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Electricity Today

Power Generation, Transmission & Distribution, Utilization

Canadian Electricity Forum

PROTECTION AND CONTROL

Relaying for Dual Supply Lines

•

IPP Protection:
Interconnection Transformer Winding Arrangement Implications

ELECTRICITY RESTRUCTURING

Report on Restructuring of the Canadian Electricity Industry

•

Observations on Electricity Trends and Issues

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ELECTRICITY TODAY

Publisher/Executive Editor
Randolph W. Hurst
rwh@istar.ca

Managing Editor/ Production Manager
Kelly Jones-Johnston
kjj@electricityforum.com

Production Coordinator
Chantelle Simpson
chantelle@electricityforum.com

Advertising Sales
Donna Gilliland
donna@electricityforum.com
Carol Gardner
carol@electricityforum.com

Web Site Advertising Sales
Barbara John
forum@capital.net

Circulation Manager
Colleen Flaherty
colleen@electricityforum.com

Visit our Web Site:
www.electricityforum.com
E-mail: hq@electricityforum.com

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IN THIS ISSUE

PROTECTION AND CONTROL

ELECTRICITY RESTRUCTURING

POWER QUALITY

GENERATION

PRODUCT AND SERVICE SHOWCASE FOCUS

ADVERTISER INFORMATION

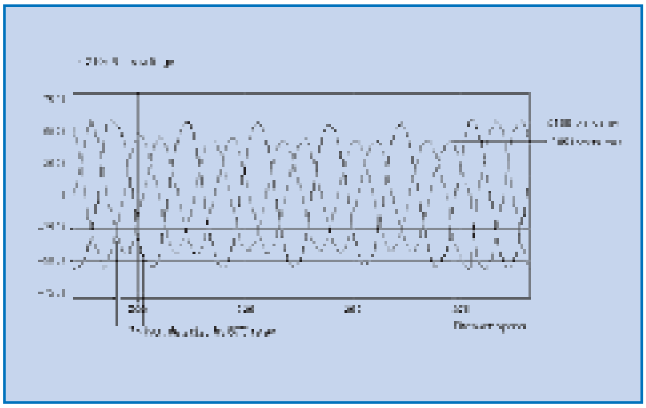
PROTECTION AND CONTROL

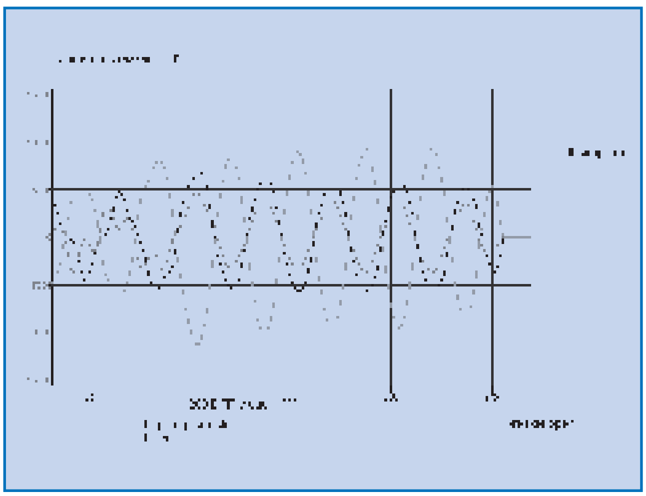
Relaying for Dual Supply Lines

By Paul Kruger

The importance of a reliable supply of electricity for many manufacturing and heavy industrial process plants cannot be overemphasized. Momentary interruptions and even temporary voltage sags or spikes can have as detrimental an impact as long term interruptions. Such events can wreak havoc with manufacturing processes and the sensitive solid state equipment that is now routinely used to control them.

One solution to the problem is to install dual supply lines. However, depending upon plant location and distribution system configuration, a second supply line could cost millions of dollars. For some heavy power users, even this level of investment can often be justified. But ,what if a company were to make such an investment, only to discover that serious supply problems continue to plague them? Having two supply lines does not always improve the reliability of the power supply for important loads.





Such was the case at an industrial plant in Eastern Ontario.

The plant has a typical two line 115KV supply with two transformers, low side transformer breakers and a normally closed bus tie breaker. The low voltage busses operate at 4200 volts. The low side bus tie potentially offers an uninterrupted supply to the load, but it also introduces the possibility that a fault on one line may affect the second, and the prospect of backfeed through the tie if the transformer breaker fails to clear on a line fault.

Such installations are normally protected by directional over current relays, over/under voltage relays, pilot wire, remote (transfer) trip from the distribution utility, or some combination thereof. Directional over current relays are generally timed and therefore slow. Pilot wire is fast but prone to false operations. Unfortunately, both remote trip and pilot wire require either expensive relaying to enable wireless communication between the terminals, or land lines which can also be expensive. Furthermore, remote tripping is relatively slow, with a time to trip initiation in the range of 40 to 50 ms, and is prone to both false tripping and failure to trip.

The plant in question originally had timed directional over current protection, timed under/over voltage protection, and remote tripping from the local utility, but the remote tripping proved to be so prone to false operations that it was abandoned. Most, but not all, of the other load terminals on the two lines had transfer tripping.

Consequently, every time either of the two lines was affected by lightning or any other fault, the terminals with transfer tripping cleared and left the plant hanging on to the faulted line, until the directional relays finally timed out. During this time the plant would carry the remaining load left on the faulted line, through the low voltage bus tie. The voltage dip at the plant was always so severe that the process control would shut the plant down and / or the large compressor motors would fall out of synchronism and trip off.

In essence, the manufacturer had paid for a Cadillac two supply line system, and as a result had doubled its exposure to line faults because a failure on either supply line would shut down the manufacturing process.

The problem, then, was to find a cost effective local substitute for remote trip or pilot wire protection, one that would clear faults reliably and with sufficient speed to prevent the process control from being affected by the momentary voltage sags that accompanied every electrical fault on either of the supply lines. The solution was surprisingly simple.

Two sets of specialized directional over current relays were installed. Each set was supplied from both sets of transformer breaker current transformers, connected in a differential configuration. This arrangement permits much greater fault discrimination as it results in little or no relay current during normal conditions, but the relay current doubles when fault or load current backfeeds through the low tension bus.

One of the protections utilizes two directional overcurrent relays type KCEG from GEC Alsthom, each directioned for current flow out of one of the 115 KV lines. The setting for the relay is 1000 amps flowing back through the transformer breakers, and it operates on current in any phase. It is supervised by pallet switches from the other breaker and by bus under voltage, set at 3500 volts. Thus configured, the KCEG relays will operate for any line fault on their associated line, or on a backfeed to connected remote loads after a fault clearance at the supply station.

During the past 5 years, the KCEG

Continued on page 29

ELECTRICITY RESTRUCTURING

Report on Restructuring of the Canadian Electricity Industry

In the traditional market structure of the electricity industry, generation, transmission and distribution of electricity are owned and managed by vertically-integrated monopolies. This form of market structure, which still prevails in much of Canada today, was widely adopted because the electricity supply industry was regarded as a natural monopoly. With respect to generation, this meant that lowest costs could be achieved by building large scale power plants. The nature of long-distance transmission systems and local distribution systems also fit the natural monopoly model. Even if competition were possible in generation, it would still not be economically feasible to build competing transmission and distribution facilities to serve the same market, i.e., lowest costs would be achieved by one facility.

Because of the concern that monopolies would be able to exercise market power, their operations were either overseen by regulatory bodies acting in the public interest or, in the case of most Canadian provinces, public ownership was established in the form of Crown corporations.

The utilities in each province tended to develop their own generation, transmission and distribution systems consistent with provincial energy requirements. In addition, interprovincial and international transmission ties were made to achieve anticipated benefits such as:

- cost savings due to lower installed reserve requirements;
- the ability to install larger, more economical generating units;
- seasonal diversity and economy energy exchanges;
- the ability to enter into firm power contracts; and
- other anticipated benefits such as service reliability and emergency assistance.

In Canada and the U.S., a number of trends began to emerge in the late 1980s and early 1990s that caused several jurisdictions to question the traditional market structure:

(i) Technological advances in generation made the construction of smaller gas-fired generating units feasible, particularly combined-cycle natural gas turbines. These units can provide incremental supply at lower capital costs, and can be built more quickly than conventional fossil fuel or nuclear plants. At the same time, it was profitable for industrial electricity consumers to purchase natural gas to simultaneously produce process heat and electricity (cogeneration) and to sell any surplus electricity into the electricity grid.

