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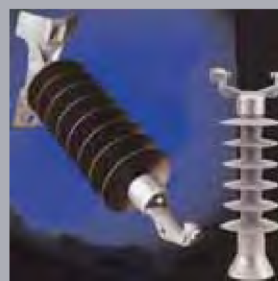

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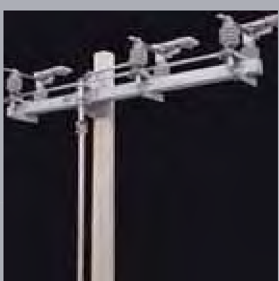

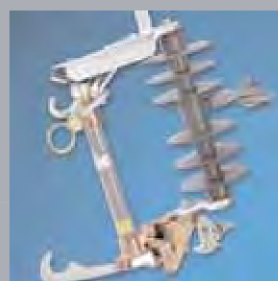

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IT'S TIME WE CAME TO TERMS WITH COAL

Don Horne, Editor

When two ships at sea are on a collision course, the captain sounds the klaxon.

Green, environmentally friendly power (wind, solar, hydroelectric) is sailing straight into the good ship coal – and politicians are having to make some very tough choices as to what and how much generation they need to build.

North American power providers have crunched the numbers and stated plainly that coal generation not only needs to be maintained at its current level but actually increased.

A CIBC World Markets report backed up what the Power Workers' Union has been telling the Ontario Power Authority for years – that the closure of the province's existing coal plants will lead to higher electricity prices.

At the moment, the provincial government has set the closure date for Ontario's coal plants at 2014 (a date that has already been extended). This is set in the backdrop of other provinces like Alberta and Saskatchewan planning on building new coal stations fitted with new clean coal technologies.

And all of this is framed by the Kyoto Protocol limiting Canada's greenhouse gas emissions, and must be factored into the country's carbon credits.

In the U.S., many states are moving ahead with new coal generation construction, part of a worldwide construction boom of more than 1,000 new coal plants destined to become operational by 2030.

But they all won't be pollution-spewing monsters.

One new coal generation plant in Jamestown, New York will feature new emission reducing technology from Praxair, which is called the oxy-coal process. Certainly not emission and pollution free, the reduction and containment system is being heralded as a plus for the community, and an opportunity to make the Buffalo Niagara region a center for research in new coal-burning technology.

An attitude that is worlds apart from just across the U.S.-Canada border, where any endorsement of coal is seen as being tantamount to political suicide.

But coal is just one part of the puzzle. The nuclear option has gained a great deal of support, despite lingering doubts regarding waste and plant safety.

Additionally, local utilities are faced with the aesthetic hurdle. No one wants overhead wires, and no one wants a generation or substation in their backyard.

Residents usually come out in force to complain about new transmission and distribution corridors. Bury it, is what they suggest – that is, until they see the cost.

On Toronto's shoreline, a brand new natural gas generation plant is under construction, drawing frowns and fumes from many area residents who would prefer a park be built instead, allowing an unobstructed view of Lake Ontario.

Unfortunately, they also frown and fume when their air conditioning and refrigeration shuts down due to a brownout or blackout. Of course they admit that it is necessary to build new generation to meet demand on the grid – and of course they point to several areas far, far away where the generation plant or substation could be located.

And for the naysayers of coal generation, they can now point to the ash coming from the "clean coal" process as being as bad or potentially worse than ordinary ash.

Tests have proven that the chemicals injected into clean-coal plants' emissions to capture airborne pollutants are changing the composition of the ash and cuts so that they cannot be used to make concrete.

In short, this arsenic and mercury-laced ash has to be sent to the landfill, and that means a possible leaching problem into the groundwater. And that doesn't factor in the ammonia, lime and calcium hydroxide that is used in the "cleaning" process that is now a part of the already toxic ash chemical coctail.

Currently there are several quite effective and inventive energy conservation campaigns being conducted in the United States and Canada. Mostly they focus on how consumers can control their demand by purchasing energy efficient appliances, light bulbs, smart meters, etc. In addition, the nuclear energy lobby has some excellent public awareness campaigns on the benefits of nuclear generation (no emissions); and in the area of wind and solar, every new farm is heralded by every level of government to the smiles and applause of environmentally conscious constituents.

The rush to eliminate coal generation is foolhardy, and the politicians need to step forward and admit as much. In addition, every one of us who uses electricity must come to grips with the fact that we have been given something very close to a free ride for far too long.

Much of the public service announcements and awareness campaigning is targeted to make the public drink the Kool-Aid on electricity conservation. Since it looks inevitable that the politicians will have to eat crow on the retirement of coal-fired generation plants, some Kool-Aid might be needed to wash that crow down.

But as much as the politicians need to face facts, the electric power industry must be prepared to bite the bullet as well by exploiting clean coal solutions now.

The race is on to build a new fleet of coal-fired power plants that rely on conventional combustion technologies – technologies known to accelerate global warming. And there is little doubt that once Congress passes any kind of serious greenhouse gas legislation involving air pollution permits, the utilities will certainly argue for all existing plants to be grandfathered in. This very scenario was played out in 1970 when the Clean Air Act was passed, and older plants were made exempt with the promise of newer state-of-the-art facilities coming on line.

And many of those grandfathered plants continue to operate today.

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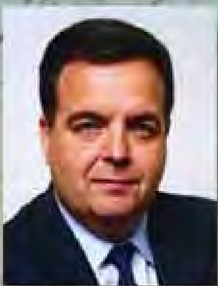
Sharpening the Blueprint

How the industry will deliver on Ontario's power plans



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DISPELLING MYTHS ASSOCIATED WITH SPREAD SPECTRUM RADIO IN SCADA NETWORKS

By Steve Emrich, FreeWave Technologies

Every year, the electric power industry deploys more spread spectrum communication solutions. With the install base of spread spectrum devices rapidly increasing, there have been a number of "myths" and misinformation that have circulated as a result. Among the more prevalent of these are the following (shown at right):

Myth	Summary
Security	Spread spectrum is not secure; someone can steal your data.
Saturation	Spread spectrum radios will shut down when there are too many radios on the same frequency.
Range	Spread spectrum radios are only one watt and won't perform as well as licensed radios.
Compatibility	If you have licensed radios you have to buy only licensed radios for expansion.
Interference	If you mix licensed radios and spread spectrum radios, or different brands of spread spectrum in the same system they, will cause interference and data will be lost
Obstructions	You must have clear line of sight, or spread spectrum will not communicate.

The objective of this article is to explore these "myths" and provide a better understanding of how to use spread spectrum technology and also show where you can expect to succeed with spread spectrum communication solutions.

SECURITY

Spread spectrum was invented for the US Navy during World War II to prevent the Germans from "jamming" American radio transmissions for radio-guided torpedoes. This original system used a mere 88 frequencies. Today, the switching is controlled in embedded software code that enables a radio to change frequencies in excess of 200 times per second and use more than 100 channels.

The technology behind spread spectrum radio is complex enough that anyone trying to intercept a signal would have to match more than 186,000 possible parameters to be on the same channel with the radio and then would only be in sync for about 1/100th or possibly 1/200th of a second. In addition to matching parameters, the entity attempting to intercept data would find that today's spread spectrum radios also utilize advanced encryption protocol to insure additional security.

SATURATION

A common fear with spread spectrum is that as more and more companies move to this "shared" frequency, it will become saturated and unusable. However, if there is a saturation point, it has not yet been reached. In many areas of the country, thousands of spread spectrum radios are delivering data to multiple end-users without conflict or data loss. Examples of these networks can be found in various regions around the country and in other industries. In Wisconsin, a major generation and transmission utility is using more than 100 radios in the field with another 300 radios to be deployed over the next year. The end-users' offices and their base stations are in a proximity where repeater towers can be shared by multiple networks, as appropriate. If there were any potential for "saturation", it would happen at these repeater sites where the wireless traffic is at its highest and the antennas are installed very near to one another.

RANGE

Another common myth associated with spread spectrum is that it is good only for short-range communication. To the contrary, spread spectrum can be deployed as a complete long-range communication solution. By federal regulation, a spread spectrum radio can only have an output of one Watt at the radio and four Watts at the antenna. Licensed radios, by contrast, can have higher output power, typically five Watts at the radio and 20 Watts at the antenna. In a contest of which radio will broadcast the furthest in a straight line, the licensed radio will clearly win the distance contest. However, with the curvature of the earth, it is extremely rare to have a line of sight range exceeding 20 miles. What spread spectrum does is add the flexibility by allowing the use of multiple repeaters to extend your system as required.

COMPATIBILITY

Many people believe that if they install a base of licensed radios, they must use the same manufacturer and model of radio they originally purchased. However, it is possible to mix spread spectrum radios into an existing licensed radio system enabling features such as multiple repeater functionality and reduced deployment costs. This network can be accomplished by placing a new repeater in the existing system. You simply need to take an existing slave site and put a spread spectrum (master) radio back-to-back with the licensed slave and join the two radios together by using a "null modem" cable between their respective RS-232 ports.

It is also possible to create hybrid systems by combining CDPD (Cellular Digital Packetize Data), satellite, cell phones and landline telephone modems individually with spread spectrum. The

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beauty of these systems is that the end user can use a communication device, such as a landline, to cover a long distance of 100 miles and then "mate" to a spread spectrum network to gather data over a wide area network (WAN). This configuration would allow an end-user to gather data from 100 devices through a single telephone connection. Since landline telephones, cell phones and satellite communication come with monthly charges, it is much more cost-effective to spread these costs over multiple devices in the field. Combining these technologies will produce the most efficient and cost-effective solution.

INTERFERENCE

Another common misconception is that spread spectrum and other radio communications will interfere with each other. The most common spread spectrum band in the United States is 902MHz to 928MHz. This frequency band is set aside by the federal government to be allocated for spread spectrum devices and the rules are structured to allow the band to be shared by multiple users. The official designation for this band is ISM, which implies it was established for industrial, scientific and medical usage. Several devices can operate simultaneously in this band. Each are limited to the same 1Watt of power and frequency hopping rules. Devices outside of this band can be eliminated by use of band pass filters.

OBSTRUCTIONS

Many times you might hear that radios must have clear "Line of Sight" (LOS). While that is a good rule of thumb, spread spectrum does have the capability of passing through obstacles. With a clear line of sight, a radio might transmit 20 miles, but if there are obstructions, such as trees and buildings, the signal might only travel 10 miles. Ideally you want a clear line of site so that your signal will propagate as far as possible, but the closer you are the more obstructions you can propagate through.

The most important thing to do is perform a "path study" prior to installation. This is the quintessential case of "an ounce of prevention being worth a pound of cure". Performing a path study prior to starting a project will create a network design that allows you to work around any obstacle and insure a solid, robust communication system, regardless of "line of sight" in the area.

CONCLUSION

It is reasonable to foresee the day when spread spectrum radios and their closest relative, the Ethernet radio, will be the dominant and preferred communication device for data collection in electric power applications.

Steve Emrich is business development manager of electric power for FreeWave Technologies, Inc., the largest independent provider of high performance spread spectrum and licensed radios.

DIGITAL CONTROL SYSTEMS FOR HIGH-VOLTAGE SUBSTATIONS - PART II

By James Propst, Western Area Power Administration (WAPA) and Mike Dood, Schweitzer Engineering Laboratories, Inc.

Western's Power System Clearance procedures detail two primary tagging procedures — one for HLO and one for clearances. Western does not tag equipment controls under clearance with power system clearance tags. The only tag included in the HMI was for hot-line orders. The HLO tag indicates reclosing has been turned off and the circuit breaker close path has been interrupted.

Within the HMI, the HLO tag cannot be turned on when reclosing is in place. The HLO is represented on the one-line screen by a yellow HLO tag and flashing indication on the PCB control screen. If the close function is selected, an HLO WARNING screen is displayed, and closing is prevented.

The PCB control screen has a representation of a physical switch for each function. The switch representation was chosen to make the HMI intuitive. The PCB control screen is the same for all equipment, with only the appropriate functions visible and active. For example, the 85 function is disabled for dedicated transformer breaker, or reclosing for a reactor breaker is disabled. The HMI works by sending the command to the protective relays and then reading the status back via the communications processor to effect changes on the HMI displays. The switch handles rotate and lights change to indicate the appropriate status on the PCB control screen.

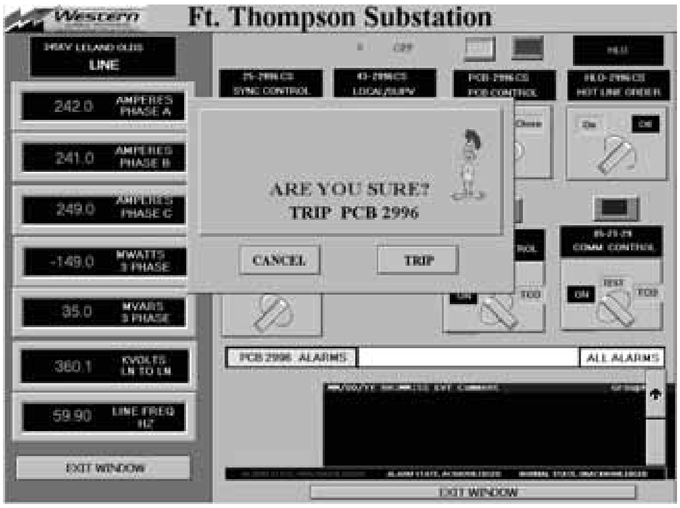

Figure 5. Right Fort Thompson PCB Control Screen. The chicken switch is displayed for confirmation of the control action TRIP PCB2996. Chicken switch confirmation is displayed for trip and close actions.

