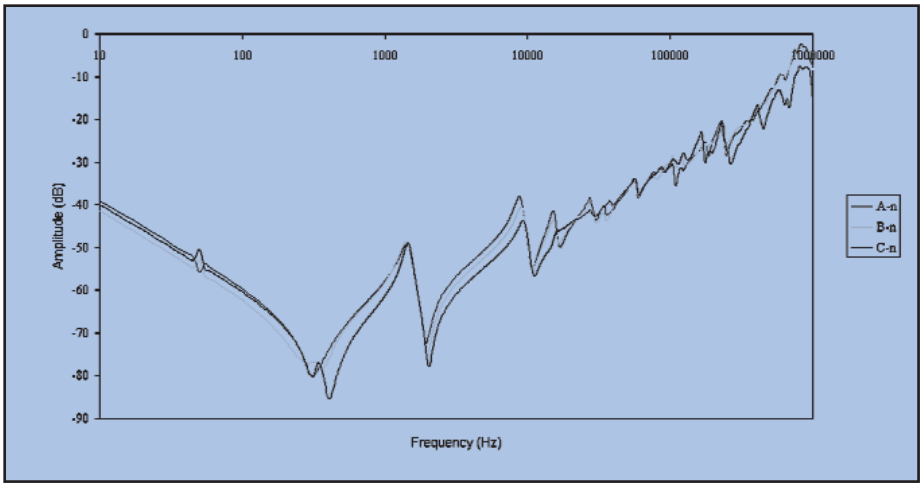

Figure 8: Frequency Response of HV Winding (series and common) of 300MVA, 400/22.5kV, Three Phase, YNna0+d, Autotransformer with Suspected Mechanical Damage to C Phase Series Winding

the availability of spares are reviewed.

The above program is quite comprehensive. It does not include any direct measurements of partial discharge, although prolonged partial discharges will be apparent in the dissolved gas analysis.

Conclusions

Frequency response analysis is a powerful tool for transformer condition assessment. It is able to detect a wide variety of internal faults, and is especially useful for faults involving damage to the windings. It can be integrated into a program with complimentary measurement techniques to provide a complete picture of the condition of the transformer concerned. This information is useful in decision making, especially for suspect transformers.

Some work still needs to be done to establish a really good method for the pre-determination of FRA measurements. (So far as the author is aware, [11] represents the best effort so far). As well, work still needs to be done on an objective and transparent method for comparing sets of FRA measurements.

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SHOW FEATURE

2001 AMRA International Symposium

Portal to Strategic Services

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Welcome to AMRA 2001 International Symposium

AMRA, its officers, trustees and Program Committee welcome attendees of the AMRA 2001 International Symposium to Québec City — one of the most beautiful and historic cities in North America. The theme this year is "Portal to Strategic Services."

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- Value-Added Services
- Information Management
- Project Implementation
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- C&I Solutions
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- Technology
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- Frank Betley, President and CEO, Continental Cooperative Services
- André Caillé, President and Chief Executive Officer, Hydro-Québec
- Stephen Fabiani, Vice President of Retail Sales and Marketing, Select Energy
- Steven Rivkin, Attorney, Consultant and Author
- Jim Rodier, Attorney and Consultant, Sanders & McDermott PLLC
- NFL legend Joe Theismann

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- Understanding and Implementing Utility Industry Standard Tables ANSI C12.19/IEEE 1377
- Using AMR Data for Building Successful Customer Services — Residential and C&I
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Ron Chebra,
AMRA President

SHOW FEATURE

An Overview of Key Note Presentation

Exciting sessions are scheduled for Monday, Sept. 10, and Wednesday, Sept. 12. Keynote presentations will be delivered by:

André Caillé, president and chief executive officer of Hydro-Québec, will discuss technologies the utility has deployed to improve service and gain business — especially in the commercial and industry sector.

Stephen Fabiani, vice president of retail sales and marketing for Select Energy, will focus on metering issues and business needs for energy suppliers and large customers.

Frank Betley, president and CEO of Continental Cooperative Services, will share his knowledge about the competitive environment in Pennsylvania, then compare it with California's policies.

Steven Rivkin, a nationally renowned attorney, consultant and author, wants AMRA symposium attendees to understand the numerous AMR and business opportunities available in competitive utility markets.