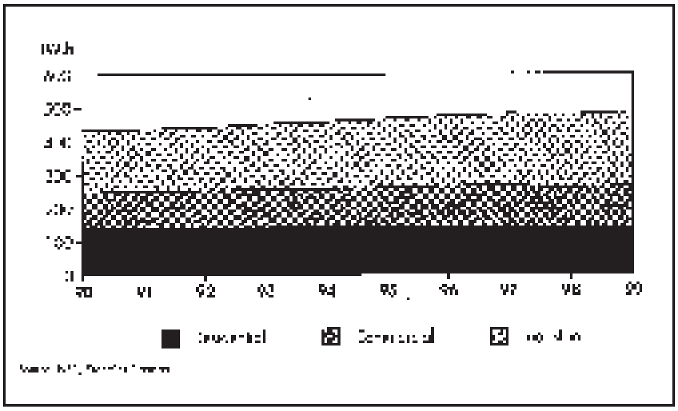
(ii) Many jurisdictions, for example in the U.S. Northeast and California, took the view that access to a utility's transmission lines should be made available to other service providers to provide access to cheaper supplies from neighbouring regions, and regions further afield. This would require obtaining non-discriminatory access to transmission systems.

(iii) Experience with deregulation and restructuring in other industries such as telecommunications, natural gas and the airlines suggested that competition between producers and service providers would lower costs and provide a broader selection of services to consumers.

Restructuring Defined

Restructuring refers to reorganizing electric utilities from vertically-integrated monopolies into separate generation, transmission and distribution service companies. This separation, or unbundling, is intended to promote competition between generators, and to "open" the transmission and distribution systems, eventually increasing competition in the supply and marketing of electricity. Increased competition offers more choices to consumers such as choice of supplier, expanded metering services and options with respect to 'green power.'

Two essential aspects of restructuring are wholesale access and retail access. Wholesale access refers to generators having the ability to obtain access to transmission systems to



Canadian Electricity Demand

compete in for wholesale markets, which may include distribution companies or independent marketers. Retail access refers to marketers having the ability to obtain access to distribution systems to sell to end-use consumers, and conversely, allowing end-use consumers a choice among marketers. Full retail access occurs when all end-use consumers have this choice. Wholesale access can occur without retail access; however, retail access requires wholesale access.

Restructuring Initiatives

In Canada, the movement toward restructuring the electricity industry has been uneven, as each province assesses its own unique regional circumstances and issues. Alberta restructured its electricity market over a five-year period culminating in full retail access on January 1, 2001. Ontario plans to implement full retail access in May 2002.

Most other provinces, including New Brunswick, Québec, Manitoba, Saskatchewan, and B. C. have implemented, or are planning to implement, wholesale access. Aside from Ontario and Alberta, no other provinces are planning to implement full retail access.

In the U.S., competition in generation was introduced when the Public Utilities Regulatory Policy Act was passed in 1979. This allowed, under various restrictions, independent power producers to sell into wholesale markets, thus ending utility monopoly over generation. Significant legislation emerged in the Energy Policy Act of 1992 . This act mandated the U.S. Federal Regulatory Commission (FERC) to implement open access to transmission systems and eventually resulted in FERC Order 888 (1996). The order requires that "transmission customers of jurisdictional utilities who take service under the open access tariff and who own, control, or operate transmission facilities must, in turn, provide open access service to the transmitting utility." Order 888 has implications for Canadian electricity exporters. It effectively requires that Canadian transmission companies provide U.S. marketers access to their transmission facilities so that Canadian exporters utilizing those facilities, and open access systems in the U.S., may obtain a licence from FERC to market electricity in U.S. wholesale markets. This is referred to as the reciprocity requirement of Order 888.

Most recently, to further facilitate competitive wholesale markets, FERC Order 2000 (December 1999) required transmission companies under FERC jurisdiction to form Regional Transmission Organizations (RTOs) by December 2001, and defined the characteristics and functions that qualify an RTO. In view of the interconnections between U.S. and Canadian transmission systems, FERC encouraged Canadian participation. In Canada, the tariffs of electricity transmission systems are in the purview of the provinces. Thus the NEB does not have FERC-like jurisdiction.

While FERC regulates interstate transmission and has a mandate to ensure that consumers have access to electricity at fair and reasonable rates, retail access is largely the responsibility of individual states. As of mid-2000, approximately 21 percent of U.S. electricity customers had retail access; however, less than one percent, accounting for 1. 5 percent of load, have exercised the option. The reason for the low participation is that, to date, the new marketers have not been able to compete successfully with the incumbent utilities

In addition to the initiatives undertaken in Canada and the U.S., restructuring of the electricity industry has been underway in several other countries during the past decade. In Australia, New Zealand and the United Kingdom this required the unbundling of government-owned monopolies.

RESTRUCTURING ISSUES

Stranded Costs and Benefits

An initial concern regarding the restructuring of electricity markets was that some generating plants would not be economic in a competitive environment and that they would become 'stranded' from the system. Consequently, their market value would be below book value, resulting in potentially large losses for the utilities owning these plants. The issue arose as to how these costs would be recovered.

In Ontario, the outstanding debt from Ontario Hydro has been referred to as a stranded cost. The debt is being managed

Continued on page 9

At the Intertie, Even Small Independent Power Producers Require Utility-Grade Protection To Guard Against Islanding.

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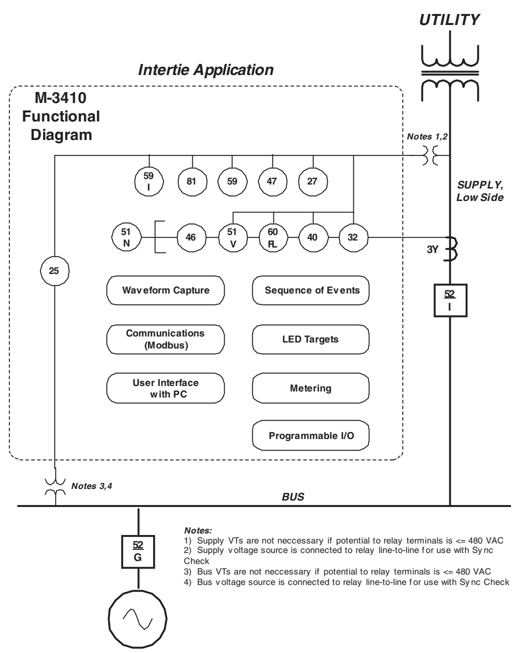

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continued from page 7

by a successor company to Ontario Hydro and will be recovered from Ontario electricity customers based on consumption.

In the U.S., stranded costs were associated with some nuclear facilities and older, less-efficient fossil fuel plants. Various ways have been designed to recover stranded costs, such as securitization and direct recovery through transition charges on electricity transmission and distribution.

Overall, as events have unfolded in the U.S., stranded costs have not been an impediment to restructuring. Initially, many utilities expected they would face burdensome stranded debt that they might not be able to recover, either because of market conditions or because some states would not allow these costs to be passed on to consumers. In fact, state regulators have allowed for full recovery and, because prices in bulk power markets have been stronger than anticipated, prices have tended to support higher values for these assets

Stranded benefits can occur when the market value of divested assets is greater than the book value. In Alberta's restructuring scheme, a stranded benefit was associated with older generating plants. The value was established at auctions that sold the rights to market the power from these plants. The residual value between the prices bid for the power and the cost of operating the plants is being returned to Alberta consumers in the form of deductions from their monthly electricity bills.

Market Power

When considering restructuring for their respective jurisdictions, regulators have been concerned that market power might be exercised in some segments of the electricity market. For example, generators that own substantial amounts of capacity (province-wide or at strategic locations) could be in a position to prevent competing suppliers from entering a particular marketplace. Transmission facility owners might be able to withhold transmission access from competitive generators. In a restructured environment, incumbent distribution utilities may be in a position to take greater advantage of new market opportunities than their competitors because they have better access to customer information.

Ontario and Alberta have each taken steps to mitigate market power. In Ontario, the Market Power Mitigation

continued on page 10

Observations on Canadian Electricity Trends and Issues

The electric power industry in North America has been undergoing substantial change as many jurisdictions have introduced competition in generation and provide access to wholesale markets and some retail markets. However, the pace of restructuring varies across regions and the extent to which restructuring will occur is uncertain. A key concern is the impact on electricity prices. Volatile oil and especially natural gas prices during the past two years have also been cause for uncertainty about electricity prices, because of the increasing use of gas in power generation. Given these concerns, this report has provided a detailed analysis of Canadian electricity markets, which has led to the following observations.

