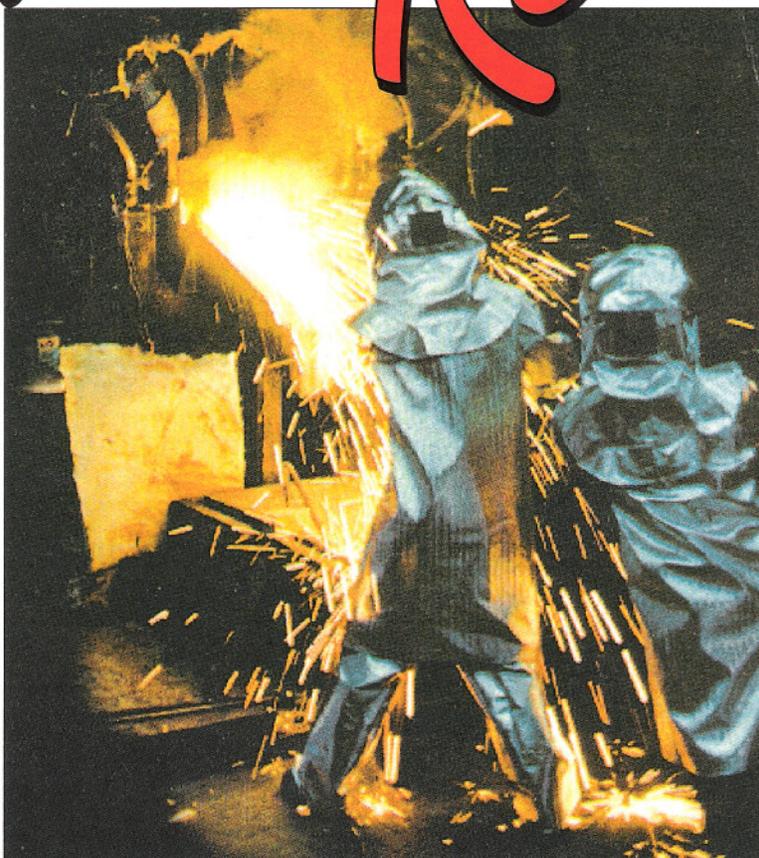


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Canadian Review



- *Control of Non-ferrous Electric Arc Furnaces*
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Cover picture

Photo de couverture

The cover photo shows the melting process of non-ferrous metal production whereby the concentrated ore is melted and separated into two components of different densities: the slag and the matte.



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Control of Non-Ferrous Electric Arc Furnaces

Introduction

Many of the most important players in the non-ferrous metal industry are Canadian companies with extended worldwide operations. These companies are involved in all aspects of metal production, from exploration and mining to metal refining and processing.

An important aspect of non-ferrous metal production is the separation process known as smelting, in which the concentrated ore is melted and separated into two components of different densities: the slag and the matte, the latter usually being the product, (see cover photo, Figure 1). The smelting process is carried out through high-power heating in electric arc furnaces [4]. These furnaces are typically powered by three-phase AC substations capable of providing high currents to the furnace electrodes. The two most common electrode configurations for these AC furnaces are: three vertical electrodes positioned at the apexes of a triangle, each of which being connected to a phase of the transformer; and six in-line vertical electrodes, each pair of which being connected to a single-phase transformer, fed from one of the three phases of the main substation transformer. New technologies using DC power supplies are also emerging for non-ferrous ore smelting. Recently, pilot DC furnaces with a single hollow electrode have been tested [3]. Concentrate fines are fed through the electrode in these furnaces for fast smelting in the DC arc plasma.

In order to maintain a constant desired matte production rate and constant matte and slag temperatures, the average furnace power must be accurately controlled and coordinated with the feed rate [1]. Furnace power regulation can be achieved by varying the electrode positions in, or relative to, the bath through controlled electrode movements, in such a way that the resulting change in impedance will bring the furnace power closer to its setpoint. Power regulation is typically implemented with cascaded phase impedance and power feedback controllers.

This paper discusses classical and novel power control technologies for three-electrode and six-electrode AC furnaces. The development of a power quality analyser for real-time monitoring of harmonics and flicker generated by electric arc furnaces [5] is also briefly discussed.

Process

Smelting

The smelting process is essentially continuous, which imposes particular constraints on its control. For example, the furnace electrodes are consumed at a certain rate, and must be replaced after a while, or have sections continually being added.

The feed system must also support the continuous nature of the smelting process in the furnace. Feed rate control is necessary to keep the furnace around its optimal equilibrium of material content. Slag tapping can be considered as a quasi-continuous process in some smelters where the tap hole may be left open 80% of the time. On the other hand, matte tapping is essentially a batch process because ladles are used to convey the matte from the furnace to the converters.

by Benoit Boulet, Vit Vaculik, and Geoff Wong,

Hatch Associates.

An important aspect of non-ferrous metal production is the separation process known as smelting, in which the concentrated ore is melted and separated into two components of different densities: the slag and the matte. The smelting process is carried out through high-power heating in electric arc furnaces.

In order to maintain a constant desired matte production rate and constant matte and slag temperatures, the average furnace power must be accurately controlled and coordinated with the concentrate feed rate. This paper presents power control technologies for high power smelting furnaces. Power quality and management issues are also briefly discussed.

Un des aspects importants de la production de métaux non-ferreux est le procédé de fonte, dans lequel le minerai concentré est amené à son point de fusion dans une fournaise. Le minerai en fusion se sépare ensuite en deux composantes de densités différentes: les scories et le métal. Le procédé de fonte est mis en fonction à l'aide d'une fournaise à arc électrique de haute puissance.

De façon à maintenir un taux de production de métal constant et à obtenir des températures de métal et de scories constantes, la puissance moyenne de la fournaise doit être asservie de manière précise et coordonnée avec le taux de chargement du minerai concentré. Ce texte traite de technologies de commande de puissance pour fournaises de fonte à haute puissance. La gestion de la puissance électrique ainsi que sa qualité sont aussi discutées brièvement.

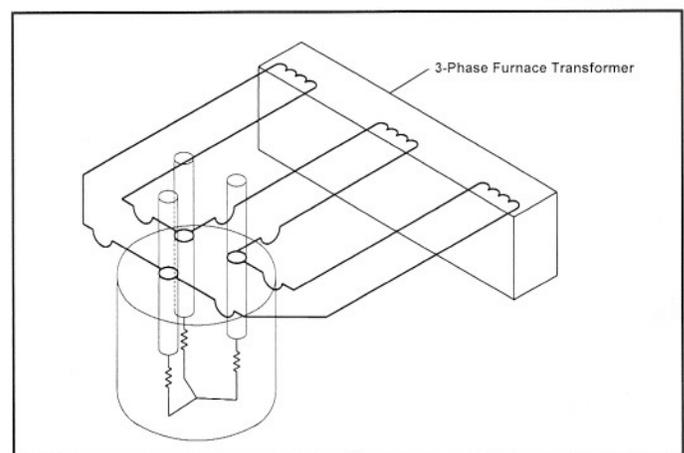


Figure 2: Three-electrode furnace circuit diagram

Three-Electrode Furnaces

Three-electrode furnaces usually have a circular shape with an outer diameter varying from a few meters, up to 30 meters. These furnaces feature three vertical electrodes arranged in a triangular manner, each of which being connected to a phase of the three-phase furnace transformer secondary (see Figure 2). The primary of the furnace

transformer can be either connected in star, or delta configuration. In star configuration, a neutral is typically connected to hearth ground straps which make contact with the molten metal and provide a ground for the electrodes. On the other hand, in a delta configuration, the matte bath essentially becomes a floating neutral.