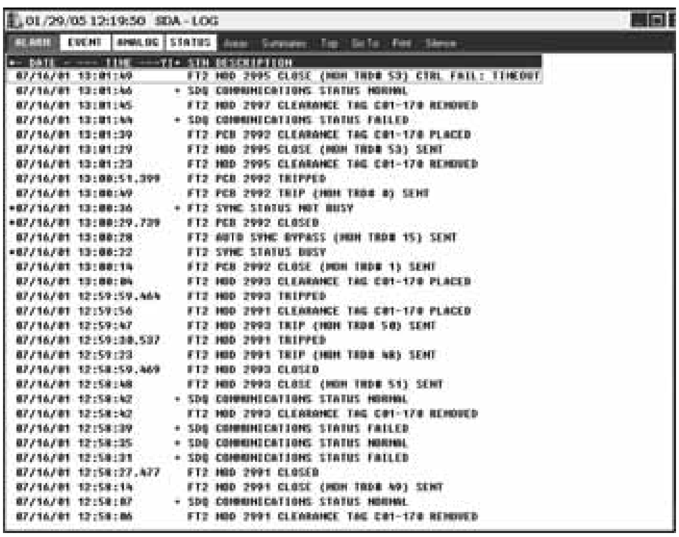

Figure 6. SCADA log was available for commissioning via Ethernet connection

Commands to open and close a circuit breaker include a "chicken" or "select-before-operate" switch, which requires confirmation of the selected action. Commands to change the 43, 79, and HLO functions do not require confirmation, as the effect of the command will not immediately impact operation — no circuit breakers will open or close. Placing the 43LS in the supervisory position disables all other controls and is represented with a SUPV label displayed over the control switch handle. The update time on the HMI is about two seconds.

A small alarm window is displayed on the PCB control screen as well, with the option of displaying all alarms or the selected breaker alarms. This function is easily accomplished with the HMI software's built-in displays. The metering associated with the circuit breaker is also displayed on the PCB control screen and can be changed to either line in the case of a ring bus or a breaker-and-a-half bus by selecting the desired meter on the left window of Figure 5. Metering quantities are especially easy to display and scale. The metering quantities are obtained from one of the protective relays.

The current alarms or the alarm history can also be displayed on the right window of Figure 5.

Alarms are displayed with status; red is active and unacknowledged, yellow is active and acknowledged, and white is reset and unacknowledged. Time, date,

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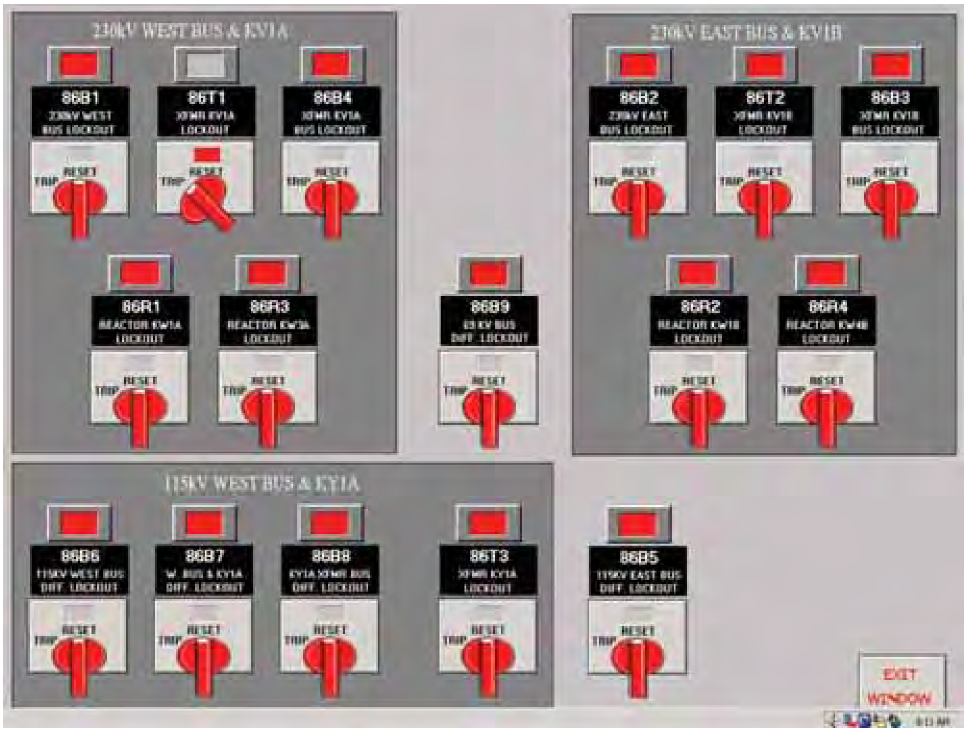


Figure 7 Lockout screen from a Huron Substation with software lockout 86T1 in the TRIP position. The lockout is reset by clicking the on-screen RESET button.

description, comment, and group name are displayed. Sort functions are also available. Because Western did not latch their alarms or events, the HMI display can miss fast resetting changes. Modbus Plus protocol does not support the SOE function. Western chose this direction because they have access to their SCADA master and believed active alarms would account for the majority of use after commissioning was completed. During commissioning, Western relied on their SCADA master for events.

The HMI interacts with the lower-tier communications processors. If SCADA control is lost, the local platform is still redundant with respect to controls. Metering quantities are obtained only from a single source. Statuses are combined in the HMI. The HLO status is "ANDed" to ensure both reclose paths are turned off and closing is prevented. The 43LS, 85, and reclose paths are "ORed" to allow for relay failure or testing.

LOCKOUTS

With the first DCS design, Western went digital — no switches, which meant a software lockout.

Wired logic or digital logic is complicated, but mixing them has a cumulative effect and further complicates each portion. Furthermore, the logic in wiring an output from a relay to trip a lockout and then wiring a contact from the lockout back to the same relay to block closing is circular and confusing. Most tripping functions of the software lockout, such as transformer lockouts, are accomplished with relay outputs. Bus lockouts are generally accomplished via the extended digital protection system by relay-to-logic processor-to-relay communication. This may add 4 ms to the tripping time, but because this function is competing with a Zone 2 trip, which in this case can take up to 20 cycles, it is not an issue.

In the DCS design, the lockout function is primarily to block close because the contact multiplication is not necessary. The block close functions are combined in the logic processor to a single bit, which is then sent to the closing relays. The lockout function is maintained until reset by using latch bits that maintain their value through a power cycle. The software lockouts are displayed on the HMI, and the reset function is active when the lockout is in the tripped position.

Software lockouts take less than one minute to manually configure in the HMI and even less time to configure in the logic processor. There are huge savings in design and installation costs with software lockouts. One of the longest wired logic strings — block closing — is completely eliminated.

A solution had to be found to the question of "How do we test it?" Because the lockouts may have distributed tripping via the relay-logic processor-relay communication, the use of logic prints and documentation is required. Because all trips are hardwired from a relay, the key is to use the documentation to find the relay and open the appropriate test switch. Whether lockout tripping is done through every available protective relay or through one chosen path determines which protective elements remain in service during testing. At Fort Thompson, distributed tripping was only through one path for the ease of testing.

On one of the newer designs, Western installed digital test switches. The digital test switches are easily created and take about the same time to create as a lockout — about a minute. They function by toggling between the open and closed state enabling or disabling the protective relay output.

One advantage of the digital test switch is the ability to alarm if a test switch is left open.

DIGITAL PROTECTION SYSTEM

Some of the more extensive wired logic in the control panels is breaker failure initiation. The use of the logic processor simplifies these installations by providing a single logic bit to each appropriate relay eliminating substantial wiring, particularly in a ring bus. The issue that once again goes hand-in-hand with the new technology is how to test it, because the initiation is done using relay-to-logic processor communication. To address the issue, the upper-right protective relay test switch was wired to an input for the relay initiating breaker failure. The input was used to supervise the relay-to-logic processor communication. Therefore, if meter and relay craftspersons open all the test switches before testing, they are safe from initiating a breaker failure operation during routine testing.

The use of a single 52a contact essentially saves a 12/C cable. In traditional designs, Western would need a 52a for the primary relay, secondary relay, breaker failure relay, each RTU (Western often has more than one), and a 52b for the sync select circuit. The 52a contact is wired to the remote I/O at the circuit breaker and the status is distributed via the logic processor to each relay and the RTU. The RTU distributes the circuit breaker SOE to each utility. Use of the logic processor, like the protective relays, creates an accurate time stamp of change of state.

Therefore, even if complicated communications schemes add communications delays, everything is time stamped relative to the same accuracy. In some cases, data moving through multiple IEDs have been measured to have up to an 8 ms delay in transit. This additional delay is not a concern and may actually improve the accuracy of the 52a timing. Usually, the 52a contacts timed in circuit breakers lead the main contacts. Because the auxiliary switches are mechanical, they must close before the main contacts quit moving. And because Western does not routinely adjust the lead times, a range of 1/4 to as much as one cycle of lead time has been observed in the 52a auxiliary switch. The protective relay needs to see a 52a transition after the trip command to complete the reclose initiation sequence. Some communications paths, even with fiber, can take longer to transmit a POTT signal, used in the reclose supervision, than it takes some of the newer SF6 breakers to operate. The delay in the 52a may actually improve reclosing performance by allowing additional time for the transmission of the POTT signal. The use of the 52a is imprecise in analysis work as well, for the same reasons; additionally, there is always some contact assertion time that must be taken into account.

The SOEs were collected by the RTU from the logic processor. Most of the SOEs were already present in the logic processor after the block close strings and breaker failure initiation functions were incorporated into the logic processor. Relay-to-relay protective functions such as POTT or DTT are echoed to the logic processor. The logic processor also provides all equipment alarms directly to SCADA. Equipment alarms were passed to the HMI via the communications processor. Connecting the remote I/O to the logic processor makes the SCADA update time totally dependent on the RTU and the SCADA master, as the logic processor updates information in relay time — every 1/4 cycle.

RTU

Analog quantities are obtained from the protective relays by the lower-tier communications processors, scaled, and sent to the upper-tier communications processor, where they are mapped for DNP. Statuses follow the same path but are combined as appropriate in the upper tier. The 43LS and Reclose functions are "ORed" and the HLO statuses are "ANDed" in the upper tier.

Update time for this process is approximately two seconds, to the point where the data are read by SCADA.

No I/O boards were used with the RTU. Nonoperational data such as "personnel on site" were wired to the auxiliary inputs on the communications processors and logic processors. Control for items such as the yard lights was accomplished with the auxiliary outputs on the communications processors and logic processors as well. The elimination of RTU direct I/O changes the function of the RTU to a multiport protocol converter. It also represents a significant savings in hardware and labor costs. An RTU for this size of facility would easily cost $20,000 with the peripheral boards. Future designs will eliminate the need for the RTU altogether.

FIBER

As was previously mentioned, part of this project included replacing the copper control cable that had been damaged by rodents. Both technical and cost considerations were taken into account in the decision to replace the copper control cables with fiber-optic cables. Because this project is using communications-dependent schemes for not only monitoring and control but also for protective applications, the reliability and security of the intrasubstation communications have become much more critical aspects of the design.

The electrical substation environment in the upper Midwest includes many environmental challenges to reliable and secure communications. These challenges include high-current faults, temperature extremes, high voltages, electromagnetic interference, and electrostatic discharge. To overcome these communications challenges and to provide economical, reliable, secure, and safe communications, Western chose to use fiber-optic cable to interconnect monitoring and control systems. Fiber-optic cable is ideal for the harsh electrical environment of the substation. In addition, fiber-optic transceivers that required no external power source or external mounting were used. They simply plug into the serial port and are powered from the communications control lines. These transceivers are designed to work dependably in the harsh substation environment, just like the equipment to which they are connected.

Because of the physical arrangement, there are two 345 kV breakers and one reactor with an MOI in each of the two bays of the ring bus. Western ran one pair of fibers to each 345 kV breaker for the breaker 43LR, 52a, 52b, and alarms; another pair of fiber for the MOD 43LR, 52a, 52b and open/close functions for each of the MODs associated with each breaker; and another pair for future use. This required a 6-fiber cable to each piece of equipment. Because each bay required 18 fibers, a 24-fiber cable was run to a central point in the bay, where the three 6-fiber cables were connected to it and placed in a ground-level vault. All fiber-optic cables were installed in conduit with fabric interduct. The conduit was directly buried adjacent to the cable tray. The fiber-optic conduit has a large coefficient of expansion and is difficult to manage in the cable trays because of heat fluctuations. Fiber-optic cable with the heavy PVC jacket was chosen for structural integrity.

On each piece of equipment, a 2' x 3' x 1' deep enclosure box with a gasket door was mounted.

The fiber termination box, fiber storage trays, and remote I/O were mounted in this enclosure.

Switchboard wire was used for connecting the I/O to the equipment. A 5/C cable was installed from each MOD to the circuit breaker. This saved up to 1000 feet of 12/C for each MOD, as wires were doubled to compensate for voltage drop.

In the control building, the fiber was terminated in storage racks in the control panels. This location made the patch cables easy to install.

During the design process, several recently completed traditional facilities were reviewed. It was interesting, as every circuit breaker had enough alarms combined to limit the total alarms for each breaker to five. This was due to normally installing two 12/C cables to each breaker. Multimode fiber was chosen, as the terminal equipment is less expensive. The 24-fiber cable cost $1.84/foot or about $0.15/foot/pair. The 6-fiber cable cost was slightly higher per pair at $0.16. So a 1,000-foot installation had a material cost of $160, the remote I/O was $375, the enclosure with termination rack was $200 ($800 split four ways as the equivalent of four 12/C cables were eliminated — two for the breaker and one for each MOD), and a fiber-optic transceiver was $362, for a total of $1,087. With 12/C #10 cables costing about $2/foot, the material cost for copper is $2,000 for each cable. The labor is difficult to compare between the two methods, but 1,000 feet of 12/C cable cannot be pulled by one person, and it takes time to dress out and terminate the four cable ends. Additionally, no further wiring is required in the building using fiber. Because the communications personnel were not wiring an RTU, they had time to fuse the fiber, and the climate-controlled environment was a nice place to work on a hot summer day.