Electricity Supply

Overall, Canadian electricity markets appear to be adequately supplied. Alberta has experienced relatively tight supply situations, particularly during periods of peak demand. However, recent announcements suggest that power developers are planning to make new supplies available over the next one to five years.

Across the country, with a few notable exceptions, new generation projects in the near term are expected to be gas-fired. These plans were, for the most part, made before the recent escalation in natural gas prices. Depending on the duration of higher gas prices, there could well be a shift toward other forms of electricity generation. In recent months, there have been announcements of new coal-fired generation projects in Alberta, which has abundant and inexpensive coal. Higher prices tend to make wind energy and other renewable technologies more feasible.

The nature of gas-fired generation plants allows them to be built closer to load centres. Although not a focus of this report, this could be an important consideration in provinces where the current coal and hydroelectric generation facilities are located far from markets, thus requiring the construction of transmission capacity (e.g., Alberta, Saskatchewan, Manitoba and Québec). A related matter is future trends in distributed generation; locating generation at industrial sites, for example, could reduce the need for both long-distance transmission and distribution facilities.

Convergence

Convergence of the natural gas and electricity markets is an outcome of the increasing use of gas in power generation. An important aspect is that gas prices and power prices have become closely related. Convergence is demonstrated by some recent trends: high natural gas prices throughout the U.S. affecting overall Canadian electricity export revenues; the price of natural gas influencing electricity prices in the Power Pool of Alberta; and electricity demand in California contributing to relatively high prices for B.C. gas exports.

The Role of Electricity Exports and Market Integration

A number of provinces have surplus energy available for export, and the country continues to be a net exporter of electricity. Exports comprised about nine percent of domestic generation in 2000.

Some Canadian entities have been granted wholesale trader status by FERC by satisfying the reciprocity requirements of open access under FERC Order 888. To further facilitate Canadian exporters' access to U.S. markets, and to facilitate access to U.S. supplies by Canadians, the transmission companies in several provinces are considering membership in RTOs. By consolidating the operations of a number of transmission systems into one independent entity, which would establish a standard tariff, RTOs further the objective of opening access to transmission. Canadian entities are not subject to FERC regulation, but due to the integrated nature of the North American transmission system, it appears that Canadian involvement in RTO formation could be potentially beneficial to all market participants, provided proper approaches for jointly overseeing a cross-border RTO are adopted.

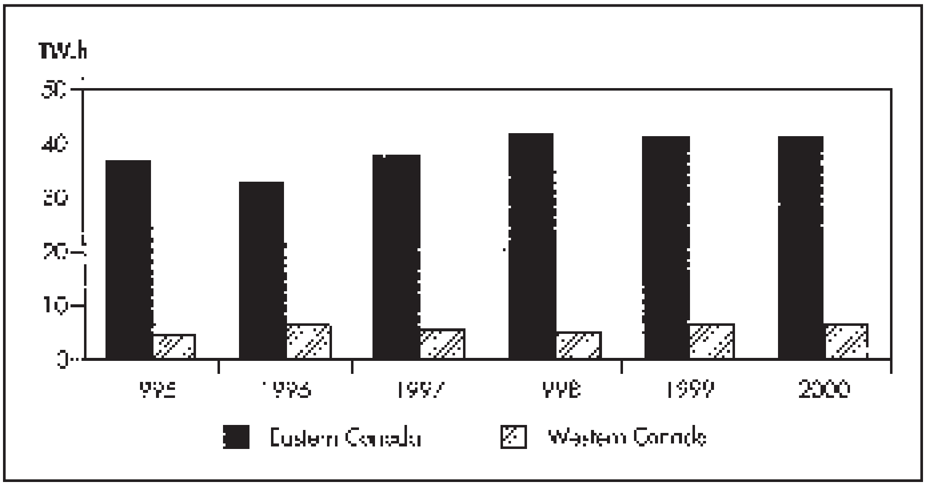
Directionally, the formation of

continued on page 12

Continued from page 9

Agreement established Ontario Power Generation's licence conditions and an Independent Market Operator has been established to assure non-discriminatory access to transmission.

Alberta's ap-proach to mitigate market power includes the creation of an independent power pool and an independent transmission administrator, as well as the auctions of power plant output to reduce the market share of incumbent generators.



Interprovincial Transfers of Electricity

Reliability

Traditionally, electric generating utilities operated with high reserve margins, often in the range of 20 to 25 percent above peak demand. This was deemed necessary and prudent because of potential unscheduled plant outages. In restructured markets operating margins tend to be lower; therefore, other things being equal, the prospects of supply disruptions are greater, although costs are lower.

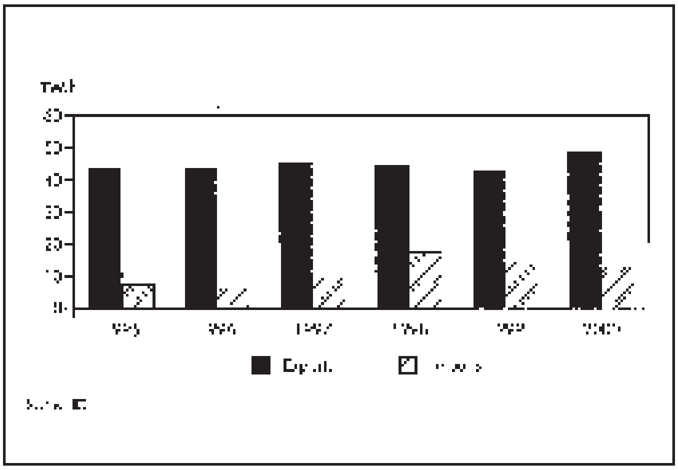
With the unbundling of the generation, transmission and distribution functions, reliability becomes more of a shared responsibility between these entities and is reflected in their tariff provisions (terms of service).

Marginal Cost versus Average Cost Pricing

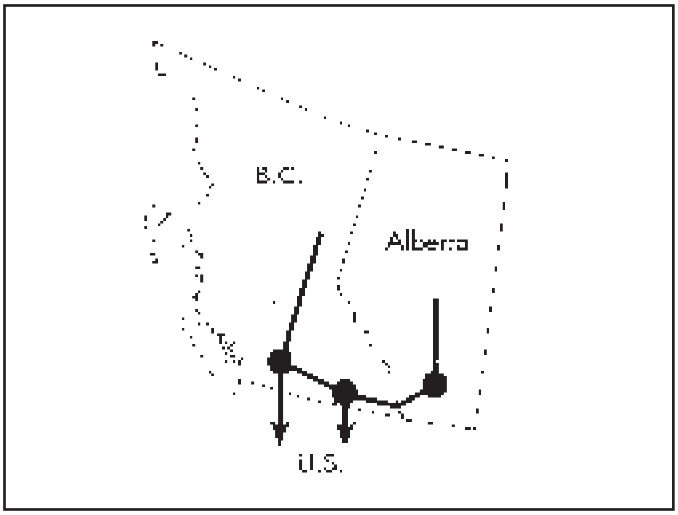
In the traditional market structure electricity prices are established by average cost pricing. Average cost pricing reflects a regulated generator's approved costs for less expensive and more expensive supply sources.

In restructured markets, where there is competition among generators, prices are based on market forces. Buyers and sellers can be brought together to settle a price in a number of ways. One way is a negotiated bilateral arrangement between a generator and a buyer. Another is the formation of a power pool where many buyers and sellers interact to establish the market price.

The power pool approach as adopted in Alberta and contemplated for Ontario employs marginal cost pricing, i.e., the



International Transfer of Electricity



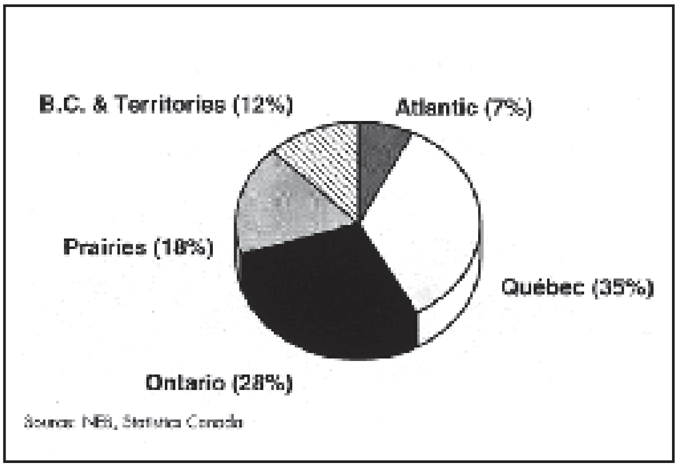
B.C./Alberta/U.S. Illustrative Transmission Interconnections

pool price is set by the cost of the last unit of supply required to meet market demand.