Typical power levels for three-electrode furnaces range from 10 MW to 80 MW, with electrode currents varying between 10 kA and 60 kA, and electrode voltages ranging from 100 V to 2000 V. Figure 3 shows a photograph of an arcing electrode tip in a furnace.



Figure 3: Arcing electrode tip in a furnace

Process Electrical

For a three-phase furnace transformer with multiple taps, the relationship between furnace power, tap voltage, and electrode current can be displayed on a so-called PVI chart, similar to the one shown in Figure 4 for a six-electrode furnace. This chart contains all the relevant information to specify furnace operating points for desired range of production rates. Typical data shown on PVI charts include: electrode current versus power curves for every tap voltage, for star and delta connection of the transformer's primary; electrode impedance curves; and transformer limits represented as an "envelope" superimposed on the curves. Note that three single-phase transformers may also be used to supply power to a three-electrode furnace.

A furnace power setpoint is selected based on the desired matte smelting rate. Recent furnace transformers have on-load tap changers that are controllable from a computer. Thus, a tap or an impedance setpoint is usually specified by the operator along with the power setpoint. The control computer takes care of calculating which transformer tap will give the impedance closest to the setpoint, and it will typically run the tap changer to reach the calculated tap while ramping the power up or down.

Six-Electrode Furnaces

Six-electrode furnaces have six in-line electrodes, with each of the three electrode pairs connected to a phase of the power system. Three single-phase transformers, one for each phase, are typically used for six-electrode furnaces (Figure 5).

These furnaces have a rectangular shape with the matte tap holes at one end, and the slag tap holes at the other end [4]. Their sizes vary from 10 m X 5 m, up to 35 m X 15 m, depending on the required throughput and the type of ore concentrate. The largest of these furnaces can smelt more than a thousand tons of concentrate per day.

Process Electrical

For each single-phase furnace transformer with multiple taps, the relationship between phase power, tap voltage, and the current flowing in the electrode pair can be displayed on a phase PVI chart (Figure 4). The transformer limits are represented as an "envelope" superimposed on the curves.

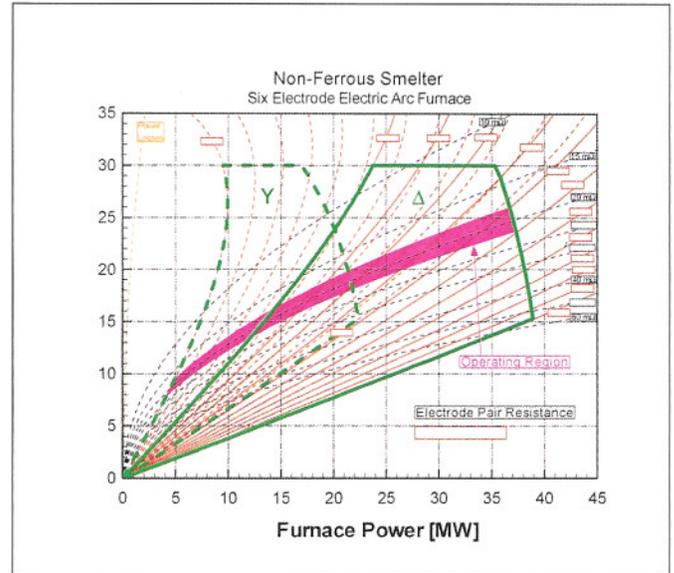


Figure 4: PVI chart for a six-electrode furnace

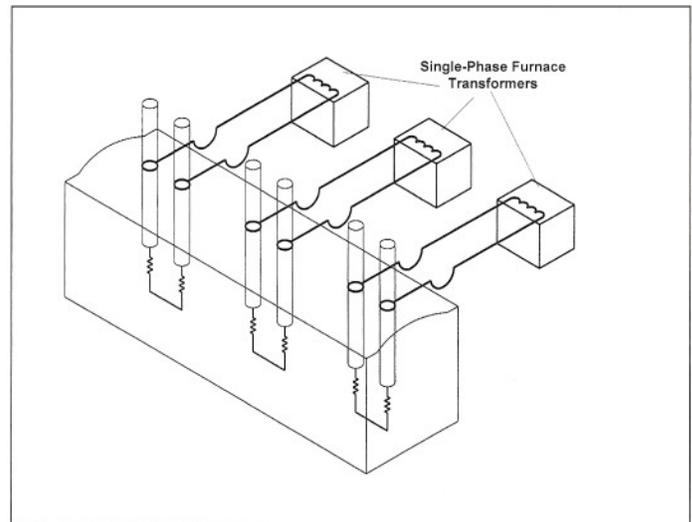


Figure 5: Six-electrode furnace circuit diagram

Each phase power setpoint is calculated as a fraction of total furnace power, and they need not be balanced. For example, it may sometimes be required to put less than one third of the total furnace power on an electrode pair close to a tap hole. Running the furnace only on one phase is also feasible, although this would cause severely unbalanced currents, which may cause overheating of three-phase motors feeding off the same medium voltage bus as the furnace.

For each phase, the control computer takes care of calculating which transformer tap will give the impedance closest to the setpoint, and it will typically run the tap changer to reach the calculated tap while ramping the power up or down.

Control

The control of electric arc furnaces is based on the relationship between phase resistance and electrode immersion, or arc length.

Arcing operation

For a furnace operating in arcing mode, the resistance of the arc partly governs the amount of power released inside the furnace. Although

chaotic in nature, the arc resistance may be thought of being roughly proportional to its length. Figure 6 shows a typical representation of a load resistance vs electrode immersion relationship. Arcing occurs for "negative" immersion of the electrode tip. Thus, the fundamental principle of impedance and power control is based on the phase resistance variations caused by moving the electrode up and down, which controls the arc length.

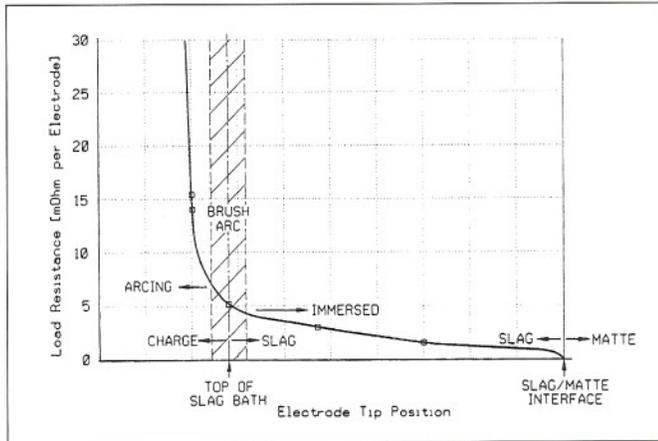


Figure 6: Electrode resistance versus electrode immersion

In an ideal steady-state operation, phase impedance and power would be constant for a fixed electrode position. However, disturbances caused by concentrate feeding, arc instability, varying slag chemistry, tapping, waves in the bath, etc., cause large, fast variations in both phase impedance and power in open loop. Hence, feedback control is necessary to reject the effects of these disturbances, and regulate the average phase impedance and power to desired setpoints (Figure 7). When a loss of arc occurs on a three-electrode furnace, half of the total furnace power is lost due to the three-phase circuit configuration. On the other hand, a loss of arc on a six-electrode furnace results in a power drop of only one third of the total furnace power.

Immersed electrode operation

The resistance of the slag between the tip of an electrode and the slag-to-matte interface decreases as the electrode is immersed deeper into the slag, until it eventually vanishes when the tip reaches the matte. This variation in resistance depending on electrode immersion is the fundamental principle for impedance and power control (Figure 6) in immersed mode.