To provide control for the circuit breakers, a 5/C cable was installed. The wires were assigned to positive, negative, trip1, trip2, and close. Therefore, one fiber pair and one 5/C cable replaced two 12/C cables. To provide control for the MODs associated with the circuit breaker, a pair of fiber replaced two 12/C cables. The materials cost for all copper would have been about $8,000 for the four 1,000-foot lengths for the circuit breaker and MODs. The fiber/copper combination material cost was less than half that amount at about $3,200 dollars. Not only was the fiber less costly, but an infrastructure was also installed for a future Reliability Centered Maintenance (RCM) program or possible digital current and voltage signals.

ETHERNET

Western installed an Ethernet network in the control building, with connections on the control panels. The Ethernet connection was used to access the SCADA master, which was used extensively during commissioning and checkout. The communications processor and HMI were connected to the network as well. Access via Western's intranet was deemed more secure than dialup. These connections allow for remote access into any of the substation IEDs to retrieve event reports. An automated scheme to retrieve these event reports is currently being evaluated.

The HMI connection allows for virus-checking software updates and remote hard-drive maintenance. The client software for the RAID controller allows hard drives to be rebuilt remotely if they stop because of an error.

Connection to the Internet during commissioning made file sharing with experts and the manufacturer's technical staff extremely easy.

DOCUMENTATION

With the new technology, new ways to document the functionality were required. Traditional ladder logic diagrams for schematics were replaced with logic diagrams as the breaker schematics became two trip contacts and two close contacts. Relay schematics became little more than wiring diagrams because the only wired inputs were trip-coil monitors and relay-to-relay communication disable; wired outputs were trip, close, and alarm.

Spreadsheets were used to track information like RTU and HMI points, tag names, DNP index, and relay element names. Tables were included on schematics to track internal protective relay element usage and function.

LESSONS LEARNED

Training

Craftspersons responsible to keep a site functioning often want to know only about the specific features being used in a system — not every function a particular piece of hardware can perform.

Therefore, Western worked with the vendor in developing a target training course on the communications processors and logic processors. This training was well received, and it was followed by questions such as "Yes, but how does it get from here to there?" and "How do I fix it?" At this point, Western internally developed a three-day block of 101-type training on the functional blocks of the DCS design, how they integrate, and basic troubleshooting.

> While basic training is essential, there is no substitute for actually working with the equipment.

The internal training was conducted for all meter and relay personnel. Other attendees were individuals from operations, management, and engineering with an interest in DCS. The goal of the training was to present an overview of the DCS system and how each function was accomplished by the components of the system. The type of information needed to troubleshoot the system was presented. Segments included alarms, SOE, control, HMI, DCS control, analogs, Fiber 101, and Ethernet 101.

While basic training is essential, there is no substitute for actually working with the equipment.

The classroom training is prerequisite, but the final part of the learning occurs during the installation, commissioning, and final checkout. Training also requires sitting down with the new primary tool — the PC, learning to work with it and developing a new set of analytical tools for the PC.

DCS Design

The architecture chosen for the first project remains unchanged in the Upper Great Plains region.

While there have been advances and changes within the individual pieces, the overall functionality is the same. For example, control interface protocol from the RTU to the communications processor has changed from Modbus to DNP, but from that point through the system, it works the same way from the first substation to the tenth substation. The Upper Great Plains region of Western has installed a DCS control system in 11 substations.

Initially, one team at Western was working with DCS designs, so a standard was not an issue. As the design spread to new projects and other regions of Western starting work on their facilities, a difference in standards developed across Western. Western is in the process of addressing these differences and working toward a common solution. Western experienced some poor results when standards were adopted and implemented without testing and verifying the design. One recent example was the implementation of a fully redundant system with redundant control, redundant SOE, redundant analogs, and redundant status. This approach proved to be very complicated and introduced decision-making logic because SCADA wants only one set of data. It should be noted that the complexity more than doubles each time a redundant data or control source is added; complexity grows exponentially.

Maintenance

The only failure at Fort Thompson was a remote I/O device. An untrained electrician replaced the remote I/O device during normal work hours. The failure was that an input stayed asserted on the I/O device without the input voltage present.

There have been some settings errors related to reclosing and similar functions. These types of errors were not related to the DCS implementation. There have been no problems with the DCS equipment. Routine maintenance consists of cleaning the air filters for the HMI PCs, file cleanup, and periodically verifying hard drive integrity.

Western is changing the way they label some of the DCS alarms in order to give more descriptive information to the operators. An alarm of "21-3A communication failure" does not mean much to our operations personnel. If that alarm is labeled as "GI Line Loss of Primary Control and Status," it has immediate meaning for operations.

CONCLUSIONS

In order to make the best use of the available features within the protective relays and also to leverage the knowledge that the Western personnel already had with the relays, the control and monitoring functions are now performed by the relays and communications processors. This monitoring and control had previously been performed by less-reliable PLCs and RTUs. The microprocessor relays are now responsible for tripping and closing either via local or via remote operators, or via automation logic settings. The relays are also used wherever practical to bring back status and analog operational and maintenance data from substation apparatus.

This eliminated many discrete components such as switches and auxiliary relays, and the associated wiring. Fewer components dramatically increased the quality and reliability of the logic processes by moving them into highly reliable IEDs designed for use in mission-critical applications.

The need to replace all the damaged copper cable in the substation provided the opportunity to evaluate installing fiber. The analysis proved that fiber is an economical solution and provided all the many benefits of using fiber instead of discrete pairs of copper control conductors for each control and monitoring function. Innovative features in the specific products chosen also provide constant monitoring and immediate alarm and notification if the cables to the field I/O are damaged. This is not available via traditional copper cable methods.

The use of multifunctional microprocessor relays resulted in a large reduction in the amount of space required in the control house. This translates into a cost savings during installation, reduced maintenance cost and effort, and higher reliability, because the design uses fewer devices, components, and wires.

The new system provides much more measured and calculated information about the power system for use by operating, maintenance, and engineering personnel than was previously available. Western makes good use of these data in part due to the fact that it is easily accessed through a common user interface. In addition to the power system data, the microprocessor relays provide a wealth of self-test and real-time diagnostic information that makes it easy for operating and engineering personnel to troubleshoot system events. Using these data, Western personnel ensure that schemes and settings are correct.

While the DCS system essentially paid for itself in direct savings, it also creates an infrastructure for new and emerging technologies such as RCM. The IEDs connected via fiber to Western's intranet have the capability to provide more information than they currently use. As the industry learns how to use this information, Western is poised to easily take advantage of new technology.

Finally, the familiarity with computers and the proliferation of available software packages has made them a logical consideration for the substation. Until recently, applications had to be chosen carefully because both desktop and industrial computers exhibit very low MTBF, or mean time between failures. MTBF is a measure of the relative reliability of a device and is used to choose between devices during design and selection. Features such as redundant power supplies and easily exchanged hard drives make computers marginally more reliable but also obviously increase the required amount of maintenance. Western offset this low MTBF by installing redundant HMIs with redundant hard drives and redundant power supplies. The advent of a new class of more robust devices, rugged computers, will improve individual computer reliability and will eliminate the need for a redundant computer system.

NHEC LINEMAN WINS FIRST EVER HUSKY TOOLS HERO CONTEST

James Robison has been an industry veteran for almost two decades.

Being a lineman is tough work – it is a job that often involves bad weather, dangerous situations and very long hours.

To celebrate its 30th anniversary within the utility industry, Huskie Tools reached out nationwide earlier this year to find out more about the linemen behind its tools in the first-ever Huskie Tools Hero Contest.

James Robison, a lineman first class with the New Hampshire Electric Co-op (NHEC), based in Plymouth, New Hampshire, was the winner.

An industry veteran for nearly two decades, Robison has gained the respect of his fellow linemen and is known for his strong work ethic, commitment to his company and dedication to his community. That is what prompted his wife Sheila to secretly nominate her husband of 21 years after seeing a Huskie Tools ad within an industry publication earlier this year.

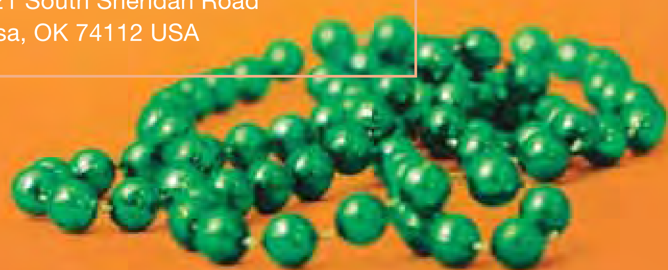
"After reviewing all of the submissions, we were most impressed with James' respect for dangerous conditions, smart approach to situations with safety in mind and his commitment to looking out for the men working by his side," said Tom Itrich, Chief Executive Officer of Huskie Tools. "James truly embodies what Huskie Tools is all about and we're proud to extend this honor to him as we commemorate 30 years of serving lineman nationwide."

Born and raised in New England, Robison attended Newfound Memorial High School in Bristol, New Hampshire. After graduating in 1984, he enlisted in the U.S. Army where he served overseas in Korea and was stationed in Fort Polk, Louisiana. During his tour of duty, Robison married Sheila, his high school sweetheart. Upon his honorable discharge, Robison joined New Hampshire Electric Co-op where he has worked for more than 18 years. When not on the job, Robison enjoys hunting, woodworking, involvement in his church and watching his three children – Nicholas (15), Zachary (13), and Abby (8) excel in school and outside activities.

Upon learning that he had won the Huskie Tools Hero Contest, Robison was quite surprised and humbled by the recognition. "It's an honor to be acknowledged by Huskie Tools for the work that I do every day," explained Robison. "Sheila and I look forward to visiting Chicago later this summer."

As the winner of the Huskie Tools Hero Contest, Robison receives an all-expense paid trip for two to Chicago including airfare, local transportation, accommodations at a top-rated hotel, celebration dinner and a tour of the Huskie Tools headquarters located outside of the city. In addition, Robison will participate in the newly created Huskie Tools Ambassador program joining other linemen throughout the country in sharing feedback and input on industry issues and product needs.

Headquartered in Plymouth, New Hampshire, NHEC is the largest member-owned electric cooperative in New England, serving nearly 80,000 members in 116 New Hampshire communities.



STATE-OF-THE-ART COMBUSTION CONTROLS CO2 EMISSIONS FROM COAL - PART I

By H. Farzan, S. Vecci, D. McDonald and K. McCauley, The Babcock & Wilcox Company
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The research and development of oxy-coal combustion for CO2 capture from coal-fired boilers has been the subject of numerous studies. Recently, The Babcock & Wilcox Company (B&W) and Air Liquide (AL), with sponsorship of the U.S. Department of Energy (DOE), have finished a pilot-scale evaluation of the technology at 1.5 MWth (5 MBtu/hr) using scale model commercial boiler equipment. The oxy-coal combustion flame stability, boiler and convective pass heat transfer, boiler thermodynamic performance and NOx emission levels compared favorably to the air/coal firing conditions. A steam generating plant engineering and economic evaluation also showed that oxy-coal combustion is a technically feasible and economically viable technology. B&W and AL are currently, with sponsorship from the U.S. DOE, undertaking a project to significantly broaden the applicability of oxy-coal combustion technology to the existing fleet of coal-fired boilers. Upon successful completion of this development effort, pilot-scale oxy-coal combustion test data will be available for application and scale-up to both wall-fired and Cyclone furnace boilers that burn bituminous, sub-bituminous or lignite coal. This article describes the research performed to date, future pilot-scale and scale-up of the technology to full-scale commercial operation.

INTRODUCTION

Over half of the electric power generated in the United States comes from coal and almost one-third of the man-made carbon dioxide emitted comes from that same coal combustion.

Over the next twenty-five years, an additional 147,000 MWe of new coal-fired generating capacity will be added in North America to meet an economy-wide electricity demand growth rate of 1.6%, as reported by the Energy Information Administration's (EIA) International Energy Outlook 2006, while at the same time increasing coal's market share. Today, over 310,000 MWe of coal-fired generating plants are in service, operating at ever-increasing capacity factors, in the U.S.

The Intergovernmental Panel on Climate Change's (IPCC) Summary for Policymakers (SPM), February 2007, recognizes that the continuous annual release of carbon emissions at the gigaton level is likely to affect the climate, and that these effects can now be resolved and modeled at the decadal level. Plausible predictions of climate change may now be made for a few decades, perhaps more. In addition, they acknowledge that anthropogenic greenhouse gas (GHG) emissions appear to be contributing to a near-term warming trend. Carbon dioxide is just one of several of these greenhouse gas emissions (along with methane, nitrous oxides, and halocarbons); however, it represents 63% of the radiative forcing causes (21% from coal) associated with anthropogenic sources.

The need for carbon emission regulatory budgets, while temporal in nature, requires development for the U.S. and must be developed in context, and in concert, with the global efforts to manage carbon. Carbon reduction budgets need to span the breadth of the economy, as this is a challenge that cannot be met by a single sector. The presence of budgets, both near and long term, will then enable long-term planning decisions to be made, decisions that impact billions of dollars in energy and electricity system assets, both existing and future.