An important point about marginal cost pricing is that all producers receive the same price even though their own costs may be lower and they might even have offered supply into the pool at a substantially lower price. This means that, all else being equal, when marginal costs are greater than average costs, the market price will be higher in the restructured environment.

If prices generally equate to marginal costs, prices will change to match the marginal cost of generation, and thus spot prices could be quite volatile. However, prices need not always reflect marginal costs. If the regulatory regime permits, buyers and sellers may negotiate bilateral arrangements for volume, price and time period. Depending on market conditions, the pricing terms could be less than the marginal cost. A well developed forward market, where standardized contracts for the future delivery of electricity are traded according to established rules and regulations, would also provide a similar price risk management function.

Most jurisdictions embarked on restructuring with the anticipation that electricity prices would decline over time, or at least not rise as much as in the regulated environment. The basic driving forces behind that anticipation were technology, which was expected to reduce generation costs, and competition, which was expected to improve efficiency.



Provincial Shares of Electricity Demand

Time-of-Use (TOU) Rates

As indicated above, a feature of competitive wholesale markets is that prices may fluctuate significantly, subject to market conditions and competitive forces. Further, because electricity cannot be easily stored prices can exhibit pronounced hourly swings.

Consumers can take advantage of these hourly swings by altering their consumption patterns. For example, industrial consumers can reschedule production into off-peak times. Conceptually, residential consumers could also reschedule activities, for example, away from the morning and evening peaks. In the traditional regulated market, utilities use moral

Continued on page 12

Continued from page 11

suasion to perform that function, because there is usually no economic incentive.

A number of observers have pointed out that real-time price signals, i.e., higher prices during peak hours, would be necessary to induce consumers to reduce consumption.

Advantages and Disadvantages of Restructuring

By moving from a cost-of-service environment to the competitive environment implied by restructuring, there are a number of advantages and disadvantages.

Advantages include:

- increased competition, more customer choice, possible service improvements;
- potentially lower costs, if competition results in improved efficiency;
- marginal cost pricing better reflects market conditions and gives better price signals to market participants; and
- trade will tend to promote price convergence between regions: high-price regions could experience lower prices.

Disadvantages include:

- price uncertainty due to changing market conditions;
- possible upward pressures on prices due to increased costs for some market participants (e.g., higher costs of capital because of higher risks);
- higher risks mean uncertainty for new investment compared with cost-of-service regulation;
- marginal cost pricing means more volatility, potential for price spikes;
- trade will tend to promote price convergence between regions: low-price regions could experience higher prices.

Summary

Restructuring of the electricity industry has been taking place in Canada and the U. S. for much of the 1990s. Individual provinces have considered restructuring and have chosen to implement changes to their markets in varying degrees, depending on their circumstances.

Reprinted from the National Energy Board's Energy Market Assessment "Canadian Electricity Trends and Issues", May 2001. www.neb-one-gc.ca. **ET**

Observations, continued from page 9

RTOs could lead to more north-south trade and increased integration of the U.S. and Canadian electricity markets. To the extent Canadian competitiveness can be maintained, higher export revenue would result. Market integration could also result in upward price pressure in some provinces.

Although market integration may be facilitated by access to current transmission facilities (as expected by the RTO initiative), persistent price differentials between regions with competitive wholesale markets may indicate that new transmission facilities are required.

Restructuring of Electricity Markets

The unbundling of generation, transmission and distribution services is occurring at an uneven pace across the country. Alberta completed its five-year program, introducing full retail access in January 2001, after implementing wholesale access in January 1996. Ontario plans to implement full retail access in May 2002.

At this time, there are no definitive plans to introduce full retail access in the other provinces; the reasons for this vary. In many provinces, it appears that, with the historical record of relatively low and stable prices and the prospect that this will continue to prevail in the near term, there is limited incentive to change the current regulated regime. However, a number of provinces currently provide, or plan to provide, whole-sale access.

A prime motivation seems to be to satisfy the reciprocity requirements of FERC Order 888.

Two main objectives of restructuring are lower prices and more customer choice. Increased competition might be expected to result in lower prices. However, there may also be higher costs associated with the increased risk faced in a competitive market environment, as compared with a regulated environment.

An example would be the increased cost of capital faced by electricity suppliers.

There is substantial debate about whether restructuring will ultimately result in higher or lower prices; however, it is clear that, in any given region, the design of the restructuring program and the supply and demand situation will be important factors in establishing the eventual outcome.

Electricity Prices

Volatile energy prices do not necessarily mean volatile electricity prices. In all provinces, with the recent exception of Alberta, consumer prices have been generally stable, or have increased by relatively small amounts, over the past several years. This stability is largely the outcome of the provincial regulatory regimes which establish prices on a cost-of-service basis and, in some provinces, the implementation of price freezes. Prices tend to be lower in provinces that generate most of their electricity from hydro resources (e.g., B.C., Manitoba and Québec). A comparison with residential electricity prices in other countries suggests that Canadian prices are among the lowest of the industrialized countries.

Continuing to establish electricity prices on the basis of regulated costs would be a departure from the pricing of other energy commodities, which is based on domestic and international market forces.

To the extent there is a difference between the regulated cost and the market value of electricity, as measured, for example, by the prices of competitive fuels in the same market area or electricity prices in adjacent market areas, electricity consumers and producers may not receive the appropriate price signals for decision-making. A regulated price that is set below market value could result in too much consumption and/or insufficient production, and a price that is set above market value would have the opposite effects.

Growing reliance on market forces in other sectors of the economy and in other electric power jurisdictions in North America is causing Canadian provinces to consider adopting market-based structures.

However, the record of low electricity prices provided, for the most part, by provincially-owned utilities under the traditional structure, and the recent experience with price volatility in California, have caused most provinces to move cautiously toward developing comprehensive restructuring plans.

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PROTECTION and CONTROL

IPP Protection:

Interconnection Transformer Winding Arrangement Implications

By Wayne Hartmann

The increased number of independent power producer (IPP) interconnections for peak shaving and power continuity applications on distribution feeders has increased the interest in, and application of, IPP interconnection protection. When operating IPP generation, known as dispersed generation (DG), is parallel with the utility, the applied interconnection transformer winding arrangement has an effect on what protection is applied to provide utility ground fault detection, and the subsequent separation of the IPP's generator from the utility. This protection and separation of the IPP's DG from the utility is required, so the IPP does not continue to feed into a utility ground fault after the utility has tripped an upstream substation circuit breaker or a line fault-clearing device, such as a recloser. Clearing a utility ground fault from all sources, including any IPPs on the feeder, is necessary to extinguish the arc. A typical circuit is illustrated in Figure 1.

After the arc is extinguished, typically an automatic reclosing sequence (by the breaker or recloser) is applied to test the feeder; it then remains closed if the fault was transient in nature. After the reclosing cycle is deemed successful (the reclaim timer expires), any IPPs on the feeder are then clear to attempt parallel DG operation with the utility.

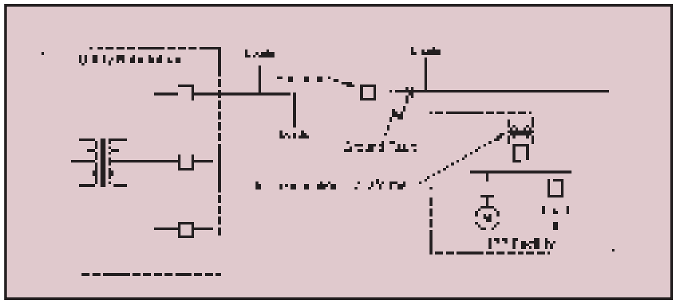

Figure 1: Ground Fault Between Utility Substation and IPP

The interconnection transformer winding arrangement can be defined as the type of winding that is applied to the primary, or utility side, and the secondary, or IPP side, of the transformer. Several winding arrangements are possible, all requiring an understanding of the impact each arrangement will have on the utility's protection, the IPP's protection, and power system operation. The common IPP interconnection transformer winding arrangements are shown in Figure 2.