As previously mentioned for an open arc operation, ideally the phase impedance and power would be constant for a fixed electrode position in steady state. But model uncertainty and process disturbances make feedback control necessary to regulate the average phase impedance and power to desired setpoints. Joule heating through the slag leads to intrinsically more stable impedance and power trends than open arc heating. On the other hand, a furnace running in arcing mode operates at higher voltages and lower currents, which reduces electrode consumption and allows higher furnace power for a given current limit. See [4] for a more detailed account of the pros and cons of different modes of arcing operations.

Control Strategy

For a fixed transformer tap, a cascade controller with the inner loop controlling the electrode impedance, and the outer loop controlling the phase power, is used in most cases. A cascade phase controller for a six-electrode furnace is depicted in Figure 8. The control signal actuates a valve or an electric drive that move the electrodes via hydraulic or electric motor-driven hoists.

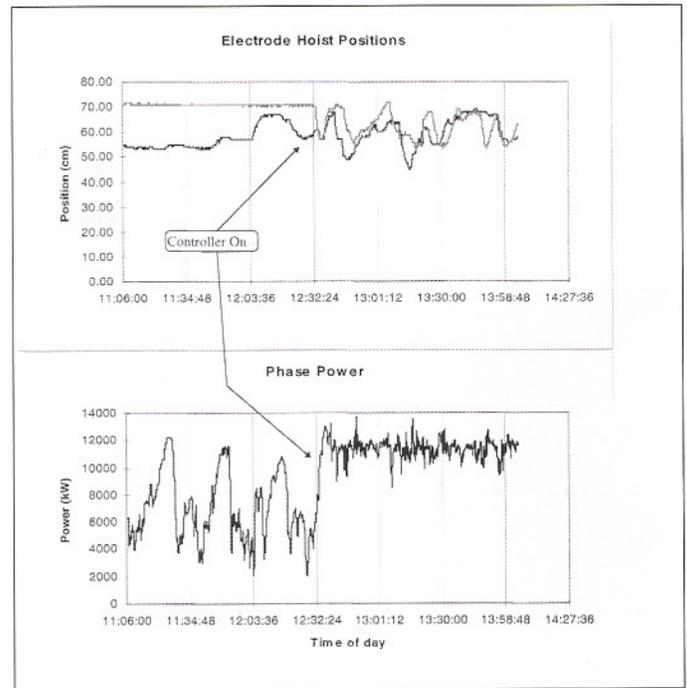


Figure 7: Phase power without, and with control

The control systems for three-electrode or six-electrode furnaces do not differ much. However, the control of six-electrode furnaces is simplified by the electrical decoupling of each electrode pair fed by a single phase. For these furnaces, it is possible to control the power accurately on a single phase by moving the two corresponding electrodes. Movements of the other electrodes will not affect the phase power, provided they do not generate waves in the bath. This allows the furnace power control system to achieve good performance with three independent power/impedance cascade controllers. On the other hand, three-electrode furnaces possess inherent couplings in the electrode currents due to their circuit topology. For instance, if only one of the electrodes is moved, all three electrode currents will change simultaneously. The current couplings make the impedance and power control of three-electrode furnaces more difficult. Novel decoupling techniques are under development to address this problem. Nevertheless, provided care is taken in their designs, cascade-type controllers have been shown to work on three-electrode furnaces as well.

Electrode Slipping

Two types of electrodes that are commonly used in electric arc furnaces are Soderberg electrodes, and graphite electrodes. Soderberg electrodes are made of a hollow steel shell filled with paste that bakes once it enters the furnace. Cylindrical steel sections (or cans) are welded on top of the electrode before adding the paste. A hoist system, with a stroke of roughly one to two meters, holds the electrode above the furnace and provides a dynamic range for electrode movement used for impedance and power control. A slipping mechanism mounted on the hoist slips the electrode, downwards relative to the hoist by a fixed short amount. Manual slipping requires that the operator monitor the average hoist positions, and initiate a slip sequence when a hoist is too close to its lower limit.

Traditional manual slip timers that initiate electrode slipping are usually not synchronized with electrode consumption, which is mainly governed by electrode current. Therefore, the electrodes may be consumed either faster or slower than the slipping rate, which causes them to migrate out of their controllable region. For instance, power and impedance control is lost when an electrode hoist bottoms out, which has been observed to occur frequently in some smelters. An electrode slipping controller is a new

technology that automatically slips the electrodes whenever required, without the need for operator intervention. Apart from can welding which is still performed by human welders, a slipping controller renders the furnace power control fully automatic and allows continuous operation of the furnace.

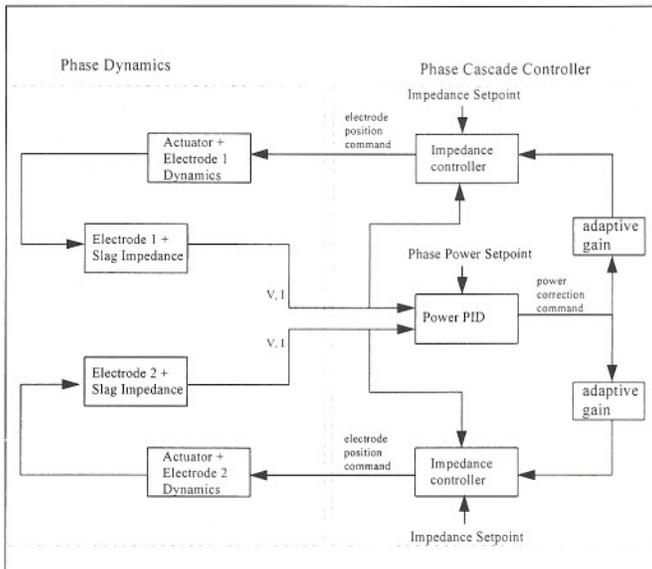


Figure 8: Cascade phase power controller for a six-electrode furnace

Feed Control Systems

Feed systems are an integral part of the non-ferrous smelting process; they provide a continuous supply of material to the furnace. The material is typically a preprocessed mineral ore blended with some additives to enhance the smelting process. The primary objective of the feed system is to maintain a black-top layer in the furnace to insulate the molten bath. This increases smelting efficiency, which increases production. It also reduces the temperature in the area above the bath, known as freeboard, which reduces the deterioration of the furnace roof and off-gas system. Control of these material handling systems is critical in maintaining optimum production.

A recent implementation of a furnace feed control system was part of an overall feed system upgrade that provided the furnace with a distributed feed system. The control system was implemented on a PLC. The system utilized an air slide with pneumatically actuated diverter gates to each of the feed ports. Feed distribution control, which determines the amount of feed delivered to each feed port on the furnace, was implemented by the sequencing logic controlling the diverter gates. The sequencing logic incorporated dead time compensation to account for the transport delay inherent in a feed system of this type. Feed rate control was implemented using a variable speed feeder under feedback control; the feedback signal was the rate of change in weight as measured by load cells in the feed bin. The feeder speed was adjusted to compensate for any error between the actual and target feed rates.

As feed systems are an integral part of the smelting process, feed system control is very much an integral part of the overall plant process control. Supervisory control functions that coordinate furnace power control and furnace feed control ensure that the two systems work together. For example, a recent implementation of a feed control system coordinated the target feed rate with the power consumption through the use of feedforward compensation. In other feed system experience, the power setpoint and the feed rate were linked with a model so that the setpoint for one is determined by the other.