Jim Rodier, an attorney and consultant for Sanders & McDermott PLLC, will draw from his knowledge about deregulation in New England to offer tips about avoiding potential obstacles to effective competitive business operations.

And to wrap things up, legendary NFL quarterback **Joe Theismann** will share his experiences, answer questions and sign autographs Wednesday, Sept. 12. He's a featured speaker during the day's General Session, where he'll talk about 'The Challenge of Change.'

All attendees — including registered guests — are invited to attend Theismann's presentation, join in on an informal question-and-answer period, get an autograph or two and maybe even win an NFL-regulation football signed by the most productive quarterback in the history of the Washington Redskins franchise.

Once again, AMRA's Program Committee has created six intensive panel sessions and interactive workshops that convene Wednesday, Sept. 12, immediately following Joe Theismann's presentation. The extended sessions delve into high-interest topics that affect everyone involved in today's utility environment.

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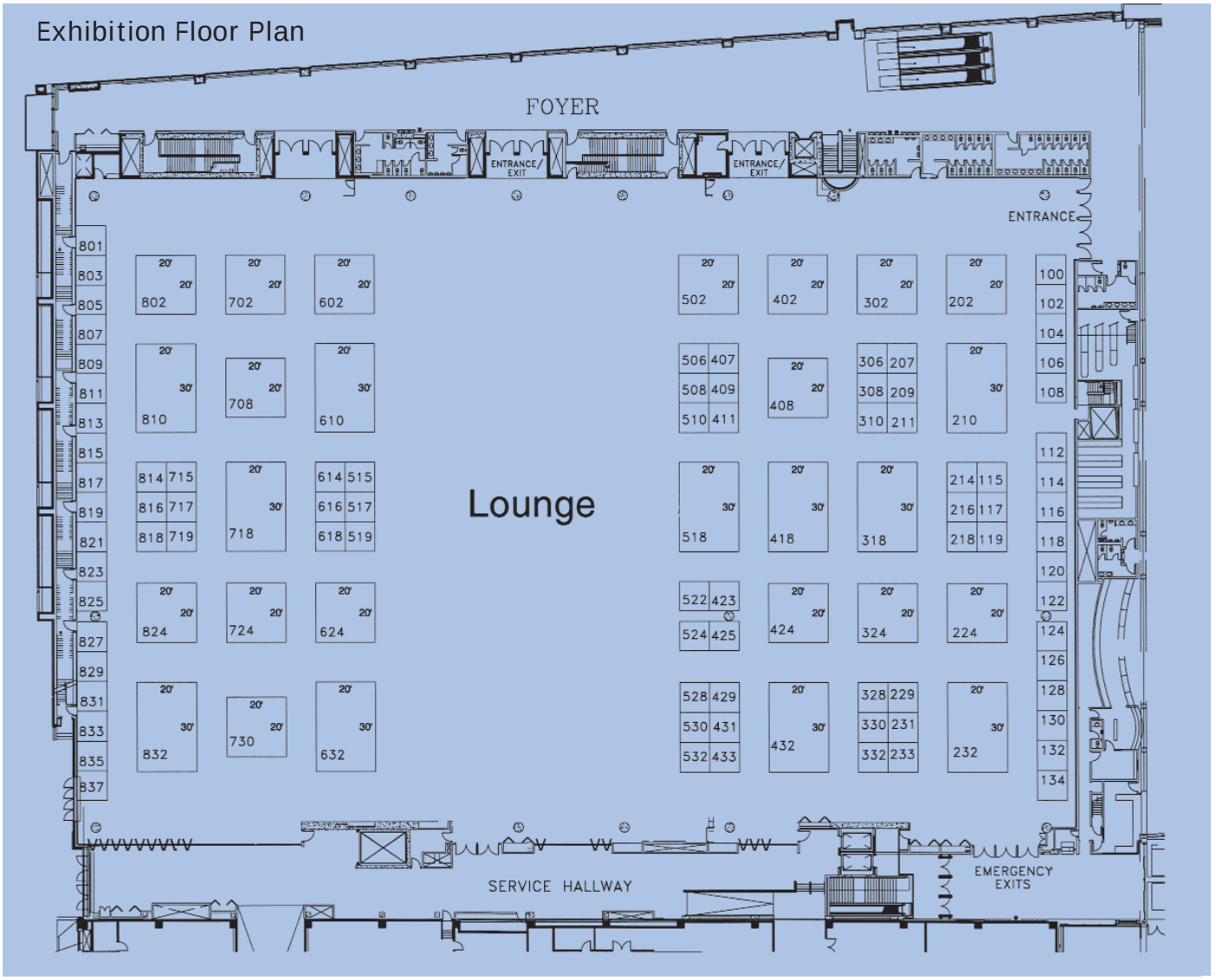