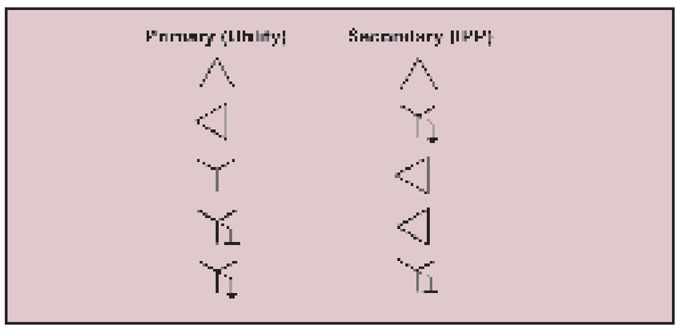

Figure 2: Common IPP Interconnection Transformer Winding Arrangements

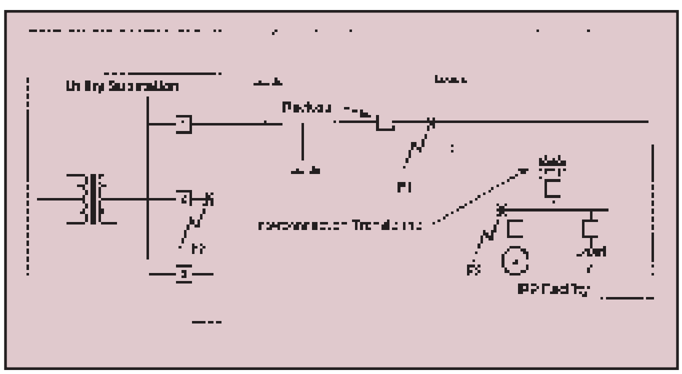

Figure 3: Ground Fault at Various Locations on Distribution System with IPP

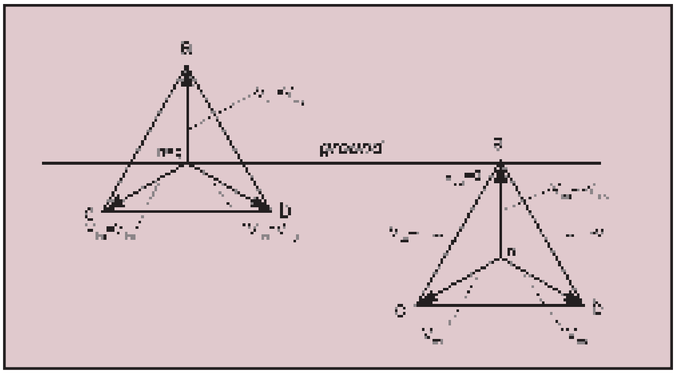

Figure 4: Voltage Shift for Ground Faults on Ungrounded Systems

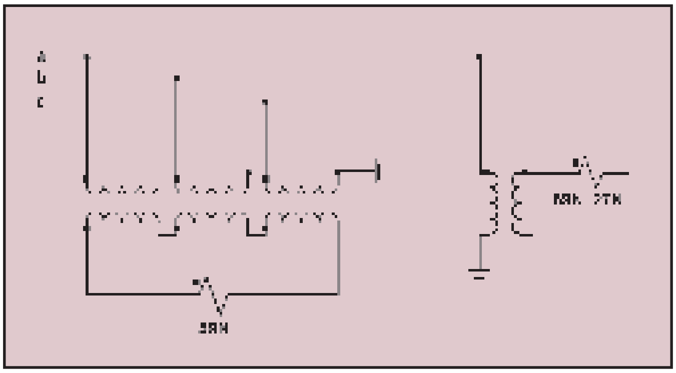

Figure 5: Use of Displacement Voltage and Over/Undervoltage for Ungrounded System Ground Fault Protection

If the generation at the IPP site is retrofitted into the facility, the usual transformer arrangement is delta-wye (grounded). This arrangement is typically chosen to provide isolation for utility for ground faults in the IPP's facility, and to supply a ground source for the IPP facility.

Examining each of the interconnection transformer arrangements, and placing ground faults on the circuit illustrated in Figure 3, the pros and cons of each may be explored.

Delta-Delta

Pros:

- Doesn't provide ground fault backfeed for fault at F1 & F2.
- Does not provide ground current contribution from Breaker 1 for a fault at F3.

Cons:

- Can supply the feeder circuit from an ungrounded source after substation Breaker 1 trips and causes overvoltage.
- Does not supply a ground source for IPP facility.

Delta-Wye (grounded)

Pros:

- Does not provide ground fault backfeed for fault at F1 & F2.
- Does not provide ground current contribution from Breaker 1 for a fault at F3.
- Supplies a ground source for IPP facility.

Cons:

- Can supply the feeder circuit from an ungrounded source after substation Breaker 1 trips and causes overvoltage.

Wye (ungrounded)-Delta

Pros:

- Does not provide ground fault backfeed for fault at F1 &

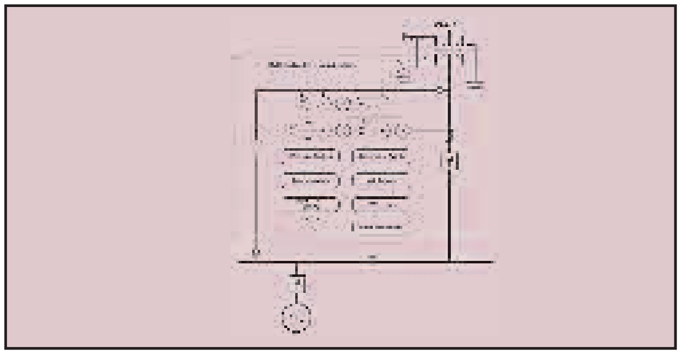

Figure 6: Typical IPP Interconnection Protection Application — Grounded Interconnection Transformer Primary (Utility) Winding

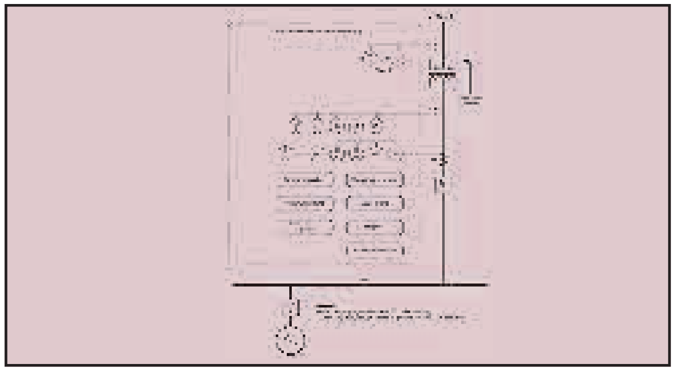

Figure 7: Typical IPP Interconnection Protection Application - Ungrounded Interconnection Transformer Primary (Utility) Winding

Continued on page 16

Continued from page 15

F2.

- Does not provide ground current contribution from Breaker 1 for a fault at F3.

Cons:

- Can supply the feeder circuit from an ungrounded source after substation Breaker 1 trips and causes overvoltage.
- Does not supply a ground source for IPP facility.

Wye (grounded)-Delta

Pros:

- Does not supply ground current from Breaker 1 for faults at F3.
- Does not cause an overvoltage for ground fault at F1.

Cons:

- Provides an unwanted ground current for supply circuit faults at F1 and F2.

Wye (grounded)-Wye (grounded)

Pros:

- Does not cause an overvoltage for ground fault at F1.
- Supplies a ground source for IPP facility.

Cons:

- Provides unwanted ground current for supply circuit faults at F1&F2.
- Supplies ground current from Breaker 1 for faults at F3.

Note: First winding is utility primary, second is IPP secondary

The first three transformer winding configurations provide a focus on interconnection protection, (and all configurations provide an ungrounded utility primary winding,) but they require a different utility system ground fault protection method than the last two transformer winding configurations, which provide a grounded utility primary winding.

When employing a grounded utility primary winding, if the utility opens its substation breaker or line recloser, the IPP's DG can backfeed the distribution line, and a ground current is available at the interconnection transformer which is detectable by employing ground overcurrent elements. On the primary (utility) side of the transformer, a transformer neutral ct may be the source for directional or non-directional ground current protection (51N or 67N).