Energy Management Systems

Power Grids

Plant smelters are typically connected to a power grid which is regulated by a provincial utility. The energy contract between the utility and the plant operations usually contains the following items: an energy cost (\$/kWh), a peak energy penalty (where the plant is charged additional funds when excessive energy is consumed during peak hours), and a power factor (pf) penalty (where the plant is charged when the pf falls below acceptable levels). The peak energy and pf penalty clauses in the energy contract may account for a significant amount of the total energy costs. In these cases, an energy management system would make-up or shed various plant loads such that an adequate power level is maintained during peak hours. Also, the energy management system would monitor real-time pf readings and modify plant operations to minimize the pf penalties.

Captive Generation Systems

Furnace power make-up and shedding greatly impacts a captive generation system because the majority of a plant's load is typically the furnace(s) [2]. Large variations in furnace power can result in plant load and frequency instability, and could easily damage a set of generators. The generators are directly affected because a captive generation system is usually geographically remote, and only has a single source of energy (e.g., hydroelectricity). Therefore, it is especially important that the furnace controller regulates the power levels in a captive generation system.

In addition, most smelter operations have multiple furnaces that can have varying power levels. Where one furnace may cause some damage to the generators, the net effect of multiple furnace power fluctuations can jeopardize an entire power generation facility.

Power Quality

Power quality throughout an entire plant, or an entire region, may suffer due to the operation of electric arc furnaces. Electric arc furnaces are very nonlinear loads due to the chaotic nature of arc impedance. Nonlinear loads are the principal cause of power quality problems including voltage dips, harmonic distortion and flicker. In a typical smelter, the medium voltage bus is connected to furnace transformers that deliver power to the arc furnace. As a result, other loads connected to the medium voltage bus and below are subjected to the effect of negative sequence and harmonic currents caused by the furnace. Under certain conditions, depending on the state of the distribution system, it may happen that the poor power quality gets also reflected to the power grid and other utility customers.

Power quality monitoring and control is a growing area of interest as utilities are starting to impose more constraints on smelter operations. The development of a power quality analyser [5] has been motivated by the need to provide a means of monitoring power quality to guide furnace operation, not only to minimize penalties, but also, to provide records for aid in negotiating power contracts with utilities. As recording intervals can span days to weeks for power studies, or months for overall operation monitoring and billing, efficient data recording methods are essential. Complete power management requires that enough quality data be stored to be meaningful, but not to be so excessive such that studying the data is too time consuming to be practical.

Conclusion

We have described three and six-electrode AC electric arc furnaces for non-ferrous ore smelting, with a special emphasis on their control requirements. Specific issues associated with furnace power and impedance control were discussed. A control strategy involving setpoint selection on PVI charts, automatic tap changing, and the implementation of cascade controllers was outlined. The continuous nature of the smelting process was shown to lead to special control requirements for peripheral

furnace subsystems such as slipping and feed systems. Finally, the impact of electric arc furnace loads on power quality and stability was discussed, and partial solutions in the form of energy management systems and monitoring systems were outlined.

Future directions in furnace control technology include decoupling control for three- electrode furnaces, fuzzy-logic gain scheduling and control, flicker control, robotic tappers and can welders, and automated maintenance systems.

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Acknowledgement

Cover picture was taken by Otakar Urban, with thanks to Hatch Associates Ltd. and Cerro Matoso S.A.

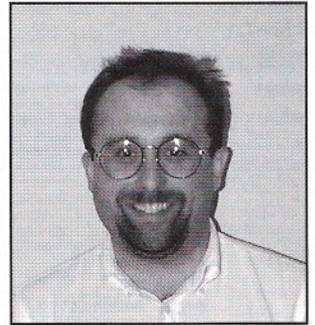
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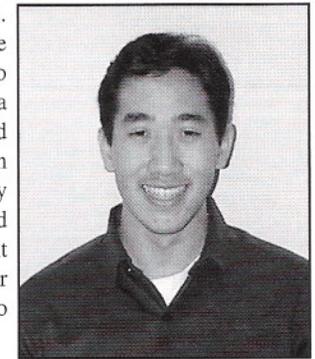
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If you visit the IEEE Canada web site you will notice that it features an online membership database. From the IEEE Canada Home Page www.ieee.ca, the database can be accessed through selecting "Membership and member services" option, and then the "Online Retrieval of IEEE Canada Member Information" item.

This shadow copy of the Region 7 membership database, is being maintained at IEEE Headquarters office and has been converted to the web accessible database by IEEE Canada Electronic Services. Now IEEE Canada members and volunteers can look up their membership information anytime, anywhere - as long as they have access to the Internet and have a web browser. For this they have to identify themselves to the system by typing Membership Number, First Name and Last Name, as the access is restricted to IEEE Canada members only.

Volunteers working at the section, chapter or branch level may obtain authorization and special password to retrieve information about members in their respective areas - this service can help them do their volunteer jobs a little bit easier. To see a preview of this facility - please click on "Executive Database Demo" button.

All members are encouraged to visit the database. If you find a discrepancy in your record - simply fill in the form on the web (Button: "How to correct personal information") or send an e-mail to the IEEE Canada Administrator at member.services@ieee.ca. Although it will take some 6-8 weeks for the corrected information to appear on the web - this is a good way to have your record fixed - the information typed correctly by you will be passed directly to the IEEE Canada Administrator and IEEE Headquarters; and your records will be updated.

Candidates for IEEE Canada Director-Elect.

Celia Desmond

Stentor Resource Center Inc.,
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33 City Center Dr.,
Mississauga, Ontario L5B 2N5.

Phone: 905-615-6660
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Personal Biography

Celia Desmond manages projects at Stentor Resource Center Inc. Previously she was a Process Consultant, establishing processes for service development in SRCI. In 1993 as Stentor's Industry Liaison, Celia organized technical seminars, approved release of technical information, and provided guidance to engineers attending external meetings. As prime for AIN in Bell Canada in 1992, Celia provided direction to a team of technical, marketing, and operations resources. Previously, in line positions, Celia provided full technical support to large business clients. She has taught courses from Kindergarten to graduate level. She currently teaches Telecommunications Management at Ryerson University.

IEEE Activities

In 1996, Celia was elected to the IEEE Board as Director Division III. She has been a member of the Communications Society Board of Governors since 1988. During 1994-95, Celia was Vice President - Member Affairs of Communications Society. In this capacity she performed studies to determine what members see as benefits, sponsored Distinguished Lecture Tours and established international Sister Society agreements. As Director - Chapter Activities from 1991-1993, Celia implemented programs mutually beneficial to Chapters and Communications Society. She has been a reviewer for IEEE Network and IEEE Spectrum, guest editor of IEEE Network October 1987 and November 1989, Vice Chair of IEEE Infocom '87, General Chair in '89. She organized ICUPC '93 and ICC 97. Celia chaired Engineering Management in Toronto 1986-1997, in Ottawa 1980 - 1983, and the Ottawa Section 1983 - 1984. Celia was awarded the Donald J. McLellan Award for meritorious service in 1991. She is a Senior Member of IEEE.

Candidate statement

In my local IEEE and Communications Society work I have focused on member needs, creating and implementing programs such as Chapter of the Year Award, lecture tours, and liaison between IEEE, local members and industry. I brought Infocom, ICUPC and ICC to Canada. As Region 7 Director, I will ensure that IEEE leaders learn more about member needs, and implement more programs to address them. I have gained insight into programs which could benefit members, frequently implementing these.

At local, Society, and Board levels, I have learned methods of achieving results within IEEE and formed many contacts. As Region 7 Director I will work with the local members, Section/Chapter Chairs, Societies, industry and IEEE executives to provide the best professional and technical services to Canadian members, ensuring that IEEE continues to disseminate quality technical information via traditional and new technologies, and enhancing the possibilities for networking of engineers.