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as of July 5, 2001

GROUNDING ISSUES

Site Protection Through Proper Grounding, Bonding and Design Practices

By Paul Simonds

Electronics and microprocessor-based equipment have become an integral part of our everyday lives. As technology advances and electronic equipment becomes faster, it also becomes more sensitive to the hazards created by poor grounding and bonding practices. Technology has advanced the speed of electronics by reducing the distance between components and lowering the voltage required to operate the system. While this increases the speed of the equipment, it also makes the equipment more vulnerable to damage at a lower voltage difference, thereby making the grounding and bonding of the equipment much more important than it was during the days of glass tube, high voltage equipment.

Ask any power quality expert today about equipment grounding and they will tell you, "poor grounding practices are second only to improper wiring as the leading cause of equipment malfunction." The standards for equipment performance mandate the installation and maintenance of a reliable, low resistance path to ground. Most electronic equipment today operates at a very low voltage and is often subjected to potentially lethal hazards, many of which are generated by the operation of the equipment itself.

A grounding system that is properly designed, and properly installed, will insure the operation of critical equipment from the hazards of transients, harmonics, and the most ultimate of transients, the lightning strike. A properly designed low resistance grounding system also provides the additional, and most important benefit — personnel safety.

Earth Grounding

As with any construction project, it is always best to work from the ground up, so the ground connection is typically where one should start with a grounding system design. A ground electrode is "a conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with the soil". This definition does not mention or refer to any actual ohm resistance value of the electrode. It is simply just a physical connection of the ground electrode to the earth itself. The resistance value is determined by the resistivity of the soil in which the ground electrodes are buried. Fault currents must pass through the soil to the assumed earth potential of zero ohms.

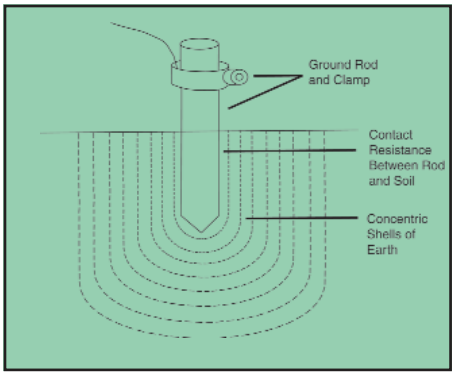
When an object is grounded, it is forced to assume the same zero potential as the earth. If the potential of the grounded object is different than the earth, electrical current will pass through the grounding electrode connection until the object's and the earth's potential is equalized. The ground electrode is the grounding connection between the equipment and the earth. The measured resistance in ohms determines how quickly and at what potential the energy is equalized between the equipment and the earth. Therefore, proper grounding is necessary to maintain an equal potential between the equipment and the earth.

Soil Resistivity

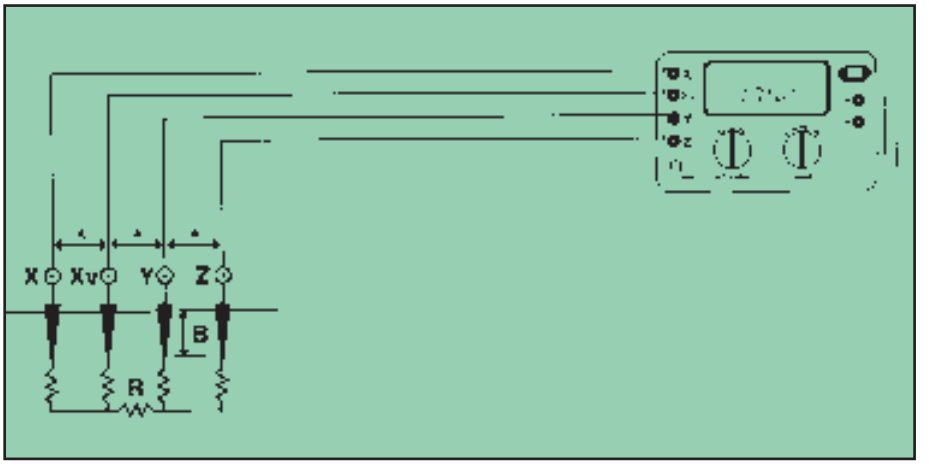
The soil upon which an equipment site is constructed is the dynamic conductor for all fault currents from the equipment, whether they are natural or man-made. It is very similar to the chassis ground in a vehicle. All grounds, no matter how they are routed, eventually reference back to the earth itself. And just as different types of metals can be better types of conductors than other metals, so too can different types of soils. Most soils naturally contain varying amounts of electrolytes that conduct electricity. As a result, the addition of moisture will enhance or reduce the conductive properties of that soil. As a general rule, soil with a higher moisture content will have a lower electrical resistance.