On the secondary (IPP) side of the transformer, phase undervoltage elements may be applied to detect utility ground faults, as the resultant voltage drop is measurable across the interconnection transformer while the utility has not yet cleared the ground fault. The measured secondary (IPP) side voltage will also drop if the IPP is sourcing the fault. For delta secondaries, in addition, voltage controlled or restrained overcurrent elements (51VC and 51VR), sometimes directionalized for greater sensitivity (67 supervision) may be employed. For grounded wye secondaries, ground overcurrent (51N) or directional ground current (67N) elements may be employed as the zero sequence current commutates across the grounded wye-grounded wye transformer.

When employing an ungrounded utility primary winding, if the utility opens its substation breaker or line recloser, the IPP's DG can backfeed the distribution line. As the ungrounded delta winding does not commutate zero sequence current to the secondary, conventional ground relays applied on the primary neutral will not detect ground fault current. This is because the ungrounded winding does not provide a ground source. The phase and ground protection on the secondary (IPP) side of the interconnection transformer will not be able to detect and clear the utility feeder ground fault supplied by the ungrounded source. Fortunately, there are methods employing voltage protection that can detect a ground fault supplied from an ungrounded source.

To detect and clear the utility ground feeder ground fault sourced from the ungrounded primary (utility) side winding, a protection scheme is applied that uses one of two options:

The displacement voltage across a broken delta transformer on the utility's system (primary side of the interconnection transformer): This method utilizes the fact that when a corner of the delta system is grounded, the normally balanced voltage triangle is shifted as shown in Figure 4. The resultant voltage across the broken delta potential transformer is three times the line-to-ground voltage (secondary).

Over/under voltage of a single phase measured line-to-ground voltage on the utility's system (primary side of the interconnection transformer): This method takes advantage of the fact that when a phase of the delta system is grounded, the grounded phase falls to zero volts, as it is now the ground reference. The other two phase voltages rise to line-to-line values. The resultant voltage across a single line-to-ground connected potential transformer will be a detectable undervoltage or overvoltage (1.73 times the line-to-ground secondary value) depending on which phase has the ground fault. Both of these methods are shown in Figure 5.

When used together with the other protections typically employed for IPP interconnection protection, we have two basic schemes, one for grounded interconnection primary (utility) windings, as shown in Figure 6, and one for ungrounded interconnection primary (utility) windings, as shown in Figure 7.

To summarize, the interconnection transformer winding arrangement applied has implications on the protection utilized at the IPP's facility; it also has possible impacts on distribution system protective elements. There is no single 'best' connection type or universally applied arrangement.

Attention must be paid to winding and utility side grounding so the proper IPP ground fault backfeed protection may be applied and other coordination issues can be realized.

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[1] ANSI/IEEE Std. 1001-1988, 'Guide for Interfacing Dispersed Storage and Generation Facilities with Electric utility Systems.'

[2] IEEE P1547, Draft Standard for Distributed Resources Interconnected with Electric Power Systems.

[3] Mozina, C.J., 'Interconnection Protection of Dispersed Generators in the New Millennium', Texas A&M University Conference for Protective Relay Engineers, College Station, Texas, April 11-13, 2000.

[4] M-3410 Intertie/Generator Relay Instruction Manual, Beckwith Electric, 2001.

Wayne Hartmann is Applications Manager for Protection and Protection Systems at Beckwith Electric Co. Inc. WHartmann@beckwithelectric.com. **ET**

POWER QUALITY Q&A

Answers to Frequently Asked Questions About Power Quality

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

Question:

We are constructing a new building where sensitive electronics will be installed. If the electrical distribution system is installed according to the Electrical Safety Code, will this be sufficient from a power quality standpoint?

Answer:

The Electrical Safety Code is a minimum standard which defines the method and materials that must be used in the installation of electrical equipment and the wiring of machinery and facilities. Its prime focus is safety. When an inspector is reviewing an installation, he or she is looking for conformity with the Code and more specifically correct wire sizing, fusing, clearances, and grounding. If we look closely at the Code, there is very little that concerns itself with the quality of the power we hope to receive.

Therefore, if we use the Code as our specification for defining power quality installation practices, we will be quite disappointed with the results.

So how do we get the results we want; a safe reliable power system that works with our sensitive electronic equipment? We have to define what is needed to achieve our goal and communicate it to those performing the installation work. One way to do this is to find an electrical engineer or other experienced professional who knows power quality issues and how to mitigate the potential problems. Engage them to write a specification that details the materials and methods that cover all your power quality concerns. Include this specification in all your electrical specification packages for bidding.

In this way, the installation contractor knows exactly what is expected, can bid accurately, and will provide you with an installation that will be reliable and trouble-free. Of course, as with any contract, you must ensure that the installation follows the specifications.

In the end, you will get the system you want and will find that the extra cost involved is minimal.

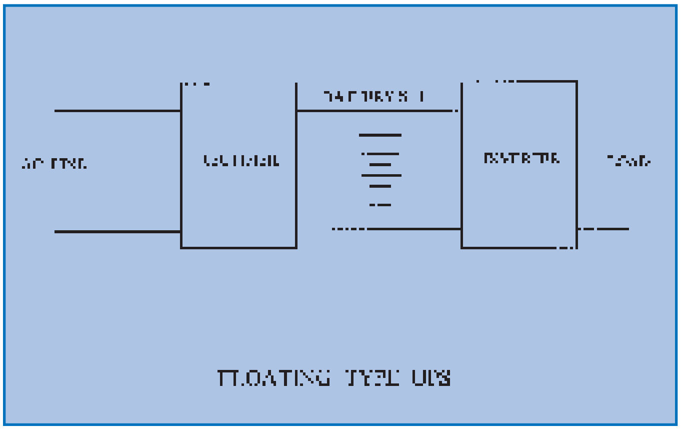
Question:

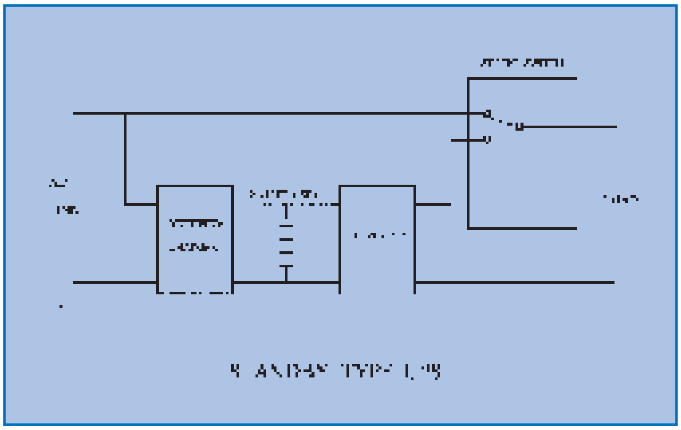
What is the best type of Uninterruptible Power Supply (UPS) to use for my Computer Centre?

Answer:

Typically, for computers we are trying to protect against a data loss from momentary outages. For longer-term outages, we are trying to buy time so that open files can be closed and our operating system brought down in an orderly fashion.

One available type is a Stand-by type system. In this type, the computer runs normally from a clean AC line. This AC supply also charges a set of batteries that remains in a stand-by mode. If an outage occurs, a static (or solid state) switch connects the battery through an inverter to the computer load.





When the AC line comes back on, the switch reverts back to its normal position and the computer is fed from the AC power supply. With this type of system, there is a short discontinuity of power during switching even though the static switch reacts very quickly. This switching may affect the computer hardware or the integrity of the data.

Another, more preferable solution would be to use a Floating type system. In this type a reliable AC source feeds a rectifier or battery charger which holds a charge on a set of batteries. An inverter uses this DC power to synthesize an AC waveform that is used to power the computer. Therefore, the computer is 'floating' or drawing inverted power from the batteries under normal circumstances. Hence, when a loss of AC power occurs, the computer continues to operate on the batteries without any switching or discontinuity. When the power returns, normal operation resumes.

Regardless of the type of UPS selected, it is vital that the UPS provide a clean sinusoidal output. A higher end UPS will do this. A check of its specifications will confirm this. A lower end UPS designed for general back-up service will give a rougher, if not square wave type output. Transients and harmonics associated with a non-sinusoidal output may create undesirable power quality effects.

Looking at the big picture, there may be other things to consider. Are there other systems that may affect the computer's operation such as air conditioning systems? If these cease to operate during power failures, will they cause a computer failure? Some strategy may have to be developed for them.