Haran C. Karmaker

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Engineering Laboratory,
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Personal Biography

Dr. Haran Karmaker, a registered Professional Engineer in the Province of Ontario, received his B.Sc. Engg. degree in Electrical Engineering from Bangladesh University of Engineering and Technology, Dhaka in 1967 and M.A.Sc., Ph.D. degrees from the University of Toronto, Canada in 1971 and 1974, respectively. Dr. Karmaker joined the Engineering Laboratory at General Electric Canada, Peterborough, Ontario as a Research Engineer in 1975, where he is now Leader of the Electromagnetics Team. His research activities include simulation and modelling of large rotating electrical machines and power electronic drives, numerical and analytical computation of electromagnetic fields and experimental studies for parameters, fields and losses. He has presented and published over 30 technical papers in IEEE and International journals. Dr. Karmaker is a member of the IEEE Working Group on Synchronous Machines Modelling and Testing, IEEE Electric Machinery Theory Subcommittee, IEC Committee on Magnetic Steels and NEMA Rotating Machinery Committee.

IEEE Activities

S'70-M'74-SM'82) REGIONS: Region 7: Central Canada Council Chair, 1995-96. SECTIONS: Peterborough: Founder/Chair, 1985-86; Bay of Quinte: Chairman, 1984-85; Vice Chairman, 1982-84. SOCIETIES: Power Engineering: Synchronous Machines Subcommittee (WG-12), 1992-95; (WG-7), 1996-97.

Candidate Statement

I am honoured to have been asked by the Region 7 Past Director Dr. Raymond Findlay to become a candidate for Region 7 Director Elect, 1998-1999 and to have this opportunity to represent and promote the interests of the members on the Board of Directors and to serve the members to achieve the value of their membership they expect from IEEE.

My goal is to justify the value of IEEE membership to retain present members and attract new members through promotions in the media, community and among fellow members. I would like to vitalize the section activities to increase educational and professional activities for the members' career planning and enhancement.

During my tenure as the Central Canada Council Chair, I have been successful to obtain the sections' support to justify and enhance the Council activities for coordination of sections' programs for the benefit of all member sections. I would like to bring my experience to promote intersection activities in the Region. If elected, I shall make it a priority to develop contacts with the Industry leaders to seek their support in encouraging their employees to belong to IEEE. I shall emphasize that the employees will contribute their fullest potential towards achieving their business objectives by networking and contributing in IEEE.

Chandra M. Kudsia
 Chief Scientist
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Personal Biography

Dr. Kudsia is an engineer, manager and educator. He joined RCA Limited Montreal in 1967, where he was involved in the design and implementation of microwave equipment for communications satellites. In 1976, he joined COM DEV. He has served as Principal Engineer, Vice-President, and is currently Chief Scientist. His technical leadership has helped COM DEV grow from a 20-man company to a world leader in microwave products for satellites employing 700 people. He has taught graduate courses, has served on many national committees, is on the Board of Directors of two of Ontario's Centres of Excellence (TRIO and ISTS), and GUARD, a publicly-traded company to commercialize university research. He is a registered Professional Engineer, an adjunct associate professor, co-author of a book, and a 'Fellow' of the American Institute of Aeronautics and Astronautics. He received Ph.D(EE) and M.Eng.(EE) degrees from Concordia and McMaster Universities.

IEEE Activities

(M'68-S'78-M'78-SM'93) REGIONS: Region 7: Central Canada Council, Awards Committee, Chairman, 1994-96. SECTIONS: Kitchener-Waterloo: Chairman, 1992-94; Vice Chairman, 1991-92. SOCIETIES: Microwave Theory and Techniques: Distinguished Lecture Organizer, 1991-94; Industry Presentations, 1991-94; Student Papers, Judge, 1991-94; Microwave Networks (MTT-8), 1987-97; Editorial Board, MTT Transactions, 1987-97. CONFERENCES: MTT-S, Technical Program Committee, 1978, 1983-97; Workshops/Session Chairs, 1983-97.

Candidate Statement

Advances in Information Technology are creating a new world order. Rapid access to information and knowledge now transcends international borders, creating new opportunities and challenges for the engineering profession, bringing organizations like IEEE into ever sharper focus. Organizations must incorporate the management of change and make knowledge more productive. IEEE would provide the best service to its members by emphasizing this theme.

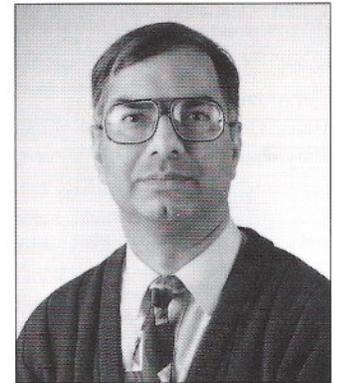
If elected, I will:

- Listen to the membership by visiting each section at least once. . Address issues as highlighted by the membership at large in Region 7, promote local programs and initiate a 'Canadian Distinguished Lectures' series, strengthening our unique Canadian identity. .
- Seek greater membership from industry by promoting the image of the engineering profession and advantages of joining and actively participating in IEEE. .
- Develop closer collaboration with universities and student community, develop strategies to add value to engineering education. I bring 30 years of industrial experience spanning numerous international space programs and a close working relationship with Canadian universities and government agencies to meet this challenge.

A few words from the Managing Editor

By Vijay K. Sood, Editor

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I am pleased to submit to you the Summer issue of the Review. As you will notice, this issue is longer by 4 pages from the previous issue. Three well-researched, practically-oriented articles were submitted. All of these

should be of general interest to all our membership. I strongly urge you all to look through these articles. The authors and editorial staff have made a serious effort to bring you something interesting; I hope you will agree.

This issue presents the second in a series of three articles on Software Patent Protection. The response from readers on this topic has been very favourable so far, and I thank those of you who took time out to send me your comments.

I am very pleased to welcome on-board a new Associate Editor (Chelakara Vaidyanathan - Vaidy for short) from Western Canada; his address is on the inside cover of this issue and this completes our team for the time being. Vaidy hopes to submit his first article in the Fall issue. Prospective authors should get in touch with any of the editorial staff for any assistance for preparing an article.

This issue also presents three very capable candidates for the position of Director-Elect 1998-99. We are fortunate to have a fine slate of candidates this time. Please read their statements carefully and vote when the time comes in the Fall. I congratulate all of the candidates for their dedication and service to the community.

We usually are happy to include items of interest to our members. If you come across items which are newsworthy, please send them in. Plans are underway for producing some special issues of the IEEE Canadian Review on the following three topics: the James Bay Hydro-Electric Project, the Confederation Bridge Project and the Hibernia Project. I am seeking authors for these issues.

Finally, as we are still in the vacation period, I wish you all "Bonnes Vacances! et amusez-vous bien."

Software Patent Engineering - Part II

Introduction

Innovations in computer hardware and software, even in such advanced applications as CAE's computer image generator and helmet mounted display system for flight simulators as shown in Figure 1, are easily recognized and understood as leading edge improvements by engineers. Such innovations are symbols of engineering achievements and result in competitive products contributing to the financial success of technology businesses. When an invention promises to be of great commercial value, exclusive rights to the invention are highly valuable and worth protecting.



Figure 1: CAE's Computer image and helmet mounted display for flight simulators

by James Anglehart, Max R. Wood, Swabey Ogilvy Renault

This is the second in a series of three papers on patent protection for software. These papers are based on a lecture on software patents given during the IEEE Montréal/Patent and Trademark Institute of Canada's two-day seminar on patents held in Montreal last October (and to be repeated on October 6 and 7, 1997 in French and on February 9 and 10, 1998 in English). This paper explores how a software invention is described in a patent, and how engineers can work efficiently with patent agents to prepare good patent applications. The third and last paper will cover the topic of how a patent legally protects a software invention.