Temperature, like moisture, can have a significant impact on resistivity. The soil resistance rises dramatically upon reaching the freezing point. Upon reaching 32 degrees Fahrenheit, any moisture in the soil will begin to freeze, and upon freezing, the soil resistance will increase by almost three times its normal value.

Frozen soil can have a detrimental effect on clay- or cement-based backfill materials that rely on water as their primary conductor. A carbon-based backfill material used to encase the grounding electrode will offer the advantage of year-



Resistance components of a typical ground electrode.



A four-point ground meter setup

The use of sharp turns when connecting to the counterpoise will choke. The conductor leading to the counterpoise in the photo above is a perfect example of this problem.

round, all-weather low resistance ground system.

Soil Resistivity Measurements

Every construction project begins on paper. Without some type of plan or design you won't know where to start or when you're finished. A good grounding system design should begin with a soil resistivity test to determine exactly what you have to work with. A 4-point ground meter is utilized to determine the conductivity of the soil and provide a basis for the beginning of the ground system.

The 4-point resistivity test, traditionally measured in ohms per centimeter, requires the user to place four equally spaced test probes in the ground at various locations within the site area to determine the actual soil resistance. Testing is performed at various spacing from five to forty foot intervals to simulate the resistance values at different depths in the soil from five to forty feet. To get a thorough test reading of the site, testing should be performed at several different locations within the site. The resistance value data obtained from the testing will then be used in the design and installation of a low resistance grounding system.

Soil with higher resistance readings will require more grounding electrodes and a more comprehensive grounding system to compensate for the poor soil. Soil values can range from 500 ohms/cm with high percentages of electrolytes, to over 1 million ohms/cm in sandy dry soil. This resistance will directly affect the overall impedance and performance of the site grounding system.

Tower and Transmission Line Grounding

Most communication sites have some type of tower or structure used to support the antennae and transmission lines which make the site function. These structures, while being highly susceptible to the most damaging of all surges, lightning, are also usually the most overlooked in the design process. Design engineers have historically tended to over-design the surge suppression area of a communications site while under-designing the grounding system.

In other words, instead of helping the lightning get into the ground, where it wants to go in the first place, they over specify products to contain the lightning damage once it has already entered the equipment shelter. Lightning is a very high frequency event. In laymen's terms this means it is an extremely fast current. Since lightning is a high frequency event, the impedance of the paths to ground, as well as the ground resistance, is very important in designing an effective grounding system.

Sharp turns or bends in grounding conductors will act as a choke to lightning transients and will be viewed as a high resistance path by the lightning energy. The actual geometry of how the conductors are installed plays a key role in the functionality of the system. The conductor leading to the counterpoise in the photo above is a perfect example of this problem.

Single Point Grounding

During a lightning strike, the ground potential at the point

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of the strike changes rapidly and can cause a difference of potential between ground reference points.