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's Power Quality Question & Answer Column. **ET**

GENERATION

Creating a Potential $5 Million Revenue Gain From Hydropower Turbines Using Computational Fluid Dynamics Simulations

By Bernard Massé

CFD simulations helped engineers at Hydro-Québec make design changes that will generate revenue gains of up to $5 million in twelve hydropower turbines. By shifting the maximum efficiency point to raise the power output by 7.8 megawatts and by raising the weighted efficiency of the turbine by 1.6 per cent, the changes will produce revenue gains of between $200,000 and $500,000 per year for each turbine. The exact amount depends upon the grid demand. These revenue gains have already been validated in one turbine and plans are being made to implement the design changes on the other eleven turbines. These gains were made by modifying the runner at the blade trailing edge to eliminate a large eddy in the draft tube elbow that was discovered to be reducing efficiency of the turbines. The eddy was discovered and the design changes were validated by using CFD in order to provide researchers with a clear understanding of fluid flows throughout the turbine.

Hydro-Québec is a world leader in generating green energy, with over 31,400 MW of installed capacity in 1998 and ranks among North America's largest distributors of energy. It serves 3.5 million residential, commercial, institutional and industrial customers in Québec. In addition, it supplies nine municipal systems, one regional cooperative, and some fifteen electric utilities in the Northeastern United States, Ontario, and New Brunswick. Since obtaining a marketer's license from the Federal Energy Regulatory Commission, it also makes direct sales, at market prices, to American power wholesalers, including public utilities, municipalities, resellers, and large industrial consumers in the United States. Its 1998 sales totaled 161.4 TWh, with Québec markets accounting for more than 88 per cent (142.8 TWh) and sales outside Québec for nearly 11.5 per cent. The company is publicly owned with a single shareholder, the Québec government.

Less efficiency than expected

A Hydro-Québec power plant, commissioned in the early 1980's, was operating with less hydraulic efficiency than was expected from the reduced scale model tests conducted by the manufac-

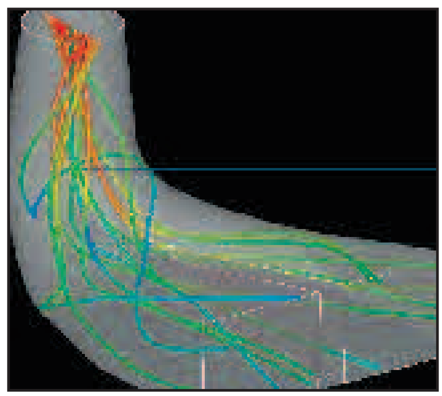


Figure 1: Reduced losses in the draft tube (before modification).

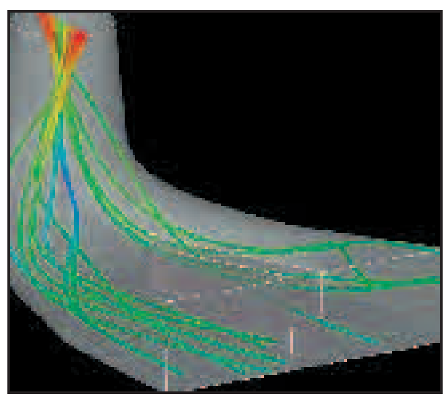


Figure 2: Reduced losses in the draft tube (after modification).

turer and confirmed by an independent test stand. When the power plant was originally built, there was no way to determine what went wrong in the design and fabrication of the 12 identical turbines used in the plant. Because of the tremendous advances since that time in numerical simulation tools, it was decided to take another look at this problem with the goal of finding the cause and, ultimately, a solution to raise the efficiency of the turbines. CFD, the technology used in this simulation, involves the solution of the governing equations for fluid flow at thousands of discrete points on a computational grid in the flow domain. When properly validated, a CFD analysis allows engineers to determine the direction and speed of flow at any point in the flow domain. Unlike a physical model, the geometry of the CFD model can be changed quickly on the computer and re-analyzed to explore different options in project design or operation conditions.

Fluid flow simulations were conducted in the whole turbine from the water intake through the penstock, the spiral casing, the distributor, the runner, and the draft tube. To compute the flow inside a complete turbine, iterations are required to link together the components, distributor, runner, and draft tube. Velocity profiles, turbulence parameters, and pressure distributions must be transferred from one component to the other in order to assure a coherent flow through the entire turbine. For a given operating condition, the mass flow and wicket gates angle are specified to compute the distributor flow field. This gives the velocity profiles and turbulence parameters to be used as runner inlet flow conditions. The runner flow is then computed and outlet profiles are used as draft tube inlet conditions. The pressure is then computed as the flow is solved in the draft tube and is used as runner outlet boundary conditions to recalculate the flow. The same is done with pressure at the distributor outlet.

Eliminating several areas from consideration

Fluid flow in the water intake and in the penstock is responsible for the flow profile entering the spiral casing. Questions were raised about the velocity profile at the entrance of the spiral casing due to the presence of an elbow just upstream and also because the flow at the water intake itself arrives at various angles. Experimental measurements were available on a scaled model of the water intake where the shape of the reservoir had been reproduced and the inlet angle could be changed. The CFD analysis correlated well with the model measurements and did not show any anomalies, leading analysts to believe that the efficiency problem was not related to the water intake or the penstock.

The flow field was simulated in the spiral casing to check for problems. The contour of radial velocities generated by the analysis indicated that the flow at the runner inlet was uniform along the circumference. In addition, no problematic flow pattern was seen in the spiral casing. The problem was then suspected to reside in the turbine itself. As the flow was seen to be uniform in the distributor, a section of the distributor was modeled for flow simulation and loss computations. In order to investigate the flow in the runner, two hydraulic passages were measured on site. A mechanical digitizing arm was used to measure the surface data of critical parts, such as leading and trailing edges and complex surfaces of the blade.

Selecting FEA-based CFD software

Hydro-Québec researchers selected the FIDAP CFD code from Fluent Incorporated, Lebanon, New Hampshire, as one of their modeling and analysis tools. This software package uses the finite element approach and has the advantage of using non-structured grids. Non-structured grids provide considerably greater flexibility in modeling the complex and irregular geometries involved in hydropower turbines. Non-structured grids also automate the otherwise impracticably tedious process of fitting elements to the complex geometries used in complex areas such as the draft tubes. Care was taken to ensure good mesh quality, especially near the walls, which are responsible in large part for the losses. Using the iterative approach described earlier, several turbine operating conditions were computed.

The simulation in the turbine showed a large eddy in the elbow. Further analyses led researchers to conclude that this phenomenon was the main cause of the efficiency problem. The eddy arises just before the peak operating point and up to the maximum load. It is related to inappropriate flow at the runner exit. The runner-draft tube interaction is responsible for most of the

Continued on page 22

Continued from page 21

losses. However, another smaller eddy was detected in the runner, near the leading edge and the crown on the pressure side of the blade.

Reducing the losses

To reduce the losses, the water flow between the runner and the draft tube had to be improved. Researchers chose to modify the runner outlet and designed a new trailing edge. A parametric study was conducted on the draft tube flow to determine the influence of the inlet flow parameters on its performance.

Several blade cuts and extensions were tried to modify the critical parameters. Once the draft tube flow was optimized, the flow in the runner was examined to reduce, if possible, runner losses at the same time. The researchers arrived at a solution that reduced hydraulic losses in the runner as well as the draft tube at the maximum efficiency point.

The efficiency measurements on the prototype, measured by an independent team, showed a significant increase in turbine efficiency at all operating conditions. The gain is about 1.5 per cent at the peak and increases as the operation moves to the maximum power point. At the maximum efficiency point, the gain is due to the improved flow both in the runner and in the draft tube elbow. In the draft tube, analysis results showed that the eddy in the elbow was gone.

Figure 3: Runner modification at power plant.

In the runner, the effect of the eddy is reduced.

The maximum efficiency point is shifted to the right and gives an additional 7.8 MW to the 195MW nominal unit with 1.5 per cent more efficiency.

Effects of new design on erosion

Researchers also looked at the effects of the new design on cavitation erosion. The CFD results indicated an increase of inlet cavitation with the modified runner. Measurements using a vibratory cavitation detection method before and after modification indicate a possible increase of 30 per cent in erosion at the maximum efficiency point and an increase of 85 per cent at maximum power. This increase was not considered to be a serious problem since the original runner cavitation level was low. The increase in efficiency far more than compensates for the expected small increase in maintenance costs.

The modifications were first applied to a single Francis turbine. The modified turbine provided more than the increase in efficiency that was predicted by the analysis. In less than a year of operation, this improved efficiency has already paid for the $200,000 cost of the modifications. Hydro-Québec management is currently making plans to implement the modifications on the other eleven turbines for this power plant. Planning is also in progress to use CFD to improve turbine efficiency at other power plants.