Cet article sur la brevetabilité d'un logiciel est le deuxième d'une série de trois basée sur une conférence prononcée lors du cours offert à Montréal octobre dernier par la section de Montréal de IEEE et l'Institut canadien de brevets et marques. Ce cours de deux jours s'offrira de nouveau en français les 6 et 7 octobre 1997 et en anglais les 9 et 10 février 1998. Cet article expose la rédaction d'une description d'un logiciel pour une demande de brevet, ainsi que la collaboration efficace entre l'agent de brevets et l'ingénieur afin de préparer une bonne demande de brevet. Le dernier article dans la série exposera la protection légale d'un logiciel conférée par le brevet.

When a software patent is applied for, the government is being asked to restrict the public's right to make use of a software feature, function or process for a period of 20 years. Any restriction of the public's rights by a government, whether for gun control, telecommunication licenses or the grant of a patent, requires balancing opposing interests. To be fair to the public whose rights are being restricted, a patent must describe a new and non-obvious invention in a way that will allow the public to make use of the invention once the patent expires, otherwise, no patent is to be granted. In patent law, there are rules for granting "fair" patents that are partly the result of political decisions made by the government and partly made up by the Patent Office policy and rulings by the Courts over time. The stakes can be high, and the rules have become well developed.

There are some basic requirements for describing a software invention in a patent application that, according to the law, are equitable to both the public and the patentee. When describing software innovations, engineers will speak of the software as "having innovative features", "having new functionalities", "using proprietary algorithms", "incorporating an advantageous structure", "using a redesigned protocol", etc. As a result of Patent Law, patent agents speak of software as providing a "new and innovative apparatus or process". This article will explain what the basic requirements are, and what type of description a patent agent needs from an inventor to prepare a proper software patent application.

The Patent Agent's Perspective

A patent agent is a person trained in Patent Law and one or more fields of technology who prepares patent applications on behalf of inventors

and represents them during the process of obtaining the patent. In order to understand what a patent agent needs from an inventor to prepare an acceptable patent application, it is helpful to understand the task of a patent agent in preparing an application. Many consider a patent application to be one of the most difficult kinds of legal documents to draft. In drafting a patent application, the patent agent must consider the eventuality that the invention may be economically quite successful in which case the patent is likely to be challenged in a Court of Law or a re-examination process. To that end, the application must be drafted with a view towards creating an effective document in terms of persuasion and advocacy. The application must therefore be technically as flawless as possible while avoiding a dry, plodding approach to the subject matter so that a reader is not only instructed but, insofar as the technology permits, inspired by a reading of the application and convinced of the merit of the invention and the advance in the art which it enables.

A patent agent must also draft the application with a view to convincing a patent examiner that the invention not only represents an advance in the art but that it is an advance which is not obvious to a person of ordinary skill in the field of the invention. To this end, as thorough as possible a knowledge of what existed at the date of the invention is invaluable to the patent agent. It is normal and understandable that inventors generally believe that their inventions are singularly unique. Some have even been known to ignore or conceal knowledge of existing technology. This is of no value to the inventor and puts his agent at a disadvantage. It is always desirable and the legal duty of the inventor to disclose any knowledge he may have of the technology as it existed at the date of invention. If the patent agent has access to that knowledge, he can inevitably provide a better opinion about the patentability of the invention and likewise prepare a better patent application which is more likely to be granted than if such knowledge is concealed.

Finally, the patent application must be written with a view to satisfying the inventors and the patentee that the invention is thoroughly understood and claimed so as to provide the best available protection in view of what existed at the date of invention. This is usually one of the easier tasks of the patent agent although some inventors do not readily grasp the concept of patent claims or the logical structure required in claiming an invention to the best advantage of a patentee. Each of these perspectives must be kept in mind while drafting a patent application. If an inventor understands the process, he is more likely to provide the information required by the agent in his first presentation and therefore more likely to make most effective use of his agent's time.

US Patent Description Requirements

A patent description has to be written from the perspective of many different kinds of readers while strictly adhering to the legal requirements established by extensive Patent Rules and precedents resulting from centuries of legal jurisprudence. The first task of the patent agent is to draft an application which permits persons of ordinary skill in the field of the invention to practise the invention given only the patent document and common general knowledge in that field. This requirement is the legal basis for the grant of the exclusive right afforded by a patent. Unless the patent application meets this onus, a patent will not be granted.

US Patent Law is more rigorous than Canadian Patent Law when it comes to setting out patent description requirements, so only US requirements are summarized here. According to Title 35, United

States Code, Section 112, a patent application needs to describe an invention in such a way that:

- a person skilled in the field or fields of technology involved in making the invention can,
- for those specific parts of the invention that are claimed in the patent application and which are to be protected by the patent,
- find the necessary guidance and instruction, in the patent application itself or in the published literature referenced in the application, to reproduce, carry out or otherwise make use of at least one form of the invention, and
- understand how the inventor would prefer to make the invention (including the inventor's choice of best suited materials, special techniques, etc. to make the invention more efficient, less costly, more durable, etc.).

Patent Law is strict that the description of the invention be complete, so important details cannot be omitted. Since the requirements depend on what is claimed as the invention, and since the patent agent will advise as to what will be claimed, the patent agent will determine what parts of the inventive system or software need to be described in detail. As to whether the description is sufficiently detailed, only the inventor can really know because one requirement is to describe the inventor's preferred way to make the invention. Consequently, ensuring that the patent description is complete is a joint effort between the inventor and the patent agent. Usually, the patent agent is not "a person skilled in the field of the invention", so either the inventor or one of the inventor's colleagues is relied on (in confidence) to determine if the description is sufficient to allow others to make use of the invention.

Inventors are creative problem solvers by definition. Many inventors are very quick to grasp new concepts and apply new technology. It comes as a surprise to them that a patent description needs to be detailed and precise, when a few scribbled notes and a sketch would be enough to convey the invention to them. It is important to be patient, and put in the effort when working with the patent agent in preparing the patent application. The final product will need to withstand the scrutiny of the Patent Office and then of the Courts, if the invention is commercially successful and the patent is contested by competitors.

Preparing a Description of a Software Invention for a Patent Agent

Unless inventors have some experience in the patenting process, they often find it difficult to prepare a written description of their invention for a patent agent. In our experience the best approach in preparing such a description is to write out the description as you would present it orally to a colleague. Do not be overly concerned about the organization of the description. Patent agents are experienced at understanding inventions and are skilled at organizing the information in the required format so long as the information is presented in a comprehensible manner.

The most common question asked of patent agents once an inventor has committed to the patent process is "What exactly do you need in order to prepare a patent application?". Most inventors assume that the agent needs a thorough and comprehensive description of every aspect of the invention. While it is true that a patent agent must have a thorough understanding of the invention and the various ways in which it may be implemented or embodied, the patent agent also requires other information which may seem to the inventor and/or the patentee as quite peripheral to the patent process.

First, one of the most important parts of a good patent application is a section called the "Background of the Invention". This section describes the inventor's understanding of the state of the technology at the date of

the invention and sets the framework for distinguishing the invention from what existed at that date. Inventors can improve their understanding of the state of the technology in the field of the invention by searching existing patents and literature. Two publicly accessible tools for searching US Patents and software literature can presently be found at "www.patent.womplex.ibm.com" and "www.spi.org", respectively. In addition to a knowledge of the state of the technology, the patent agent must understand the inventor's motivation in making the invention. What factors inspired the inventor to express the inventive ingenuity which gave birth to the invention? What, if any, long-felt needs existed in the technology at the date of the invention and how did the invention advance the technology to satisfy those needs? And, what were the primary objectives of the inventor when he set out to make the invention?