The power industry has successfully met the challenge of reducing sulfur dioxide, oxides of nitrogen, particulate matter and more recently mercury. Carbon dioxide challenges the industry in a new way because the quantities are vast and the technologies are still under development. The Babcock & Wilcox Company (B&W) and Air Liquide (AL) have been leaders in one such technology, Oxy-Coal Combustion (OCC), which is now ready for commercial demonstration.

The OCC process allows for the isolation of CO2 from the combustion process without the need for a separate carbon capture process, and is the pathway to a Near Zero Emissions Power (NZEP) plant.

B&W and AL have been actively involved in the development of oxy-coal technologies for power generation for the past ten years. From earlier participation in various consortia focused on these technologies, AL and B&W have become major players and have been leading several projects in this field. Together, B&W and AL performed pilot-scale oxy-coal combustion tests on a 1.5 MWth pulverized coal (PC) boiler, economics of full-scale 500 MWe PC power plants and preliminary oxy-coal advanced boiler design. Following very promising results, the efforts moved toward more detailed engineering studies at full-scale (300-500 MWe) along with feasibility studies at demonstration scale (22 MWe and 30 MWth). These studies are about to be completed providing extended understanding on some critical technical points of the oxy-coal technology. Worldwide, several studies have also concluded showing great interest in the oxy-coal technology for CO2 capture from coal-fired power plants.

BACKGROUND/PREVIOUS WORK

Oxy-coal combustion for enhanced oil recovery was evaluated by B&W initially in 1979 at the request of a major oil company. Since the late 1990s, B&W has been a member of the CANMET oxy-coal combustion consortium and participated in 1-million Btu/hr tests in Canada. AL has likewise been a leader worldwide with extensive R&D and subject patents and has collaborated with B&W in North America. They have been, in particular, involved in developments and industrial implementation of oxycombustion processes on many diverse industrial processes such as in metals production or glass melting for more than 40 years. In addition, they have been a leader in Air Separation Units design and operation for many years, in particular for energy production including from coal gasification.

The historical perspective of oxy-coal combustion has been reported by Santos.(1) The concept was first proposed by Abraham in publicly available literature.(2) The process was then investigated by Argonne National Laboratory (ANL) through a series of techno-economic, pilot-scale and demonstration plant studies.(3,4,5,6,7) During the 1990s, the technology gained more interest for CO2 capture and additional work was performed by a research consortium led by the International Flame Research Foundation (IFRF).(3,8,9) B&W and AL work on oxy-coal combustion started in the late 1990s and has provided the means for assessing the potential of the technology for application to coal-fired power boilers to the point of near commercialization.

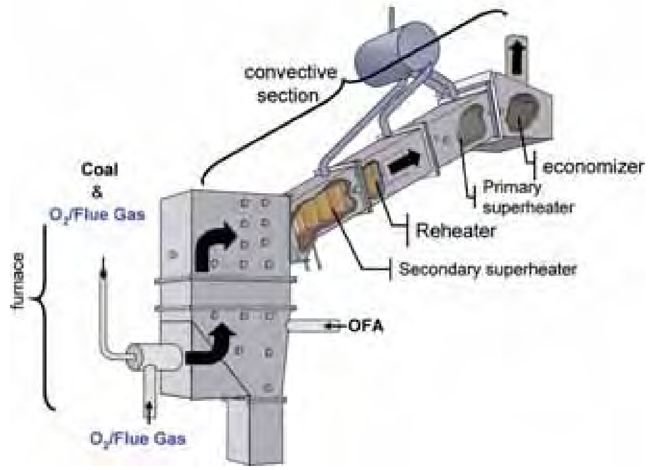

Fig. 1 B&W small boiler simulator (SBS-I).

RECENT PILOT-SCALE EVALUATIONS

Pilot-scale development of the technology for coal-fired boilers began several years ago at B&W in collaboration with AL.(10,11,12,13) Highlights of the pilot-scale oxy-coal combustion experience are described below.

DESCRIPTION OF THE TEST FACILITY

Shown in Figure 1 is B&W's 1.5 MWth (5 MBtu/hr) Small Boiler Simulator (SBS-I) facility used in oxy-coal combustion development work. Pulverized coal (PC) flow from a storage bin is measured and controlled by a calibrated weigh feeder. The coal is then transported by heated primary oxidant (PO) at about 150F to the burner. Secondary oxidant (SO) flow is preheated indirectly to 600F by a gas-fired heater. For staged combustion, the 600F tertiary oxidant (TO) is directed to overfire ports located above the main combustion zone. The SBS is shown here in the PC mode but the unit can be converted for Cyclone firing. The oxygen levels in the primary and secondary streams and convection pass exit gas are measured with oxygen sensors. For safety purposes, boiler permissives and interlocks are set to limit the oxygen concentration in the flue gas at 25% for secondary and 21% for the primary zones using the oxygen sensors and the oxygen flow controls.

Liquid oxygen from an onsite 9,000-gallon (34,000 liters) oxygen tank was vaporized and regulated to an appropriate pressure for delivery to the SBS via a copper line. The oxygen delivery control system was integrated into the boiler safety interlock system. Flue gas was sampled continuously from the convection pass exit and the concentrations of O2, NOx, CO, CO2, and SO2 were measured on a dry basis by calibrated gas analyzers. The stack flyash was isokinetically sampled and analyzed for carbon content to determine carbon utilization.

RESULTS

The oxy-coal combustion technology has been successfully demonstrated and characterized in the pilot facility while burning a low-sulfur sub-bituminous coal and high-sulfur eastern bituminous coal. The overall oxy-coal combustion characteristics were comparable to the air-firing case even with the change in oxidant composition from air to oxygen-enriched flue gas. The NOx emissions from oxy-coal combustion were significantly lower (65% less) than the air-fired case. The thermodynamics and heat transfer in the furnace and the convection pass changed only modestly. In commercial applications, site-specific studies will determine the boiler performance, but based on this pilot-scale study, no heat transfer surface changes are anticipated. Air infiltration into the boiler under oxy-coal combustion conditions was reduced to the equivalent of 5% of the overall stoichiometry. Substitution of combustion air with oxygen and recycled flue gas increased the CO2 concentration from 15% to 80% at the boiler exit. Boiler upgrades can further reduce the air infiltration and increase the flue gas CO2 concentration. With oxy-coal combustion, the flue gas volume exiting the boiler is reduced by 70% relative to air-fired operation, downstream of the recycle take-off point, thus minimizing additional processing or treatment that may be necessary to prepare the CO2-rich stream for permanent storage.

TECHNICAL-ECONOMIC ANALYSIS

After the successful pilot development effort, the technical and economic barriers to the technology were evaluated to apply the technology to existing and new boiler applications.

Previously, extensive simulations and cost assessments were performed on the subcritical PC plant; here the scope was extended to assess the oxy-coal combustion technology with supercritical (SC) and ultra-supercritical (USC) steam cycles with more engineering and manufacturer's data input.

Below are some of these technical and economic results and items requiring further study.

Technical evaluation

Our joint development efforts have been performed with an eastern bituminous and a sub-bituminous coal, at the 1.5 MWth (5 MBtu/hr) pilot, equipped with a wall-fired burner. To broadly commercialize the oxy-coal combustion technology, we need to widely expand the applicability of the technology to other boiler types and coal ranks, and demonstrate the technology at a larger scale.

Coal rank

Previous development efforts have been performed with an eastern bituminous coal and a sub-bituminous coal. Similar to normal air-blown combustion, the major differences in coal properties (e.g., heating value, ash and moisture content and ash elemental composition) affect the coal pulverization, flame stability, flyash unburned combustibles content, convection pass deposition and heat transfer. To expand the applicability of the technology, lignite testing and characterization need to be performed.

Combustion and boiler equipment

The development effort has been performed using a scale model of a B&W low-NOx burner that was modified for oxygen firing. The oxy-coal combustion process needs to be adapted for application to Cyclone-equipped boilers and lignite fuel PC burners. Cyclones operate in a slagging mode that requires modifications of oxy-coal combustion technology before it can be used in these boilers. This technology provides a means for CO2 control from existing Cyclone boilers. An added benefit of the oxy-coal combustion process, especially for Cyclone units, is that it provides reduced NOx emissions from the boiler. Thermal NOx is reduced since there is less molecular nitrogen in the oxidant stream. In addition, some of the NOx in the recycled flue gas will be reduced to molecular nitrogen via reburning by hydrocarbon radicals in the flame. As a result, the high NOx levels that have been characteristic of Cyclone boilers will be much lower when Cyclones are retrofitted with oxy-coal combustion. Oxy-coal combustion will be adaptable for applications to Cyclone boilers, but due to the unique Cyclone slagging mode of operation, the wall-fired experience will not be directly applicable.

Oxygen/recycled flue gas mixing and control, oxygen levels

Oxy-combustion provides a challenge of coordination of the combustion system and the air separation unit (ASU) equipment to the design engineers. In other words, it is not enough that both systems function; they need to be adaptable and work in harmony with each other. AL and B&W have completed an engineering study on a 22 MWe PC boiler retrofitting the unit to oxy-coal technology.(16) During the progress of the project, many technical issues were identified and resolved that were never addressed in any paper or engineering study. Below are some of the items requiring special attention, generic to any PC boiler operation in oxy-coal combustion mode.

• The ASU should not be considered separately from a power plant while designing the oxy-coal power plant. The ASU has to be customized to the specific needs of this application for safety, reliability, and efficiency. In the course of the technology development, AL and B&W have come up with key insights on how to optimize an oxy-coal power plant.

• The ASU mode of operation when supplying oxygen to a power plant is different from other traditional applications. Those specifics need to be addressed during the ASU design phase.

• Boiler startup and transition between air combustion and oxy-coal combustion modes is critical with respect to safety and technicality. AL and B&W have developed this expertise during pilot scale tests and are applying the knowledge to 30 MWth and 300 MWe oxy-coal boilers.

• Mixing of oxygen with recycled flue gas should be addressed and carefully designed. AL has patented O2 injectors and has extensive expertise in this area over many years.

• Interaction of the ASU with other parts of the power plant, other than the boiler, was identified as critical and needs to be addressed.

Near full-scale oxy-coal combustion pulverizer-burner performance

The challenge of retrofitting the oxy-coal combustion system to an existing coal-fired boiler is to simplify the oxy-coal combustion technology and to minimize the boiler heat transfer surface changes. Our research and development efforts have shown that by appropriately designing the process, the expensive pressure part modifications can nearly be avoided. Therefore, boiler modifications are limited to recycled flue gas duct, and oxygen introduction to the process, monitoring, and control. The application of oxy-combustion in a new boiler provides the designers with an opportunity to potentially reduce the size of the boiler and, therefore, reduce cost.

In the oxy-coal combustion process, oxygen is mixed with recycled flue gas to replace the normal combustion air at the pulverizer. This primary stream consists of CO2, oxygen, and water vapor and its density is higher than the normal air. The pulverizer performance is affected by flue gas composition and may require more recycle gas than air to maintain acceptable performance, especially with low-rank coals. More development in this area is needed on the mill performance, which directly affects the burner design and operation.

Our research and development was conducted with a 1.5 MWth (5 MBtu/hr) scale version of a commercial B&W low-NOx burner. Although the burner performed satisfactorily in our pilot with a bituminous coal and a sub-bituminous coal, a near full-scale burner development is needed to reduce the risk of scale-up directly from a small burner, which will be explained below.

To address these technical barriers, B&W has initiated two projects:

• Under sponsorship of US-DOE, NETL (National Energy Technology Laboratory) award No. DE-FC26-06NT42747, a pilot-scale evaluation project has been initiated to address the effect of coal ranks and boiler types. This will be discussed in the section titled Oxy-coal combustion for retrofitting coal-fired boilers.

Table 1 Major Economic and Financial Assumptions

Capacity Factor	85%
Costs Year Constant US Dollars	2005 (January)
Illinois # 6 Delivered Cost	\$1.27/10^6 Btu (\$4.33 /MWh)
Design/Construction Period	4 years
Plant Startup Date	2015 – 2020*
Land Unit Cost	\$1,500 /acre
Project Book Life	20 years

* The ASU proposed in this study is designed and quoted using today's commercially available technology

Table 2 Presumptive BACT Values

Pollutant	Emission Limit	Control Technology
PM/PM_{10}	0.015 lb/10^6 Btu (0.023 Kg/MWh)	Fabric Filter or ESP (99.5 to 99.8% efficiency)
SO_x	0.1 lb/10^6 Btu (0.16 Kg/MWh)	FGD (98% reduction)
NO_x	0.07 lb/10^6 Btu (0.11 Kg/MWh)	LNB/OFA/SCR for air combustion, LNB/OFO for oxy-fuel
Hg	90% removal	Activated Carbon Injection

Table 3 Study Matrix

Case	Steam Cycle	Oxidant	Product CO_2	Product Purity
1	SCPCRef	Air		
2	USCPC	Air		
3	SCPC-OC	95 mol% O_2	Spec. A	Saline Formation
4	SCPC-OC	95 mol% O_2	Spec. B	Saline Formation
5	SCPC-OC	95 mol% O_2	Purify to meet Spec. B	Saline Formation
6	SCPC-OC	95 mol% O_2	Spec. C	EOR
7	USCPC-OC	95 mol% O_2	Spec. A	Saline Formation
8	USCPC-OC	95 mol% O_2	Spec. C	EOR

• Scale-up is being pursued in B&W's existing 30 MWth pilot facility, which features a near-full scale commercial oxy-coal combustion burner fed directly by an on-line pulverizer. This will be explained in the section titled CEDF oxy-coal combustion campaign.