This application provides an excellent illustration of how CFD simulations can identify hydropower problems and help develop alternatives to improve machine performance.

Bernard Massé is Hydraulic Machines Team Leader with the Hydro-Québec Institute of Research (IREQ). **ET**

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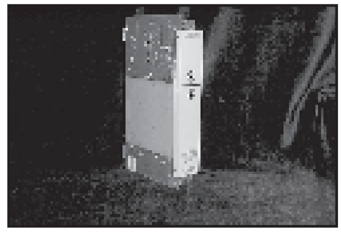

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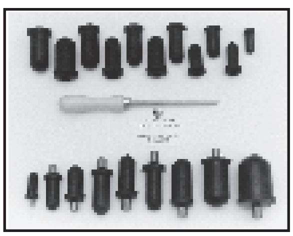

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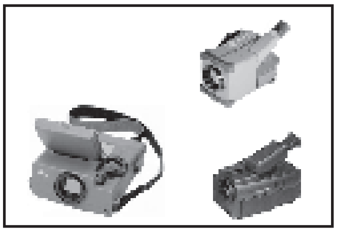

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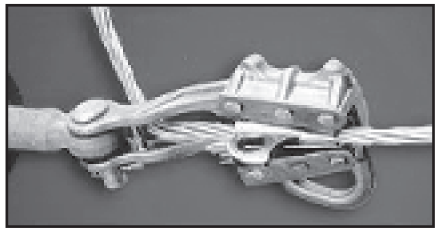

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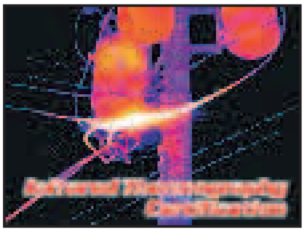

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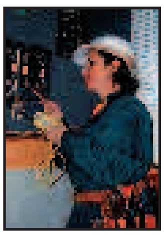

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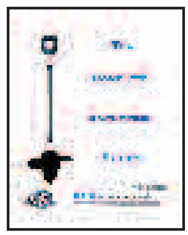

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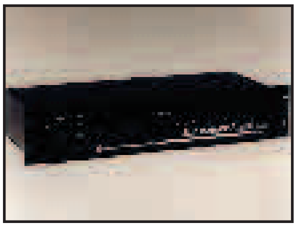

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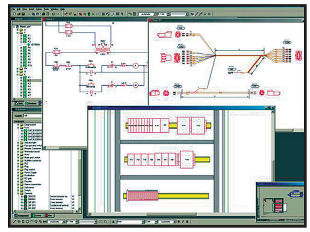

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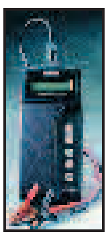

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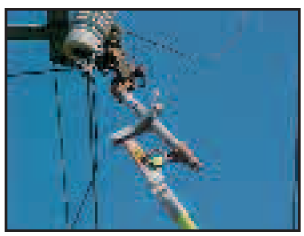

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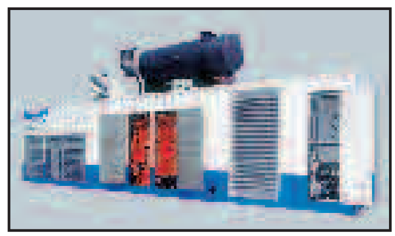

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Waukesha Engine has announced the details of a new lease program for its popular Enginator(engine/generator packages. According to company officials, the Waukesha Engine Lease Program offers customers the same advantages as owning a distributed power generation system ñ but without the risks.

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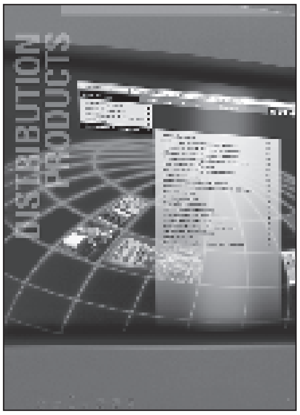
Electricity Today Literature Review

CUTLER-HAMMER
Products and Services Catalog



Eaton's Cutler-Hammer Products and Services Catalog 2001 provides product descriptions, detailed specification and pricing. You can also learn about the broad spectrum of solutions offered from Cutler-Hammer Engineering Services and Systems (C-H ESS). These catalogs are easy to use and are the most complete industrial resources currently available. Call 1-800-957-7050 to order yours today!

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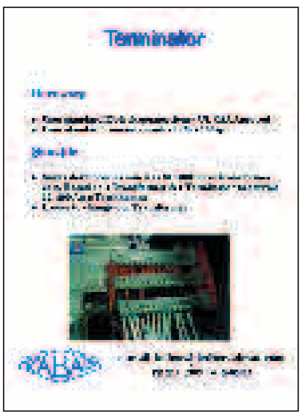
Please email literature requests to: INFOHPS@HubbellOnline.com

KABAR INDUSTRIES
Terminator Secondary Feed-Through



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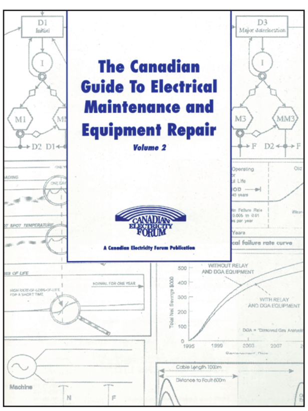
CANADIAN ELECTRICITY FORUM
The Canadian Guide to Electrical Maintenance and Equipment Repair Vol. 3



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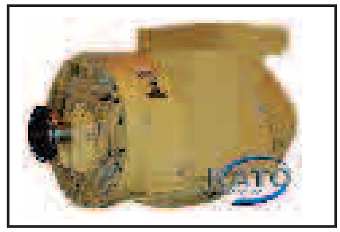

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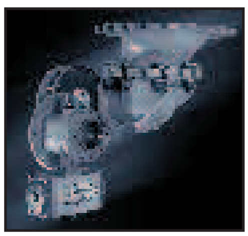

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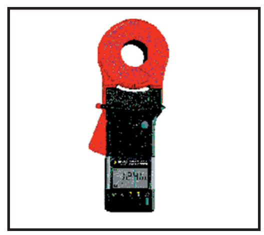

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Continued from page 5

had one false operation when it tripped both lines. The cause was traced to the delta voltages that were used to direction the relay. The directioning voltages were replaced by four wire star connected potentials to solve the problem.

The KCEG is a reliable, effective protective device, but it does not initiate tripping until about 60 milliseconds or almost 4 cycles after the fault occurs. It was considered advisable to try to reduce this time and thus the plant's exposure to the inevitable voltage sag, and to replace the ineffective remote tripping function that had previously been removed.

Accordingly, the author developed a prototype relay called the PCS, which incorporates a number of enhanced features to improve performance and reduce cost, as follows:

- The relay operates in 20 ms, about twice as fast as normal remote tripping and three times as fast as the KCEG.
- The relay sends a trip signal directly to the breaker, eliminating the cost and time delay inherent in auxiliary relays.
- A single relay provides protection for both 115KV lines with separate trip outputs for each transformer breaker.
- The relay is designed to ensure correct directioning for both trip outputs under all voltage collapse conditions.
- The relay is currently configured to trip only when there is reverse current in all three phases. It thus serves the specific purpose of identifying load backfeed conditions, as its function is to replace remote tripping. It should be noted that the relay can also be configured to operate on a single phase of reverse current.
- The pick up setting for the PCS is 500 amps per phase.

The new directional over current protection has been in service for over five years and during that time, except as noted above, the plant has never suffered a single shut down for normal one line faults, nor has the prototype PCS relay either false tripped or failed to trip for the conditions for which it was designed.

The KCEG relays clear slightly more faults than the custom relay, as would be expected because it is designed to operate for all line faults. See fault recorder records of fault cleared by the PCS relay. The fault was a lightning arrester failure right in the switch yard. The voltage dip lasted only 70 milliseconds.

This pilot project has proven conclusively that instantaneous directional over current relays can replace pilot wire relays and/or remote (transfer) tipping with their associated leased telephone circuits in a dual supply line configuration, at lower cost and with increased reliability. This relay configuration can also be used to connect two feeders from different sources to a common load bus for improved security, provided the two sources can be synchronized.

For comments or more information, Paul Kruger can be reached at (613) 389-3716 or at wkruger1@cogeco.ca. **ET**

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