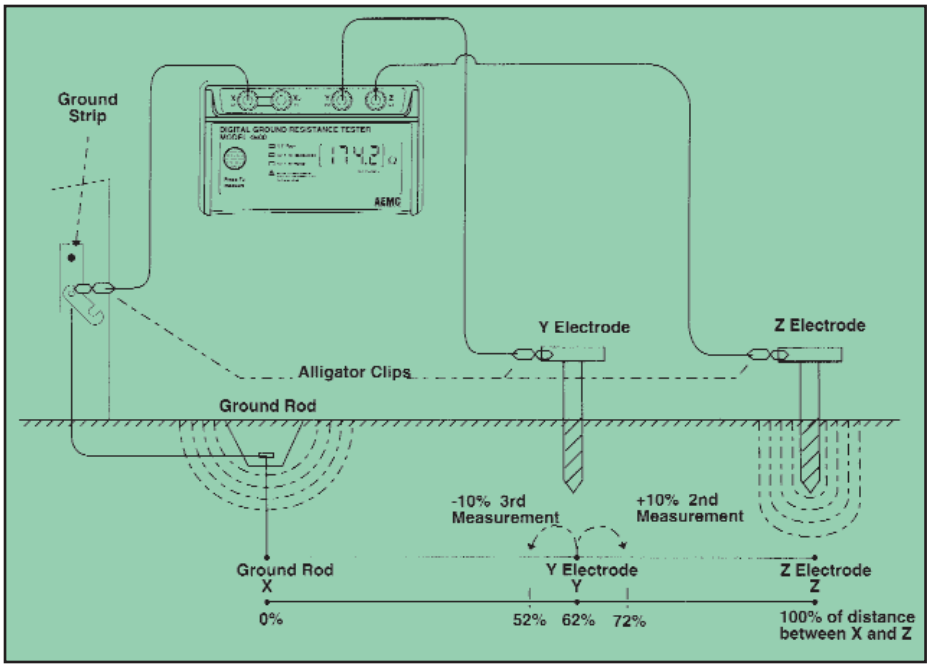
The design of the internal equipment shelter grounding system, and how it is connected to the earth grounding system, is crucial to the protection of sensitive equipment and to the safety of personnel located inside the shelter. System design has changed dramatically over the past couple of decades from the old grounding specifications requiring grounding at all corners of the equipment room and usually several places in between. With the new technology in communications equipment over the past two decades, it has been learned the hard way that even a small amount of difference in ground potentials can cause equalization directly through the equipment.

Single-Point Ground Referencing is a system design that allows all of the equipment to reference ground potential at only one point, thereby eliminating ground loops and potential differences. Single-Point Ground Referencing is obtained simply by bonding all of the internal equipment together, and taking it to ground at one single point. This design eliminates the possibility of any ground potential differences or transients equalizing through the equipment. Any change in ground potential does not damage the equipment. It is the difference in potential that equalizes through the equipment that causes damage.

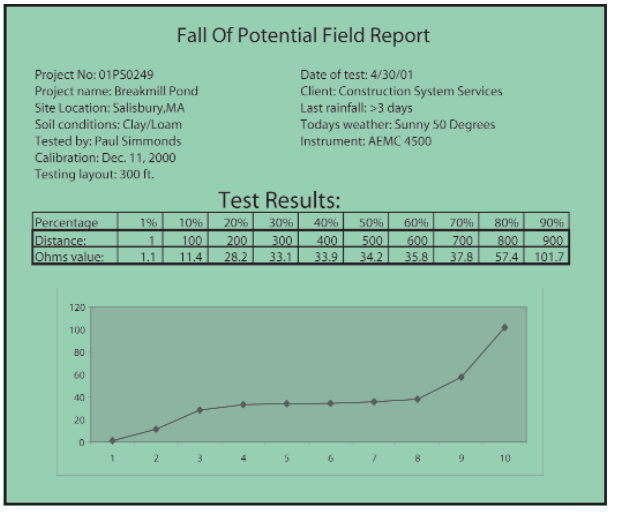
Post Installation Testing

Once a ground system has been designed and installed, it is then a very good idea to verify that the system will work properly. This is accomplished by the use of a three-point fall-of-potential ground resistance test. This post installation test is performed by placing two test probes into the ground within the site area and testing from those probes back to the grounding system. The distance from the test instrument to these probes is determined by the size of the facility that is being tested. This traditionally is five times the diagonal distance of the grounding system that has been installed.

It is imperative that this test be performed before tying into any other ground source; for example, the power company ground or telephone company ground. The reason for testing before it is tied into any other ground is to verify that your system has met the designed ground resistance value without influence from any outside sources. If the test is performed after the power is connected, the Clamp-On ground resistance tester can be utilized. This involves clamping onto the power neutral between the transformer and the site ground. The user must be aware that a 0.7 ohm reading indicates a continuity loop and is not a ground resistance reading.



Three-point fall-of-potential ground testing. The lengths of the conductors are determined by the size of the facility.



A typical fall-of-potential report that is obtained from three-point testing.