Economic evaluation

Oxy-coal combustion can be used for retrofit or new boiler applications. As a retrofit option for existing coal-fired boilers, engineering and economic evaluations have shown that oxy-coal combustion retrofits for carbon dioxide capture are technically more straightforward and less expensive than other technologies (amine scrubbing). For oxy-coal combustion to be considered as an original equipment manufacture (OEM) technology option for new supercritical boilers (SC), it has to be competitive with integrated gasification combined cycle (IGCC), amine scrubbing, and other alternative combustion systems such as circulating fluidized bed (CFB).

AL, B&W, and WorleyParsons, under sponsorship of the U.S. DOE, performed the following economic study.(14) Air Separation Unit (ASU) design, boiler design and its modifications, and CO2 compression and purification train design were carried out with fine details along with the cost estimations. Analyses were done looking at cost of electricity (COE), net plant efficiency, and avoided cost of carbon dioxide.

Approach and assumptions

The gross power was adjusted to generate 550 MWe net power output for all studied cases. The design and cost estimation of the oxy-coal and PC boilers was conducted by B&W in conjunction with AL, who provided the ASU and CO2 compression system designs and WorleyParsons who performed overall balance of plant design and cost estimates. Major economic and financial assumptions are presented in Table 1.

The environmental approach for the study was to evaluate each case on the same regulatory design basis, considering differences in technology. Based on the EPA (Environmental Protection Agency) Green Book Non-attainment Area Map (http://www.epa.gov/oar/oaqps/greenbk/mapnpoll.html), relatively few areas in the Midwestern U.S. are classified as "non-attainment". Thus, for the design scenarios considered in this study, environmental control equipment is defined to meet presumptive BACT (Best Available Control Technology) emission rates shown in Table 2.

Steam conditions for the Rankine cycle cases were selected based on the NETL Advanced Materials for Supercritical Boilers program. The goals of the program dictated the steam conditions selected for the study:

• For supercritical (SC) cycle cases - 3500psig/1110F/1150F (242 bar abs/599C/621C)

• For ultra-supercritical (USC) cases - 4000psig/1350F/1400F (277 bar abs/732C/760C)

CASES STUDIED

A summary of the different plant configurations considered in this study is presented in Table 3.

CO2 Specification A - Flue gas composition exiting system with 95 mol% O2 oxidant after drying to specified moisture content (Moisture<30 lb/106 cf CO2). These oxy base cases provided good cost/benefit ratio.

CO2 Specification B - Flue gas composition exiting system with 99 mol% O2 oxidant after drying to specified moisture content (Moisture<30 lb/106 cf CO2).

CO2 Specification C – Flue gas purified to meet EOR spec: CO2≥95%; N2 + O2 < 5%; (Moisture<30 lb/106 cf CO2).

The results of the air-fired SC and USC boilers compared with amine scrubbing and SC and USC oxy-coal combustion cases are presented here (Figure 2). Impact on efficiency shows 11% and 12% (absolute) efficiency decrease for SC and USC cases, respectively.

When comparing COE increase and CO2 avoided cost for amine scrubbing and SC and USC oxy-coal combustion cases, oxy-coal combustion seems to be the lowest cost CO2 capture technology (Figure 3).

The cost reduction potential for CO2 capture oxy-coal combustion technology was evaluated. If the FGD is eliminated (for coals with <1% of sulfur), the COE increase can be reduced for the USC case from 44% to 36% which represents a CO2 avoided cost reduction from $30 to $24 per metric ton.

The technical results are as follows:

• Conversion of air blown supercritical and ultra-supercritical designs to oxy-coal combustion to facilitate carbon dioxide capture and storage resulted in net plant efficiency (HHV) penalty of 11 and 12 percentage points, respectively.

• Presumptive BACT NOx emission rates were met in all oxy-coal design cases without a post combustion NOx control system (SCR).

• No air emissions were released in design cases modeled to meet CO2 specification A (no specific CO2 purity targeted), i.e. NOx, SOx and PM were removed in bulk with the CO2.

• It was concluded that the utilization of 95% mole oxygen with compression and purification treatment is most economical as compared to 99% mole oxygen, for the same CO2 specification (EOR).

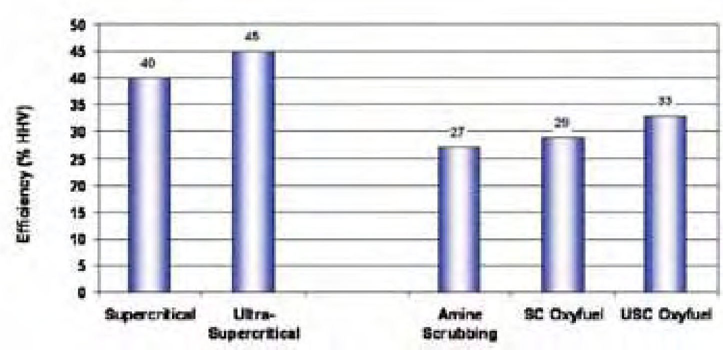

Fig. 2 Efficiency impact for different scenarios.(14)

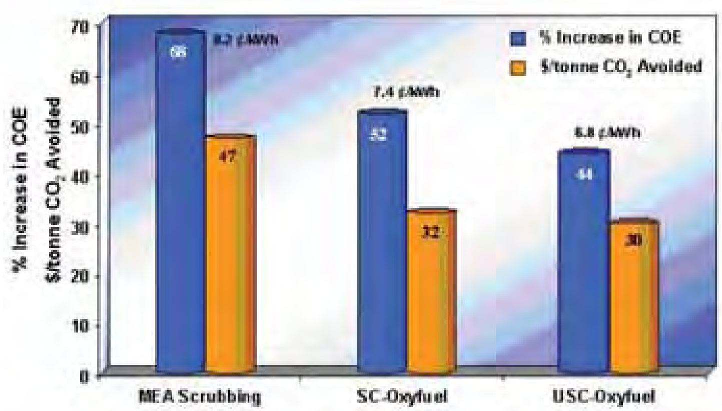

Fig. 3 COE and CO2 avoided for amine scrubbing and oxy-coal combustion. (14)

Look in the November/December issue for the conclusion of this article

ELECTRICITY - ITALIAN STYLE

By Lauchlin Murray

Italy's urban areas pose difficulties when seeking right-of way access due to inadequate planning and public opinion.

Italy's geography, history, and politics make its electricity market different from America's. Consumers pay much more than any other European state. Consumption per capita is about a quarter of North America's, true. Yet, that is misleading given its size and the quantities of dollars involved.

Italy depends on outside sources for 10 to 15 per cent of its electricity. They are unable to effectively harness resources for hydroelectricity. Compared to Canada, Italy has an inverse relationship with fossil fuel and hydroelectricity. While many Canadians heat electrically, almost all Italians heat by gas, wood stoves, and fossil fuels. Italians are conservative with lighting and use less than Americans in public places and along highways. Another reason Italy avoids hydro is attributed to two dam bursts. One in 1963, killing 1,800 and another in 1985 killing 80 people.

Since 1987, Italy has had no in-country nuclear power production. A 1986 referendum soon after Chernobyl made Italy nuclear-free forever. Four nuclear plants have been under curiously slow dismantling. In 2005, Italy's largest utility group ENEL decided to get around this by entering reactor construction projects with Electricité de France, EDF. Semi-privatized ENEL signed a memorandum of understanding assuring EDF they would take about an eighth of output from up to seven reactors being built on French soil. Last February, Italy left it's French counterparts behind, to finance and manage projects in Russia and Eastern Europe, and strengthened their Spanish and Dutch interests. France scrambled for new buyers.

Relatively few or modest security measures have been taken to protect Italy's distribution facilities from trespassers.

This development is difficult to evaluate. It is possibly a result of long negotiations between Russia and Italy on many energy related subjects. Maybe it is part of Italy's leftist government led by Romano Prodi, which took power from Silvio Berlusconi's right leaning government between the signing of that memorandum and ENEL's change of plans. Much of Italy's anti-nuclear movement is attributed to socialists and leftists. Whichever the causes, and despite an obvious desire for unification of services — utilities, military, transportation communication — by the European Union, Italy wants things their way. Rome, Italy is hosting the 20th World Energy Congress in November. It is no coincidence that attendees will be a mix of financial institutions and energy suppliers.

Italians want it their way more than a civically minded North American market. They want better and cheaper electricity, but suffer from a severe NIMBY 'not in my backyard' complex.

Perceptions of health hazards from electricity towers cause citizens to turn out in droves to protest new installations near residential areas. Italy's concentration of populace and cramped territory demand projects be close to homes – there's no other way. Utilities, therefore, construct without public support.

In September 2003, an 18 hour blackout struck most of Italy. Supply from France was stopped by trees across lines in Switzerland. A report by five

Continued on Page 28

Italian Style

Continued on Page 26

European countries left Switzerland and Italy pointing fingers. Italy appealed to the European Union in Brussels for help. This influenced EU regulations requiring better security of transmission lines; but in fact, little has changed. New substations were built along Italy's northern borders; but implementation of laws are handicapped by 'notwithstanding clauses' and delayed implementation dates. Different from North American markets, Italians must cope with a larger variety of governments, organizations, laws and standards.

There are pros and cons of Italy's entry into the EU. Massimo Motti, 38, is a partner in an electrical contracting firm in Northern Italy. Europe's conversion to a common currency came with a rapid rise in material prices he says. Another

Italy's primary electrical utility provider ENEL is converting traditional residential analog meters to digital ones.

difficulty is Europe's attempt to unify standards. Motti is happy labour prices have gone down with the EU allowing workers to move cross-border more easily. He finds foreign trades provide the same quality as Italians at lower costs.

In Motti's home, which he is building, he considered alternative energy sources, such as Solar PV panels. He found it difficult that ENEL wanted him to turn over all he produced and buy it back. He thinks Italian energy suppliers have a mentality unsuited for implementing alternative energy programs. He wants Italy to reverse its commitment to stay nuclear free. He feels dangers have been exaggerated, and energy price increases will soon force Italians to reconsider anyhow.

Massimo Giacon, 36, an electronics engineer finds it odd that nuclear plants exist in other European states, but not in Italy. Giacon understands that a major part of ENEL's energy is bought from outside of Italy and he wants this to change because it is bad for Italy's economy. He thinks Italians will wait until the last minute when they have exhausted other sources of energy to switch over. He repeats that Italy has no clear plans for its energy future. He believes Italians will shy away from residential solar-power due to high costs of installation and maintenance, and that Italians will look to the United States for alternatives when a crisis has arrived.

Both Massimos noted electricity use is higher in their more industrialized north. Italian industry is moving to countries offering cheaper costs, like China and former Soviet bloc regions; yet, Italy's annual consumption is creeping toward 300 terawatts.

From a less global perspective, in Italy, using electricity in one's home is less straightforward than in North America. Outlets provide 220 to 230 Volts. In many homes you find shoe-boxes of adaptors for plugs. There are too many standards organizations setup to protect Italian producers. Wiring often pre-dates the First World War, is sloppy, has cut-corner installation, and is sometimes under-the-table work performed without proper inspection. Wiring is installed in solid concrete walls that require days or weeks of jack-hammering on typical residential projects. It is much slower than the hollow-wall construction in North America. There are similarities of course, but one has to pause.

In a macro or micro sense, Italy's electrical market is closed, with Italy selling management methods abroad. Unable to generate new energy markets internally – they make-up by telling others 'how to'. It leaves one wondering what exactly it is they are selling outside of their borders, when they are operating with deficits.


No Italian home is complete without a myriad of adapters to match various post-war products and installations.

Lauchlin Murray has had over 25 years of experience in construction engineering and management in North America and on several international projects. He has had almost 10 years of experience observing Italy's construction and marketplace first-hand.

AECL LOOKS TO THE FUTURE WITH THE ACR-1000

By Dr. David Torgerson, Chief Technology Officer, Atomic Energy of Canada Limited

In North America and around the world, the demand for clean, safe and reliable baseload electricity will grow dramatically over the next decades and nuclear power technology — with newer, safer, more economically competitive designs — is poised to play a major role.

Atomic Energy of Canada Limited (AECL) is the designer/developer of the CANDU nuclear reactor and has been building nuclear plants for more than 40 years. CANDU units are operating successfully in Canada (Ontario, Québec and New Brunswick), South America, Asia and Europe. AECL's recent plant construction has been focused on its 700-MWe-class CANDU 6 plant — with projects ongoing from the late 1970s to now.

To meet upcoming needs, AECL has now designed a Generation III+ plant — the Advanced CANDU Reactor, ACR-1000 — adapting the successful features of the CANDU reactor and incorporating innovations. The basic design is complete and the ACR-1000 is already in full project mode.

The ACR-1000 was chosen this year for generic design assessment in the United Kingdom. Additionally, there are active ACR-1000 new-build initiatives in Canada — in Ontario, Alberta and New Brunswick. Energy Alberta Corporation has recently applied to Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC), for a site licence for up to two ACR-1000 units.

CANDU technology is inherently amenable to localization because the key components of the CANDU reactor core comprise a large number of small, identical fuel channel components. For Canadian ACR-1000 projects, for example, 90% of equipment, supplies and services can be sourced domestically.