In addition to this information, the patent agent also requires information respecting the economic objectives and the business plan of the inventor and/or patentee. Without an understanding of what the patentee intends to do with the invention, the patent agent may not be able to properly craft the claims in order to protect that which the patentee may commercialize from the invention. There is nothing more disappointing than to issue a patent which fails to protect the product which is eventually brought to market. Such patents may actually stand in the way of protecting the interests of the patentee because they disclose but fail to claim embodiments of the invention which are eventually commercialized. It is therefore important that the patentee make an effort to ensure that his patent agent has a thorough understanding of his business objectives. Patents are, after all, expensive to obtain and every effort should therefore be made to be certain that the finished product will provide the desired leverage in the marketplace.

Finally, the patent agent needs a comprehensive description of the invention. In most cases, this entails a description of the essential characteristics and features of the invention expressed in some form other than the computer code in which the invention is embodied. While patent agents may have a thorough understanding of the process of writing code, they cannot be expected to be conversant in every computer language and should not be expected to sift through reams of code to find an invention. While they may be capable of doing so, this is not an effective use of their time. The description of the invention should, therefore, be rendered in the form of pseudo-code and/or block diagrams or flow charts which present an overview of the major components of the code and the way they interact to provide a novel apparatus when the code executes on a computing machine. It should also be remembered that software inventions are not necessarily exclusively software. They may include or involve hardware components which are not necessarily unique or inventive in and of themselves but which become both unique and inventive when combined with inventive software.

Block Diagrams and Flow Charts

A block diagram in a software patent is really a block diagram of a computer system that highlights the new structure and operation in the computer system created by the software. Each block represents a functional element that accomplishes a particular task. It may be a software or a hardware element, and it may be a component or part of a system, or a stand alone device. A block has a specific function and typically has inputs and outputs. The input and output data signal lines should be labelled. A complete block diagram provides a lot of information in a compact format, and it will usually be clear to a person

knowledgeable in the field how the invention works, just by looking at the diagram.

In the first article in this series, examples of how to recognize a patentable feature in software were given. A software invention is usually the result of the addition of one or more new functional features/elements or processing steps. The block diagram's *raison d'être* is to illustrate what the invention is, and so it is essential for the new functional elements to be shown in separate blocks in the diagram. Sometimes, to highlight what the invention is, a separate block diagram labelled "PRIOR ART" will be included to show the known system configuration for contrast with the new invention block diagram. To start with, it is best to keep the number of blocks to a minimum, while still illustrating the basic functional components of the working invention. If a block is not an "off-the-shelf" component or a known piece of software, it may be best to provide a further block diagram illustrating how the new block can be built.

In the example block diagram, context sensitive help is the invention. This example of an old software invention (and to the authors' knowledge, an invention which was never patented) was given in the first article in this series. Let's presume that it was previously only known to provide a user activated menu help system in application programs which always points to the top help menu. The "new" invention is a procedure that automatically determines what the program state is at the point when the user activates the help system, and looks up a help text indicator corresponding to the program state, so that the most appropriate help text appears in response to the user's activation of help. The block diagram shows five blocks: help request "F1" input, context determinator, system variables store, help text database, and help text display (Figure 2).

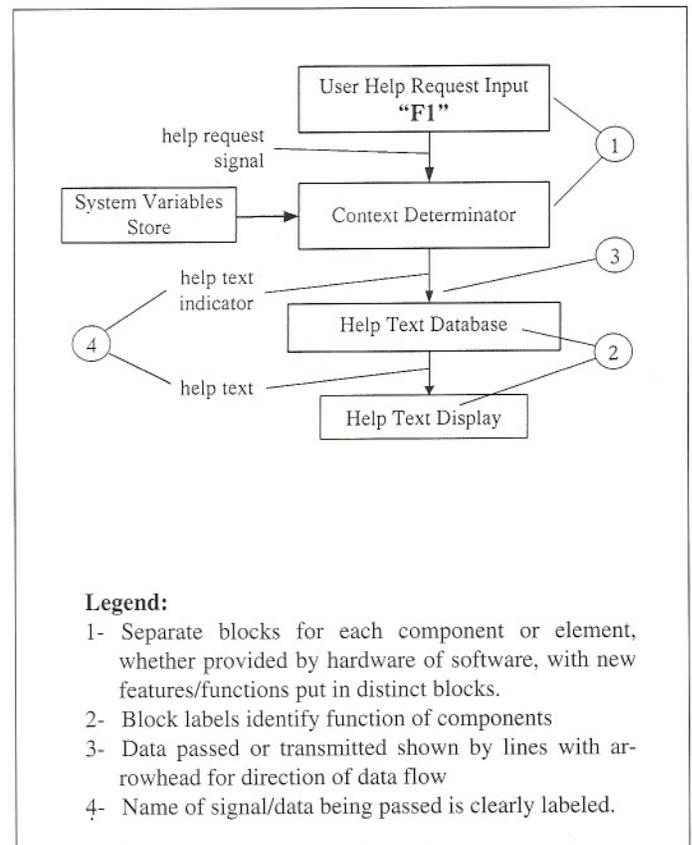


Figure 2: Example of a block diagram

As can be seen, nothing other than the invention is shown. Other features of the help system, such as the tools used to browse the help text and select other help screens, are not illustrated. The application program and the computer hardware devices "per se" that are not part of the functional elements, are also left out of the block diagram. The "context determinator" is a block which is created by software not previously known before the invention. If the inventor's preferred way to code this procedure is by creating a simple table, the written description of the how the table is set up and used by the software may be sufficient, and it may not be necessary to elaborate further by providing another block diagram or flow chart showing how the context determinator functions. By labelling the output data from the blocks, the basic operation of the invention will likely be fully understood without the supporting description.

Although such block diagrams are familiar to electrical engineers, they are rarely used by software engineers to sketch out a new software design. A procedure which passes data and returns data is not typically thought of as a system component having input signals and output signals. The design of software is different from hardware, and the mindset is also different. However, since a software patent describes and protects a new machine or process created by software, a hardware "model" for block diagrams in software patents is best.

The conversion from software structure to hardware structure can be easy. In hardware, component devices of the circuitry act on input signals and send output signals directly to other devices. In software, a virtual machine or a finite state machine is created. A software object, module or procedure is not typically running independently in parallel with other system components, and is therefore not typically "responsive" to input data. However, if the output data transformed or obtained by a procedure is shown to be "connected" directly to those other blocks which will use the same data as input for other operations, then the block diagram is relatively easy to sketch. Main programs that call procedures in a particular sequence are often not shown in the block diagram, unless the main program provides a function of processing related to the invention. When a procedure provides different functions depending on when it is being called and the type of data being passed to it, the block diagram may include separate, differently labelled blocks for the same procedure. If you have difficulty conceiving a block diagram, start by writing out a list of core procedures or program operations and their corresponding input and output data which are used. The list will be very helpful in constructing the block diagram.

As a final remark on block diagrams, there are no standards in the patent profession or rules set out by the Patent Office on how to prepare block diagrams. Strict compliance with any particular format is not required, but the format proposed in this article provides for easily understood block diagrams. Whether the diagrams are being read by a Patent Office Examiner or by a Judge, ease of comprehension is an asset.