Low Resistance Grounding System Design: A Site Survey

The design process for a grounding system should begin with a site survey of the installation area including a complete survey of the existing AC power, Telecom, TVSS, and UPS systems and all of their associated bonding and grounding. Remember to include a survey of any other services that may be special to your specific site, such as, cable tv, direct data links from adjoining buildings, intercom systems, security systems, etc.

A proper site survey must also include soil resistivity analysis at several depths, relevant site plans, topography analysis, and a boring core sample, if available.

The site survey will show any physical barriers such as rock, high resistivity soil, power lines or any other variables that could affect the earth-ground resistance in the installation area. Once this information is obtained, an effective and properly designed grounding system can be installed.

Conclusion

A properly designed, low-resistance grounding and bonding system is a major component of a well-protected and efficient facility. A properly designed and installed grounding system is an integral part of any site and should be designed and purchased with the same research and consideration as any other critical piece of equipment.

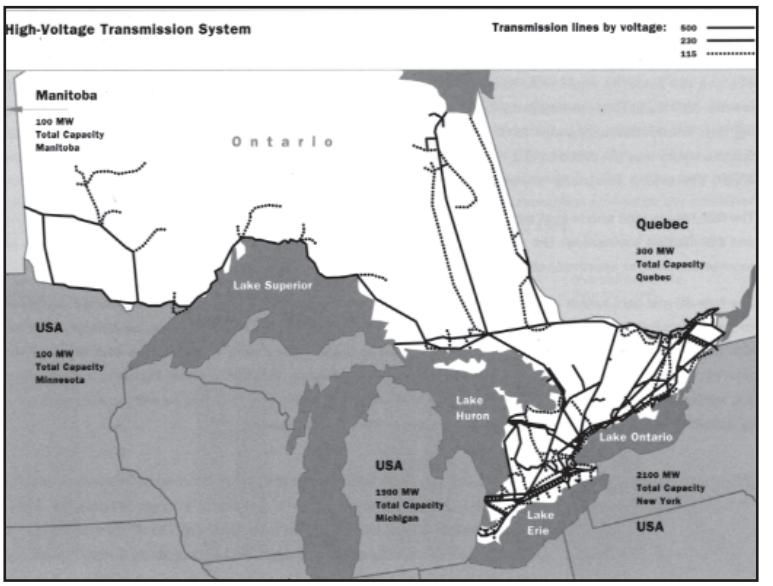
Paul Simonds is Director of Engineering with ALLTEC Corporation, Canton, NC. Alltec Corporation is represented across Canada by Interfax Systems www.interfax-sys.com. ET

GEOGRAPHICAL INFORMATION SYSTEMS

Hydro One Decides to Standardize Its GIS Platform

Hydro One, one of the largest utilities in North America is standardizing its geographic information system (GIS) platform.

After an extensive evaluation process to select an enterprise solution that would enable the creation, management, and dissemination of information found in its Enterprise Data Warehouse, Hydro One elected to used technology developed by ESRI. One of the deciding factors was that since it is based on open standards, ESRI's ArcGIS is capable of integrating with Hydro One's other enterprise systems.



Hydro One's transmission network spans the entire province of Ontario.

Hydro One

Hydro One transports electricity to large industrial customers, municipal utilities, and over one million smaller end-users across Ontario.

Hydro One was formed as part of the major restructuring of Ontario's electricity industry, and acquired the transmission, distribution and energy services businesses of the former Ontario Hydro.

Hydro One's transmission business owns and operates approximately $6.7 billion of assets, comprised primarily of Ontario's high-voltage transmission system. In 1999, approximately 144.1 TWh of electricity was transmitted through a 28,900-kilometre network to distributors and large industrial customers. It serves local distribution utilities, its own distribution system and over 50 large industrial customers. The transmission business also owns and operates 17

Continued on page 28

Hydro One transports electricity to large industrial customers, municipal utilities, and over one million smaller end-users across Ontario.

Continued from page 27

interconnection facilites that connect its transmission system with systems in neighbouring provinces and U.S. states.

Hydro One's distribution business owns and operates an approximately 113,400-kilometres low-voltage distribution network. Customers of this network include small municipal electric utilities, a few large industrial customers and retail consumers consisting of primarily seasonal, rural and northern customers.

Long Time GIS User

A long time user of GIS, Hydro One first implemented the technology more than 20 years ago. Since then, it has developed sophisticated applications, and is currently upgrading its GIS to leverage spatial information and technology across the Hydro One organization.