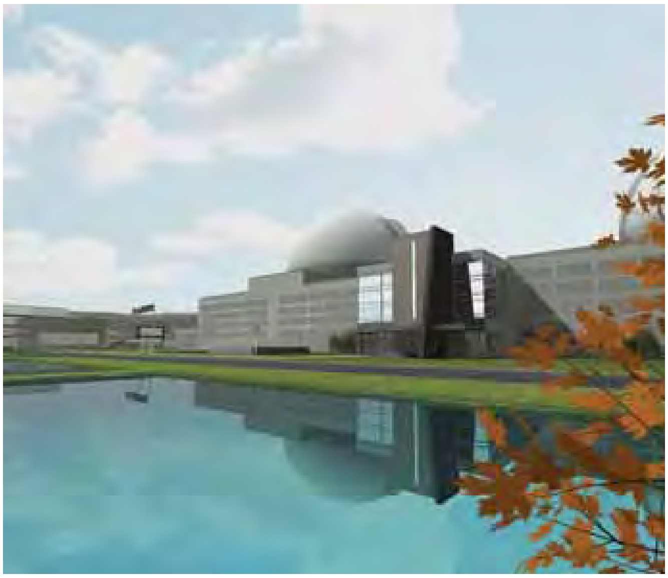

Figure 1: ACR-1000 twin-unit plant

EVOLUTIONARY PRODUCT

The ACR-1000 is a 1200-MWe-class nuclear power plant with a 60-year design life. It is a light-water-cooled, heavy-water moderated pressure-tube reactor which has evolved from the well-established CANDU line. It retains basic, proven CANDU design features while incorporating innovations and state-of-the-art technologies to further enhance safety, operation, performance and economics. Many of the innovations were developed using experience and feedback gained in the design, construction and operation of top-performing CANDU 6 reactors operated by utilities around the world.

Key CANDU strengths retained:

- modular, horizontal fuel channel core;
- simple fuel bundle design;
- separate low-temperature and pressure heavy water moderator;
- passive safety features including reactor vault filled with light water surrounding the core and two independent, passively driven, safety shutdown systems;
- on-power refueling;
- reactor building access for on-power maintenance.

ACR-1000 innovations:

- more compact core design;
- steel-lined, 1.8-metre-thick containment building, to withstand aircraft strike;
- light water reactor coolant, reducing heavy water inventory and resulting in lower costs and reduced emissions;
- thicker pressure tubes and thicker and larger calandria tubes;
- stainless steel feeders and headers;
- mechanical zone control rods, solid-rod guaranteed shutdown state, no adjusters;
- use of low-enriched uranium (LEU) fuel, in advanced CANFLEX-ACR fuel bundles, to help achieve negative void reactivity;
- option to efficiently burn other fuel types such as mixed oxides (MOX), thorium and actinides;
- improved plant thermal efficiency through use of higher pressures and temperatures in the coolant and steam supply systems;
- enhanced accident resistance and core damage prevention features;
- further enhanced passive safety;
- customer-driven improvements in operability and maintainability, with designed-in maintenance features;
- distributed control system/plant display system; modern control centre incorporating human factors;
- improved plant performance through SMART CANDU advanced on-line diagnostic systems;
- four-quadrant design: essential operating and safety systems separated

into four divisions; permits online maintenance, flexibility during outages.

These technical improvements, along with system simplifications and advancements in project engineering, manufacturing, and construction, result in a reduced capital cost and construction schedule, while enhancing the inherent safety and operating performance of the ACR-1000 design.

All innovative features of the ACR-1000 have been or will be fully tested and proven before the first project. Because of this — and because 80% of plant features, equipment and specifications, are based on the successful CANDU 6 reference plant — the initial ACR-1000 build project will be executed with a high degree of confidence.

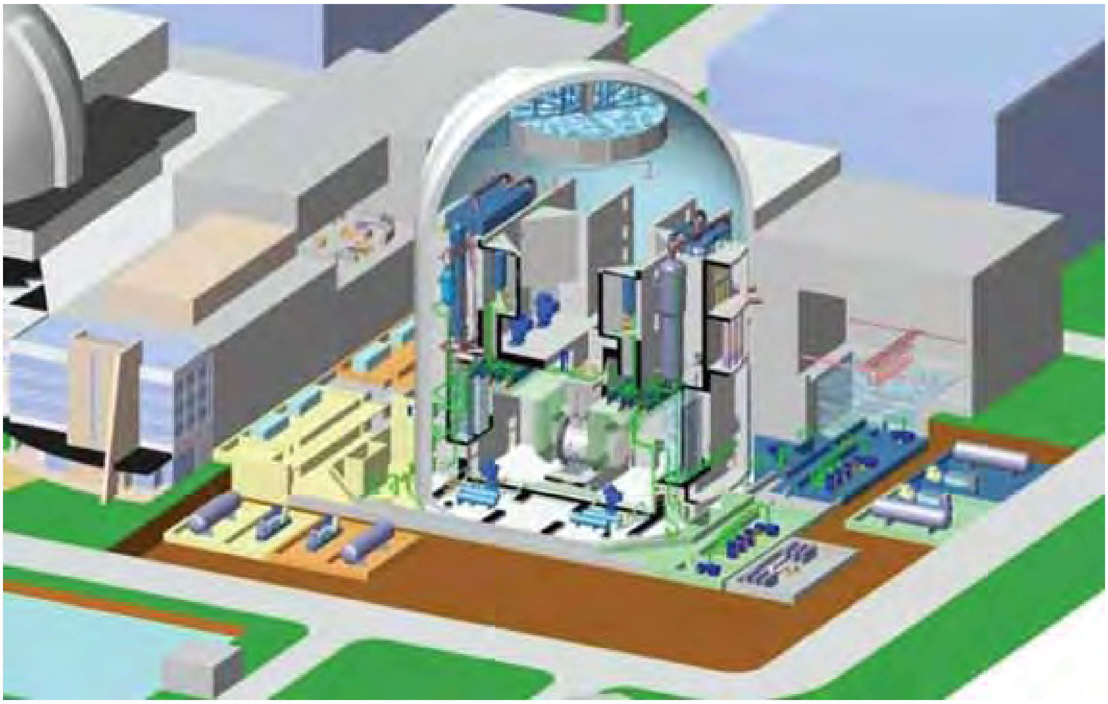

Figure 2: Cutaway of ACR-1000 showing four-quadrant design

ENHANCED SAFETY AND SECURITY

The ACR-1000 is laid out to provide separation by distance, elevations and the use of barriers for safety-related

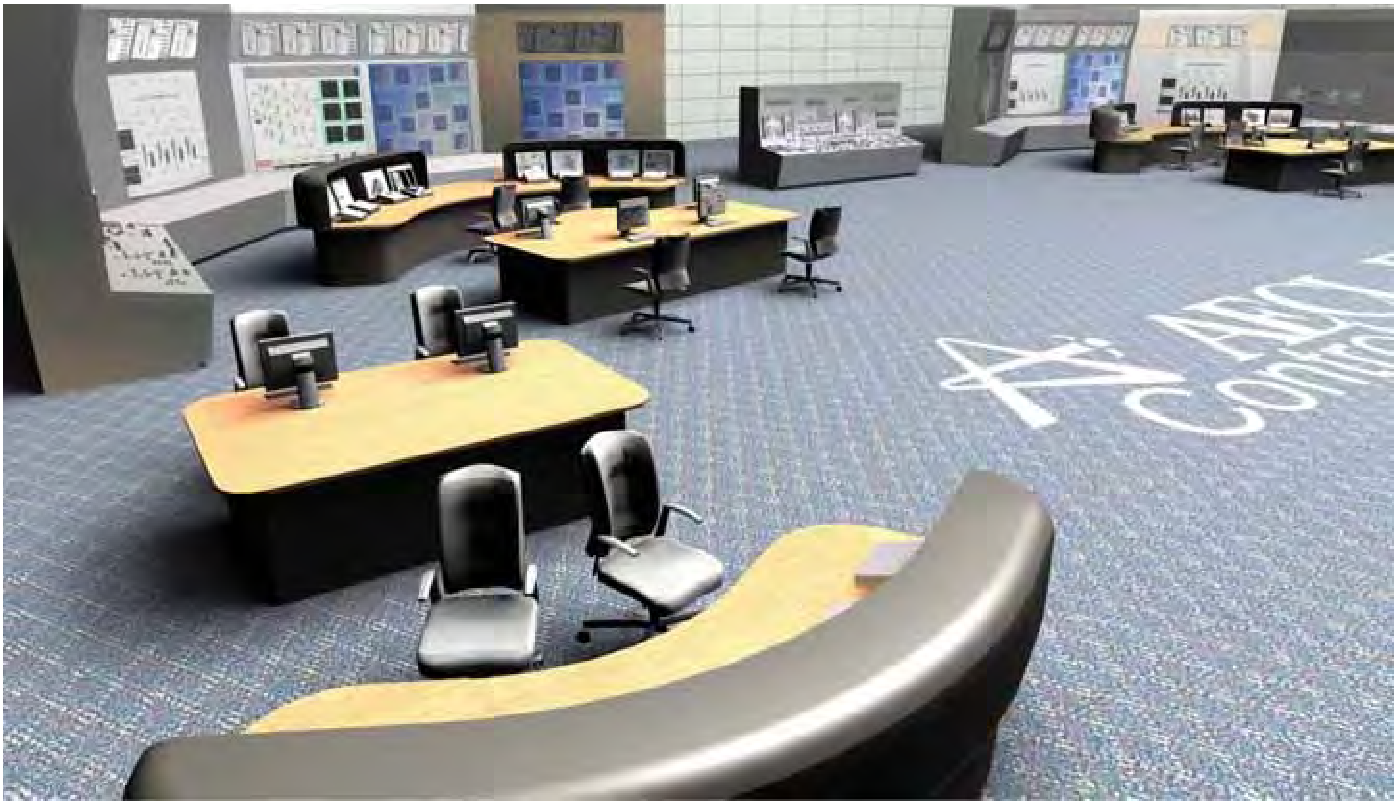

Figure 3: ACR-1000 advanced control room

structures, systems and components. Each corner of the reactor auxiliary building houses redundant safety equipment in a four-quadrant design, with quadrants separated by three-hour fire barriers.

The ACR-1000 design takes advantage of both passive and engineered safety characteristics, including distinctive features that arise from CANDU design principles. The core is designed for a small negative reactivity coefficient. This feature provides inherent protection against transients with any inadvertent increase of reactor power, while limiting complexity in engineered systems and operating procedures that deal with large reactivity swings.

Central to ACR-1000 safety are two fast-acting, fully capable, diverse and separate shutdown systems, physically and functionally independent of each other and also from the reactor regulating system. Based on proven CANDU technology, each shutdown system is designed to cover the whole spectrum of design-basis events and to perform its safety functions with a high degree of reliability. Additional defence-in-depth is derived from the inherent passive-safety features of the CANDU fuel channel core, including extra heat sink redundancy for potential accident conditions.

Security and physical protection have been addressed to ensure that the response to potential common and abnormal events meets latest criteria. The ACR-1000 containment is designed to withstand external events such as earthquakes, tornadoes, floods, aircraft crashes and malevolent acts. The plant is designed for an exclusion zone of 500 metres.

IMPROVED OPERABILITY AND MAINTAINABILITY

The design-basis lifetime capacity factor for the ACR-1000, over the operating life of 60 years, is greater than 90%, and the design-basis year-to-year capacity factor is greater than 95%. The high average annual output is achieved by a low forced loss rate of less than 1.5%.

AECL-designed and -built CANDU 6 units are already achieving a lifetime capacity factor of 88.1%, and the combined average for 2006 was 92.4%. Also, the newer Ontario Power Generation and Bruce Power multi-unit CANDU stations are operating well, with annual capacity factors well in excess of 90%.

AECL-designed and -built CANDU 6 units are already achieving a lifetime capacity factor of 88.1%, and the combined average for 2006 was 92.4%. Also, the newer Ontario Power Generation and Bruce Power multi-unit CANDU stations are operating well, with annual capacity factors well in excess of 90%.

Key to meeting or exceeding performance targets has been direct feedback provided by CANDU plant operators on how to enhance operability and facilitate maintenance. This has allowed new features to be designed into the plant to reduce operating risk. Use of data on CANDU operating experience provided by the CANDU Owners' Group network (COG) has also been applied.

Designed-in, on-line inspection and maintenance has revolutionized the ACR-1000 outage strategy. The traditional outage of up to one month has been improved for the ACR-1000 to one planned outage every three years, with a standard duration of 21 days. For Plant Life Management (PliM) purposes, the reactor design supports a planned, mid-life, extended outage for replacing the pressure tubes.

The ACR-1000's outage philosophy is based on replacement and not repair, with the requirement for a significant inventory of spare parts. Removed parts will be repaired after the outage in preparation for the next outage. The use of a solid rod Guaranteed Shutdown State (GSS) enables rapid entry into outage work conditions and provides faster return to power following the outage.

The ACR-1000 features enhanced power manoeuvering capability to simplify reactor operation and make the reactor inherently more responsive. This is possible because the use of LEU fuel and light water coolant results in a lower xenon load, following reactor power reduction. Enhanced power manoeuvering ability includes load following and daily load cycling capability, which are facilitated by CANDU's inherent ability to refuel on power.

The ACR-1000 also has station blackout capability, ensuring a rapid return to full power on restoration of electrical grid. It can supply the unit's services from the grid or the turbine generator and also has two independent, on-site standby power generation facilities.

Other important aspects of the ACR-1000 that enhance operation and facilitate or minimize maintenance include:

- improved, long-life materials and experience-based plant chemistry specifications;
- advanced control room based on human factors engineering allowing "control from the console", with restricted traffic flow and clear sight-lines to Large Screen Displays;
- computerized testing of major safety systems and automatic calibration of in-core detector control systems;
- improved plant performance through integrated SMART CANDU modules, which provide on-line health monitoring and diagnostics for plant chemistry, predict future performance of components, determine maintenance requirements and optimal operating conditions and ensure maximum power output;
- on-power maintenance strategy, maximizing component life and minimizing component replacement time, thus reducing radiation exposure, maintenance costs and staff requirements;
- improved plant layout, with a permanent elevator, walkways and platforms and provision for electrical, water and air supplies built in for on-power and normal shutdown maintenance;
- increased shielding in radiologically controlled areas, reducing worker exposure and occupational dose.