As well as historical AM/FM and engineering purposes, GIS will continue to be integrated enterprise-wide, explains Geoffrey Cameron, Senior IT Analyst for GIS, Hydro One.

The main benefit of GIS to any organization comes when spatial data can be shared and leveraged amongst all business units. By viewing spatial information as another attribute in a data warehouse, business applications can now benefit from the additional functionality of GIS.

A fundamental component of Hydro One's Enterprise Data Warehouse is spatial information. Whether it is customer, asset, environmental, or competitor related data, geography will become the integration framework for all of its business-related databases.

Various business units in Hydro One will drive the GIS requirements. For example, the Asset Management departments will utilize the GIS infrastructure and data to support various spatial business needs, including Outage Management. Hydro One expects this system to greatly expedite the implementation of enterprise-wide projects and project management.

"With the largest utility in Ontario selecting ArcGIS as their standard, it is further evidence that ESRI has the tools and functionality within the core GIS suite to satisfy the diverse requirements of the utility market", said John Houweling, Ontario Regional Manager, ESRI Canada.

Hydro One will begin to standardize its GIS platform by using the ArcGIS product suite. ESRI's ArcIMS Internet technology will play a pivotal role enabling Hydro One to disseminate information stored in the utility's geographic data warehouse through a one-window portal.

"We are very enthusiastic about working with Hydro One to ensure that the company is able to successfully leverage its geographic data and GIS knowledge across the organization. We will play an important role by providing local support in the form of training and implementation services for Hydro One," concludes Mr. Miller. ET

POWER QUALITY Q&A

Our Expert Offers Answers to Frequently Asked Questions About Power Quality

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

Question:

Some transformers used for harmonic loads are rated with a 'K' factor. What does this mean?

Answer:

When a non-linear load is supplied from a transformer, it is sometimes necessary to derate the transformer capacity to avoid overheating and subsequent insulation failure.

The reason for this is that the increased eddy currents caused by the harmonics increase transformer losses and thus generate additional heat. Also, the rms load current could be much higher than the kVA rating of the load would indicate. Hence, a transformer rated for the expected load will have insufficient capacity.

The K factor is a number derived from a numerical calculation based on the summation of harmonic currents generated by the non-linear load. The higher the K factor, the more significant the harmonic current content

The calculation goes like this:

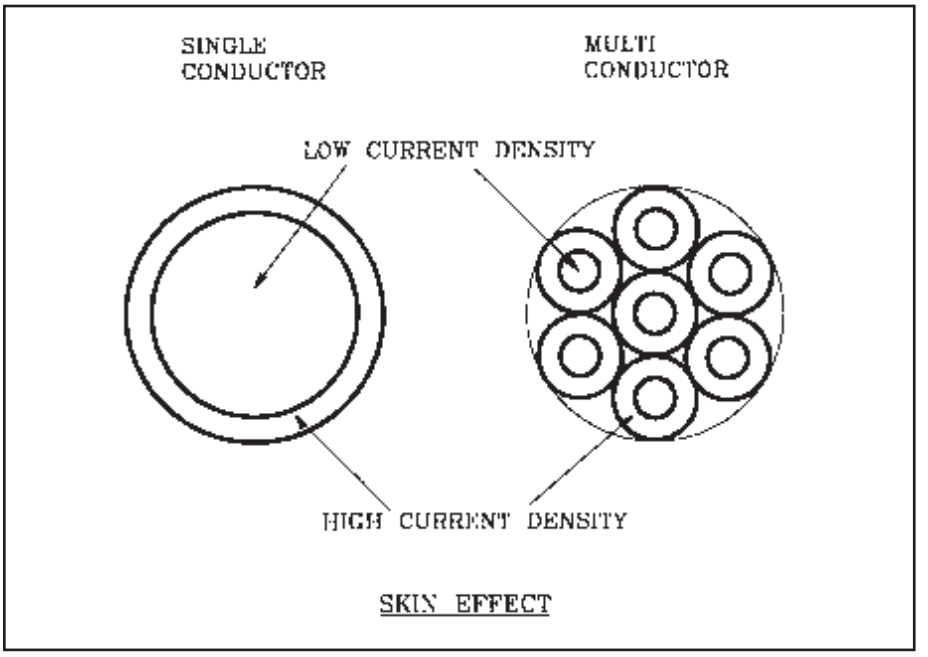
$$K = \sum_{1}^{h\,\max} I_h^2 h^2$$

where I_h = current at harmonic h
h = harmonic number

Details of the calculation method can be found in IEEE Standard 1100-1992.

To help get around the problem of successfully applying derating factors to conventional transformers, the K factor is used by transformer designers to develop transformers made especially for non-linear loads and the extra heating caused by the harmonic currents. Transformers come in basic K factors such as 4, 9,13, 20, 30, 40, and 50.

The strategy is to calculate the K factor for your load and then specify a transformer with a K factor of an equal or higher value. In this way, the transformer can be sized to the load without derating.



The advantage of using a K factor transformer is that it is usually more economical than using a derated, oversized transformer.

Question:

When grounding a VFD system, do I have to take any special precautions?

Answer:

When one is designing a system for signal or communication purposes, we generally think in terms of normal 60 hertz grounding methods. In this case, a copper conductor of sufficient size to carry the expected fault current will usually meet all of our needs.

However, there are applications, such as VFD applications, where higher frequencies are involved. Here carrier or signal frequencies get into the kilohertz or higher ranges. In these cases, we have to think about how a copper wire will react to increased frequencies. One of the more commonly known effects is called the skin effect.

As the frequency increases, the current flow in a solid conductor will tend to track more closely to the outer surface, leaving the interior part of the conductor unused. Hence, there is less cross-section of copper available for the current flow and thus the impedance of the conductor increases.

How does this affect grounding? Well, if we have a high frequency component to the power, although we have lots of copper, the impedance may be high enough to disrupt our bonding and equipotential strategies and goals.

The increased impedance may cause potential differences between equipment, unwanted ground current loops, and perhaps even some safety issues.

How do we get around this? The way to reduce the impedance is to use smaller, multiple conductors to do the same job. In effect, multi-stranded wire is used. Braided straps or welding cable have many fine conductors and make excellent high frequency ground conductors.

In this way, the skin effect is minimised by keeping the conductors small but increasing the number of conductors. There is more usable copper and thus frequency will not have a significant effect.

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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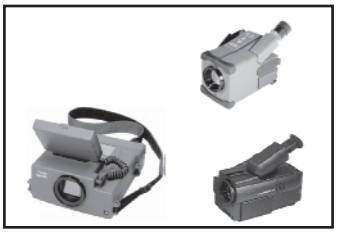

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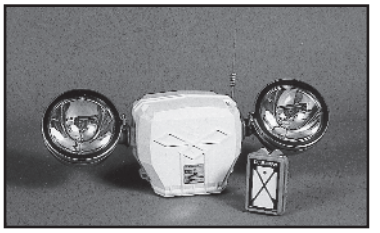

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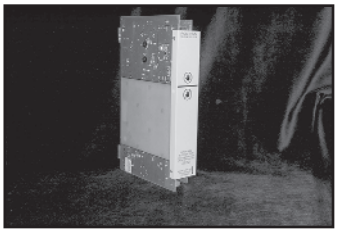

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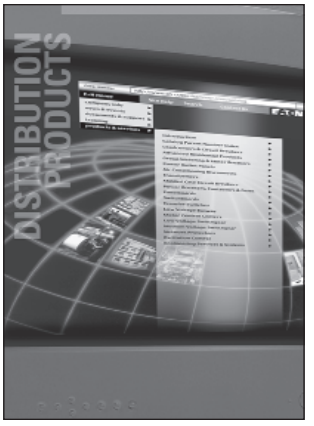

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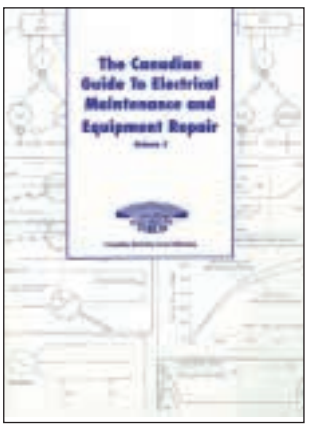

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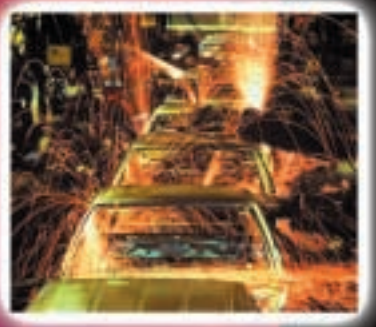

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