ACR-1000 DESIGN STATUS

The successful CANDU 6 fleet is the foundation for the ACR-1000 design. The ACR-1000 program focus is to plan and execute work based on risk analysis, assessment and mitigation, ensuring licensability and addressing customer input,

to achieve an in-service date of 2016. The program plan is project-based and will ensure that all required documentation is available to support the Environmental Assessment and Site Preparation and Construction Licence applications. All design documentation will be completed prior to construction.

The ACR-1000 program is being managed as a full-scale project, under AECL's Commercial Operations group. New technology input has been confirmed and the licensing basis has been established. All elements of the detailed engineering program are in progress and project risk management processes and procedures are in place. The Preliminary Safety Case Package (PSCP) will be submitted in 2008 and the Preliminary Safety Analysis Report (PSAR) for a site construction licence is scheduled for 2010.

The Level 3 production schedule — covering the detailed engineering program together with completion of the remaining R&D work and licensing activities, and comprising more than 10,000 activities — has been issued and is being carefully tracked.

Figure 4: Very-heavy-lift crane and open-top, modular construction at Qinshan Phase III, China

LICENSING BASIS

The design of the ACR-1000 systems, structures and components is based on the CANDU 6 and Darlington nuclear steam plants (NSPs). Minimal manufacturing and supply changes are anticipated due to the similarities of major NSP equipment and components for the ACR-1000 and CANDU 6. Major equipment and components have been proven through many years of continuous operation of 10 CANDU 6 plants. A proven licensing and safety basis builds on 40 years of CANDU licensing experience in Canada and around the world. The Balance of Plant (BOP), comprising 40% of total plant equipment, is a scale-up of the proven CANDU 6 BOP.

The ACR-1000 is designed to meet regulatory requirements in Canada and other countries. Its design:

- is developed to meet the Canadian Nuclear Safety Commission's new requirements for new reactors;
- fully complies with the IAEA's NS-R-1, which is the International Atomic Energy Agency's (IAEA) Safety Standard for the Design of Nuclear Power Plants;
- meets Canadian and international requirements for international nuclear plant siting;
- incorporates international codes and standards, as they apply;
- has benefited from pre-licensing review

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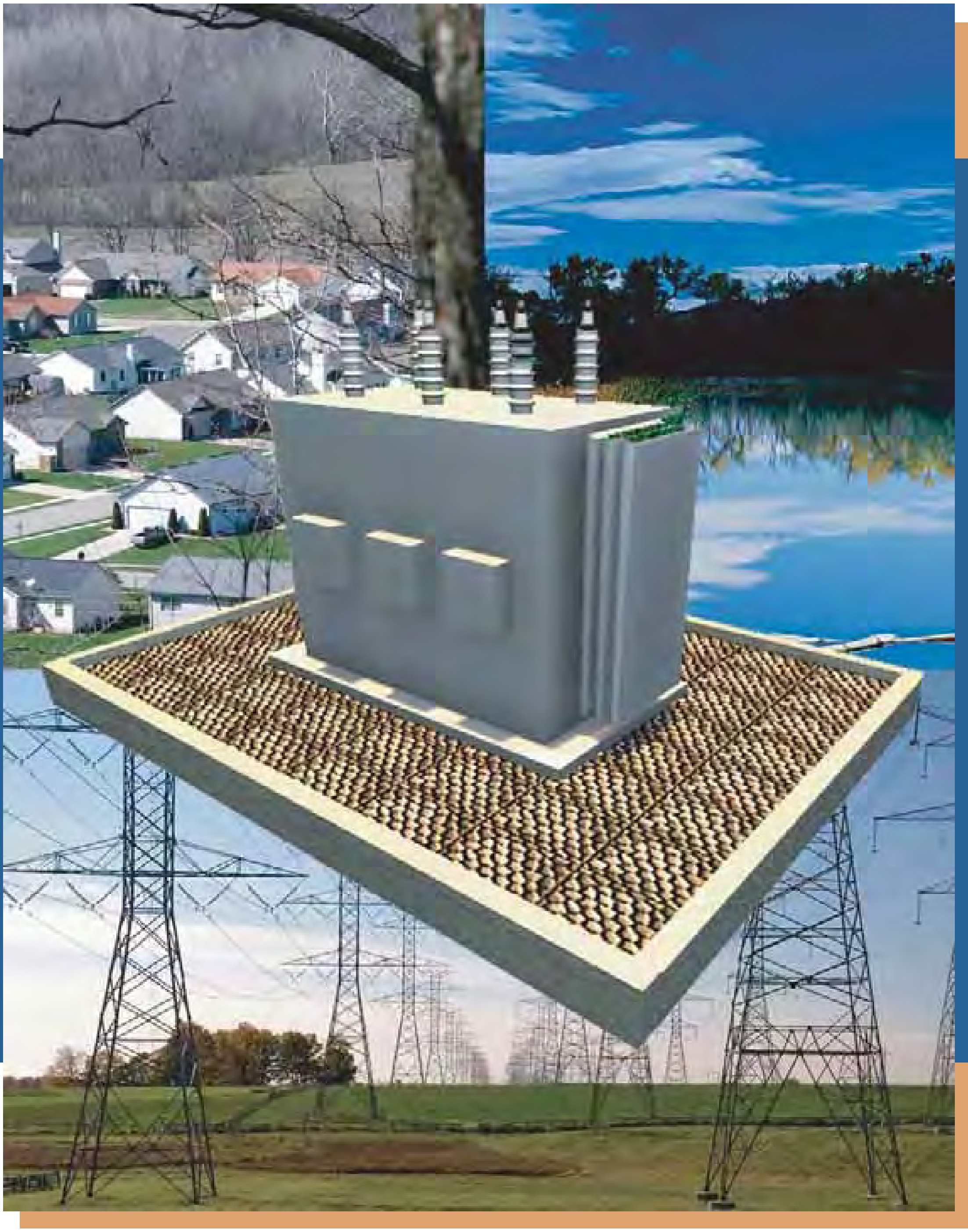
The SorbWeb™ Plus Solution



- Proven system that effectively contains oil spills from equipment and transformers
- No pumps, no oil water/separator, no maintenance
- Engineered and designed around site requirements
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AECL and CANDU
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by the US Nuclear Regulatory Commission.

ONGOING TECHNOLOGY AND PLANT SUPPORT

The ACR-1000 is an evolutionary design and enhancements have resulted from extensive AECL efforts in code validation and R&D on reactor and fuel design and materials properties, as well as operations and maintenance input provided through COG. Comprehensive R&D facilities at AECL's Chalk River Laboratories in Ontario remain instrumental to the success of the new Generation III+ ACR-1000 and continue to assure ongoing support to operating CANDU reactors worldwide.

CONSTRUCTABILITY AND PROJECT IMPLEMENTATION

Maximum use of modularization and "open-top", parallel, construction — which have already been demonstrated at the Qinshan Phase III units in China, both delivered under budget and ahead of schedule — are key to AECL's ACR-1000 project model.

The plant layout is also designed to achieve the shortest practical construction schedule while facilitating maintenance. Buildings are arranged to minimize interferences during construction, with allowance for on-site fabrication of module assemblies. The footprint of the two-unit plant is minimized with the adoption of common areas for the main control room and service and maintenance buildings.

Advanced integrated project management tools have also contributed significantly to AECL's successful project performance. These include:

- Intergraph 3-D plant modeling and design;
- TRAK electronic document management systems;
- CANDU Materials Management System (CMMS) supply chain management system;
- IntEC wiring design and management system.

AECL has assessed and qualified internationally renowned manufacturers and suppliers of nuclear and conventional equipment and materials. These form the foundation of the supply base for new-build projects, enabling AECL to obtain highly competitive pricing and delivery terms from a variety of sources.

SUMMARY

AECL's CANDU reactor has evolved to the next generation. The new ACR-1000 design retains basic, proven, CANDU features while incorporating key innovations and state-of-the-art technologies. Safety has been further enhanced and AECL has placed a major focus on constructability, operability and maintainability, to ensure that the plant's performance and economics are optimized.

With the basic design complete, first site construction licence scheduled for 2010, a target in-service date of 2016 and real interest from customers in Canada and abroad, the ACR-1000 gives AECL a challenging and exciting future.

» SOLUTIONS FOR EVERY INDUSTRY

LEADERSHIP. INNOVATION. COMMITMENT.

STUDY AND DESIGN OF POWER PLANT TRANSFORMER EXPLOSION AND FIRE PREVENTION - PART I

By David Scheurer, Research Department Engineer; Alexis Nesa, Research Department Engineer; Sylvain Prigent, Research Department Engineer; Philippe Magnier, C.E.O, SERGI; Moumèn Darcherif, Research Manager, EPMI

1 INTRODUCTION

The study of the "Power Plants Transformer Explosion and Fire Prevention" started on request of a large western U.S. utility which had experienced a severe hydro power plant transformer explosion. This incident occurred underground, destroying one transformer and damaging another nearby. This now common event lead to a four-month total power plant shutdown and 10 months unit unavailability.

Several on-line monitoring systems were installed on the transformers to try and anticipate another failure. The major concern was that this monitoring might not prevent an explosion, so SERGI was contacted to avoid a second catastrophic incident, should another transformer fail.

SERGI specializes in transformer vessel explosion and fire prevention. The Design Department has conducted research since 1995 to understand and quantify the energetic transfer phenomenon that takes place within a vessel during a short circuit, which has led to the Magneto-Thermo-Hydrodynamic model (MTH) development.

SERGI decided to study the prevention of power plant transformer explosions, because of the harsh arcing that can occur. During short-circuit, transformer faults are fed for seconds due to the generator inertia. Therefore, designing a system able to prevent a power plant transformer explosion fully satisfies the explosion prevention of any other kind of incident for transmission or distribution transformers.

The purpose of these studies was to determine an efficient way to depressurize the transformer vessel during and after these short-circuit conditions in order to avoid explosion and the resulting oil fire. SERGI extensively investigated

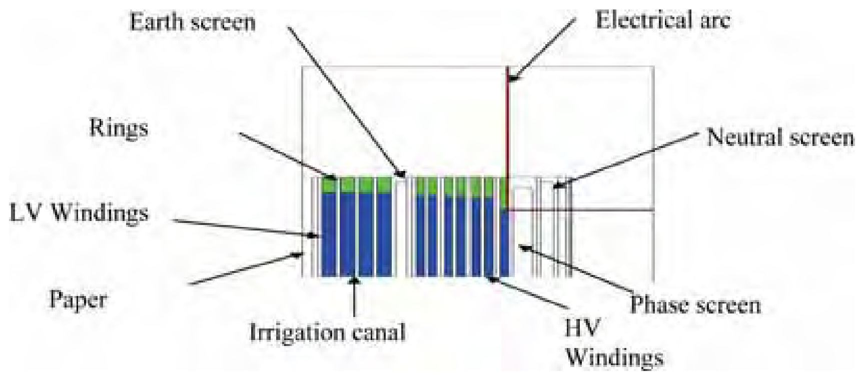

Figure 1: Transformer winding geometry

the event, simulating causes, calculating the transformer vessel pressure rise, and proposed a suitable solution. The aim was therefore to design a system capable of preventing the worst-case scenario in order to satisfy the prevention of any other kind of incident.

As in every case already studied by SERGI, the results brought to pressure rise with slopes from 60 to 900 bars per second.

The fault was fed both by the generator and the network. As a consequence of the ongoing exponential gas production due to the continuous transformer energization from the generator side, calculations have shown an oil plug phenomenon which appeared in the Depressurization Chamber after system operation, leading to another pressure rise. Therefore, more calculations were conducted in order to size and shape a Depressurization Chamber that would eliminate this occurrence. The pressure inside the transformer will, therefore, be kept below the vessel maximum tolerated pressure during transformer short-circuit.

Other aspects were also examined, such as the oil-gas mix exhaust speed and flow through the Depressurization Chamber, as well as the volume of explosive gas produced and the volume of oil to expel, in order to safely depressurize the transformer.

The resulting Depressurization Chamber diameter required to avoid vessel explosion was determined to be 12 inches. It was calculated that the SERGI Transformer Protector Rupture Disk used for depressurization fully opened in 0.6 millisecond for a 236 kA short-circuit.

With other researches already published by SERGI, along with the company experience in Transformer Explosion and Fire Prevention, the best-adapted solution has been designed for power plants. In addition to the vessel, the Transformer Protector is also conceived to avoid explosion and fire of all transformer oil capacities such as Bushing, Oil Bushing Cables Boxes and On Load Tap Changers.

The study presented here, which is the result of twenty-five months of

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research, includes the fault calculation, energetic transfer in the oil, the vessel pressure increase, the amount of gas produced, the fluids evacuation and the associated SERGI Transformer Protector design.

2 SINGLE-PHASE TRANSFORMER CHARACTERISTICS AND SIMPLIFIED GEOMETRY DESCRIPTION

The studied transformer is single-phase, step up, located downstream of a 450 MVA generator.

- Nominal Power: 150 MVA
- Primary voltage: 18 kV delta
- Secondary voltage: 133 kV L-N
- Impedance: 15.5 %
- Cooling: Forced Oil, Water cooled
- Dimension: 121” diameter, 156” high

The physical and electromagnetic material parameters, HV and LV windings were taken into account as well as the influence of paper, paperboard insulation, thermal and hydraulic concerns. The heat transfer between the transformer and the outside or the magnetic circuit was imposed, as conditions to the limit.

Oil is injected at the vessel bottom at 20° Celsius, 68° Fahrenheit and extracted at the top.

3 FAULT SCHEME AND CALCULATION

3.1 Calculation

The method used to calculate the fault current is the Symmetrical Component Method, based on the fragmentation of the problem in two major parts, each subdivided as follows:

1. Direct system study
   - Thevenin for the direct fault calculation;
   - Reverse scheme;
   - Homopolar impedance calculation.
2. Fault equation settling and resolution

3.2 Fault Scheme

The problem resolution is detailed in reference. The fault current was calculated with the symmetrical component method and gave the value of 11.8kA during the incident. However, the utility has required SERGI to simulate the case with 34.5kA, 118kA and 236kA faults in order to oversize the resulting transformer protection.

4 SIMULATION

4.1 Method

The simulation purpose is to formulate a coupling of electromagnetic, thermal and hydrodynamic phenomena. It was therefore necessary to:

- Determine the magnetic field created by the inductance and/or arc in the surrounding field versus the injected current per phase;
- Calculate the induced currents and the Joule and Eddy current local dissipated power;
- Calculate the temperature by using the resulting above values as heat sources.

The calculation is done through four sub models. The first equation to solve is magneto-dynamic:

$$r\vec{o}t(v_r \, r\vec{o}t\vec{A}) = \mu_0 \vec{J}_{source}$$

It derives from the Maxwell equations, which rule the overall electromagnetic phenomena.

The magnetic field is expressed through the potential vector:

$$\vec{B} = r\vec{o}t\vec{A}$$

The thermal sub model resolves the partial derivative equations in a Cartesian geometry and is the following:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p V grad T + div(-K grad T) = Qth = I^2$$

Diffusion term (Transient) Convection term Conduction term (steady)

Where:

ρ	: Volume mass
Cp	: Heat capacity
V	: Speed vector
K	: Heat conductivity
Qth	: Heat sources density

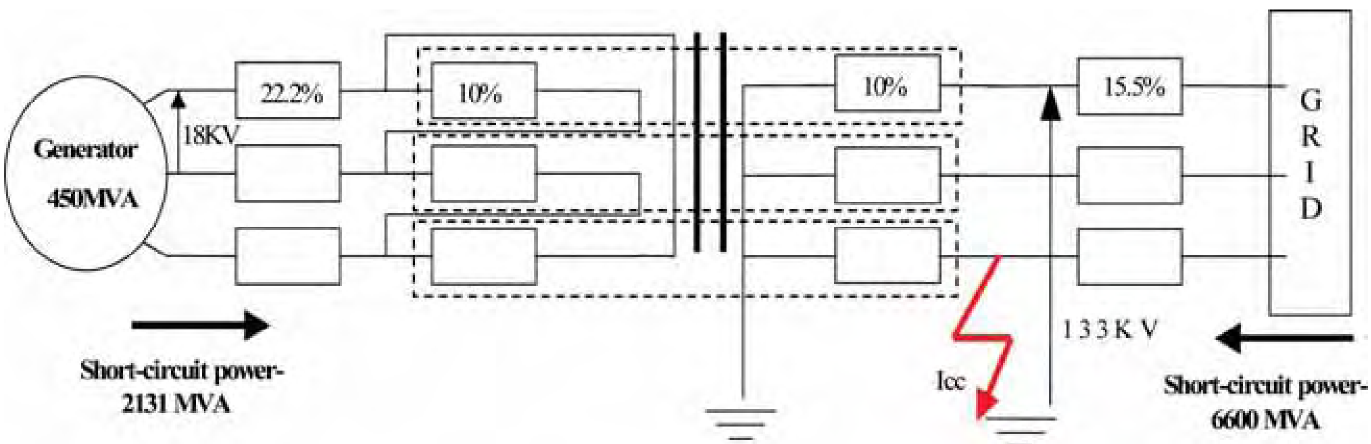

Figure 2: Short circuit scheme

The hydrodynamic sub model resolves Navier-Stokes equations and mass conservation equations as:

$$\rho\frac{\partial\vec{v}}{\partial t}+\rho\left(\vec{v}\cdot\vec{\nabla}\right)\vec{v}-\vec{\nabla}\cdot\overline{\overline{\sigma}}=\rho\vec{g}$$

$$\frac{\partial\rho}{\partial t}+\vec{\nabla}\cdot\rho\vec{v}=0$$

The kinetic submodel is ruled by the Arrhenius Law:

$$k = A.e^{-\frac{E_a}{R.T}}$$

Where:
- A : Pre-exponential factor
- Ea : Activation energy
- R : Perfect gas constant
- T : Temperature
- k : Constant expressing the quickness of the reaction

The pre-exponential factor of the expressed Arrhenius Law is determined experimentally. The data are gathered according to each type of gas and associated activation energy:

• The oil-gas composition is identified for every temperature;

• The different element concentration versus time and temperature in mineral oil environment is known; this factor is part of the software coded by SERGI.

4.2 Transformer cooling

Calculations were conducted with the hypothesis of forced and directed oil circulation. The magnetic core was made free in temperature.

4.3 Steady state

Before simulating the disruptive failure in the transformer, the steady state was simulated in order to obtain a basis for the rest of the calculation.

Steady state calculation enables to observe the transformer behaviour under nominal electrical load. It corresponds to the normal transformer operation at normal temperature and pressure levels. Figure 3 shows the heat dissipation in the right side of the transformer winding.

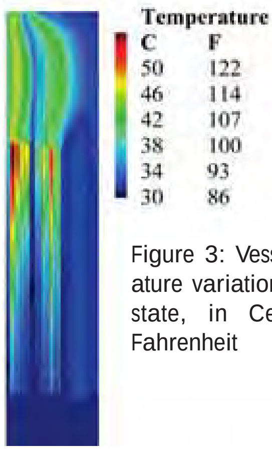

Figure 3: Vessel temperature variation in steady state, in Celsius and Fahrenheit

4.4 Transient state

The calculated conditions can be worsened in the case of maneuver shocks, power surges, etc. In this case, the transient state simulations were conducted under three different faults:

• Maneuver shock at 35.4kA

• Lightning surge at 118kA

• Lightning shock at 236kA

We made the hypothesis that no generator circuit breaker would operate during the fault. The fault is therefore simulated all through the depressurization process.

The electrical arc is simulated in the transient state by inserting a copper wire fed by the above given currents. Once the wire reaches the temperature of electrical arcing, oil cracking process, gas production and pressure rise increase severely.

5 VESSEL PRESSURE RISE DURING SHORT-CIRCUITS

5.1 Results

Along with the calculation of the evolution of temperature, an associated pressure is calculated for each type of fault. Figures 4 to Figure 6 below show the calculated pressure rise curves versus time. Yellow circles on the figures indicate arc ignition. Red lines represent the vessel tolerance to pressure. The lap time before arcing is due to the copper wire heating, creating the favourable arc plasma.

Look in the November/December issue of Electricity Today for the conclusion of this article.

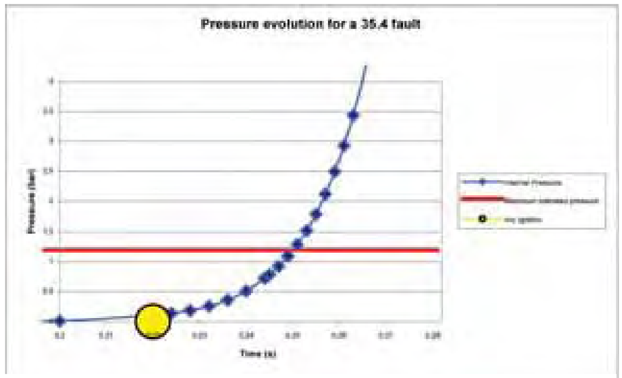

Figure 4: Transformer vessel pressure evolution after a 35.4 kA short-circuit

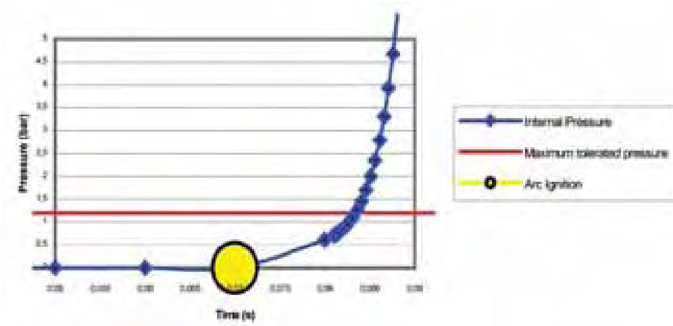

Figure 5: Transformer vessel pressure evolution after a 118 kA short-circuit

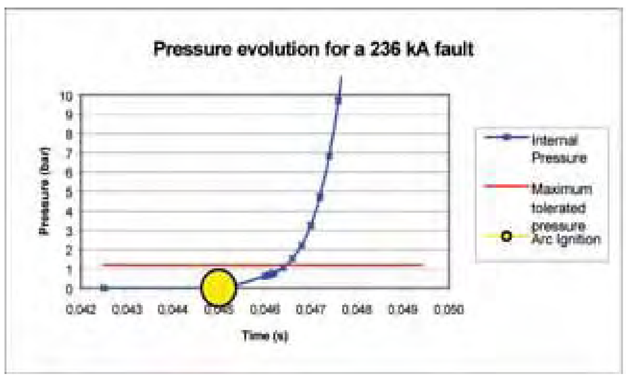

Figure 6: Transformer vessel pressure evolution after a 236 kA short-circuit

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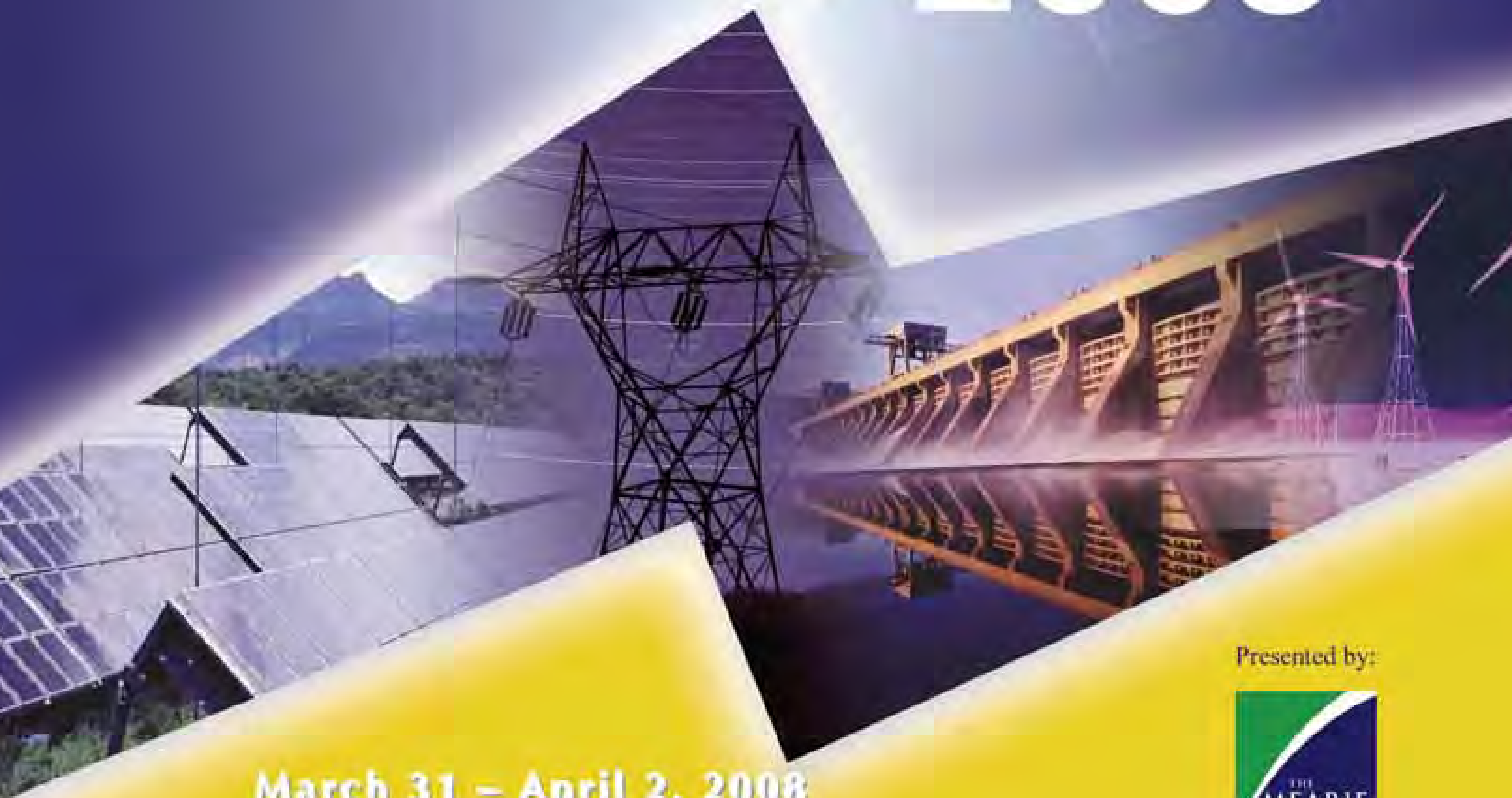

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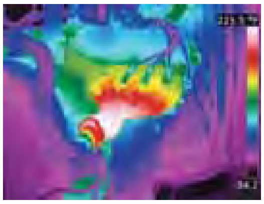

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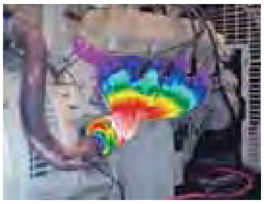

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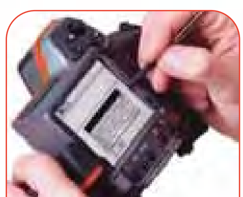

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