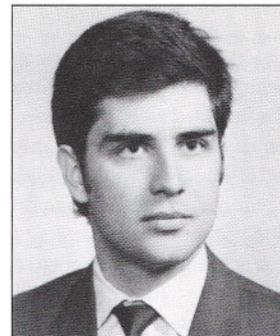
In addition to block diagrams, a physical equipment diagram and a flow chart diagram may also be included in the patent application to improve understanding of the invention. The physical equipment diagram shows the whole installation, such as the computer motherboard housing, keyboard, modem, printer, monitor, mouse and other peripherals relevant to the invention. It may be prepared as a pictorial representation, but usually it is like a block diagram with at least some of the rectangular blocks replaced by pictorial symbols, such as those used for printers, monitors, etc. The physical diagram also gives the reader an understanding of what makes up the invention

physically, and is good for teaching the general context. Flow charts are more important, especially in process or method inventions, and show the steps involved in the data processing. Flow charts in patents are typically flow charts which focus on the invention, but otherwise follow the same layout and conventions used by engineers.

In the next and final article of this series of three articles, some of the basic concepts behind understanding how a patent legally protects a software invention will be presented.

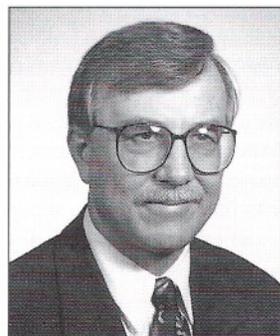
About the authors

James Anglehart is a registered Canadian and US patent agent working with the firm of Swabey Ogilvy Renault, Patent and Trade Mark Agents, in Montreal (e-mail: "j.anglehart@ieee.ca") in the area of electronic and computer-related inventions. He received his B.A. degree in Physics (Co-op) and French from the University of Victoria in 1987. He is chair of the Public Awareness Committee of the



Patent and Trademark Institute of Canada (PTIC) and is a member of Sigma Xi. He is director of the IEEE/PTIC two-day patent course, held in Montreal for the first time last October.

Max R. Wood is a registered Canadian and US patent agent and partner in the firm of Swabey Ogilvy Renault in Ottawa (e-mail: "mwood@ott.swabey.com"), working in the area of telecommunications and computer-related technologies. He graduated from Purdue University with honors and obtained his B.Sc. in experimental psychology in 1967. Prior to qualifying as a patent agent,



he worked in private industry as a computer systems analyst where he concentrated on software design and application development. He is a member of the PTIC and he serves on the Canadian Patent Agents Examining Board. He is chair of the Trade-Marks Automation Advisory Committee, a member of the Joint Liaison Committee - Patents and a member of the Computer-Related Technology Committee of the PTIC.

The IEEE Canadian Foundation



The IEEE Canadian Foundation is a registered charitable organization associated with IEEE Canada, the Canadian entity of the worldwide Institute of Electrical and Electronics Engineers (IEEE) Inc.

Activities

The Foundation currently supports 27 McNaughton Learning Resource Centres at Canadian Colleges and Universities through a programme of startup and improvement grants (which fund up to 75% of approved expenditures). It awards up to 10 scholarships annually to exceptional students who are registered in Electrical, Electronics, and Computer Engineering or Technology programmes for application towards their final year of undergraduate studies, and who have demonstrated leadership in their McNaughton Centre. It also confers special grants in support of educational activities. McNaughton Centres are established at Universities and Colleges by IEEE Student Branch members to provide facilities to enhance student activities on campus. Named after the noted Canadian Engineer, General Andrew McNaughton, these facilities are supervised by a faculty member who provides advice to the students, and recommends nominees for McNaughton Scholarships.

The following is the list of McNaughton Centres with the date of formation for each; University of Manitoba 1979, Carleton University 1980, University of Waterloo 1980, University of Toronto 1980, Niagara College 1981, University of New Brunswick 1982, McMaster University 1982, McGill University 1983, Queen's University 1983, University of Regina 1983, University of Calgary 1983, Red River College 1984, Laval University 1985, Conestoga College 1986, University of British Columbia 1988, Concordia University 1988, Technical University of Nova Scotia 1989, Seneca College 1989, University of Saskatchewan 1990, University of Ottawa 1991, Ecole Polytechnique 1991, University of Quebec at Trois Rivières 1992, St Clair College 1992, Southern Alberta Institute of Technology 1994, Algonquin College 1995, Ryerson University 1996, University of Alberta 1996.

If you have the opportunity to visit one of these Centres, you will find wonderful examples of student creativity and energy. These centres provide curriculum enhancements - tools for experimentation; computers for simulation, report preparation, and Internet services; ham radio stations; robotic laboratories; and much more.

Management

The IEEE Canadian Foundation is incorporated in the province of Ontario and has a nine-member board of directors who meet quarterly. Any changes to these bylaws must be approved by IEEE Canada and IEEE Inc. The IEEE Canadian Foundation and the IEEE Foundation exchange minutes of board meetings and normally send one member annually to attend each other's meetings to foster interaction, understanding and cooperation.

The IEEE Canadian Foundation operates a web site at "power.eng.mcmaster.ca/icf/" and uses the world-wide web to effectively communicate information about its operation to the students and faculty members at Canadian Universities and Colleges who are the primary applicants for the funds.

by *Robert Alden, McMaster University and
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The IEEE Canadian Foundation solicits donations to fund its support of educational activities. This overview of Foundation activities is presented in response to member inquiries.

La Fondation Canadienne de l'IEEE sollicite des dons pour supporter leurs programmes éducatif. Ce compte rendu sur les activités de la Fondation présentent une réponse aux enquêtes des membres Canadiens de l'IEEE.

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Many Canadian IEEE members have noticed the recent appearance of a "donations line" for the IEEE Canadian Foundation on their dues renewal notice (or annual letter, in the case of life members). Many of those members have elected to send a contribution and some of you have asked for information about the Foundation - hence this article.

One of the questions that has been asked concerns the conversion of donations between Canadian and U.S. funds. If you donate using the annual dues renewal form (or life member letter) which you return to the U.S., your donation is processed in U.S. dollars, and sent to our Foundation Treasurer, who converts to Canadian dollars and issues you a receipt for the converted amount. Your receipt will likely be slightly lower (or occasionally higher) than your donation because of fluctuating exchange rates and conversion charges.

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A Brief History

The IEEE Canadian Foundation evolved from IEEC Inc., a corporation which existed to operate the Toronto-based IEEE conference which was known for many years as the International Electrical and Electronics Conference and Exhibition. The directors of IEEC Inc. invested the reserve funds of the conference and developed the tradition in the 1960's of using proceeds of the investment, not required for conference operations, to fund educational activities associated with IEEE Canada - formerly known as the IEEE Canadian Region or Region 7. The conference ended in the mid 1980's, and the IEEC Inc.'s tradition of operating as an informal foundation was continued and formalized.

Network Survivability: A Crucial Issue for the Information Society.

Introduction: "Serious Impacts"

Industry, finance, commerce, medicine, education, police, government, agriculture: all these aspects of modern civilization are increasingly, if not critically, dependent on the availability of communication networks. At 10 Gb/s one optical fiber carries the equivalent of 129,000 voice or data circuits. And there may be 48 or more such fibers in a cable. This huge capacity, plus advantages in cost, weight, size, payload flexibility, and transmission quality have made digital fiber optics the technology of choice for future transport networks. But as the capacities of these systems grow, so does the impact of failure. Consider for instance that a single fibre optic cable cut in the AT&T network in 1991 caused a 10 hour outage impacting 60 per cent of the traffic entering and leaving New York City [1]. Despite physical protection measures fiber optics is a relatively vulnerable cable-based medium. Now that hundreds of thousands of route-kilometers are deployed in North America alone, cable cuts are surprisingly frequent and serious.

Although services such as voice, data, videoconferencing, Internet, private networking, credit verification, and so on, appear as separate systems to their users, virtually all traffic today is combined and multiplexed up to Gb/s rates and transported on relatively few 'backbone' fiber optic inter-office and inter-city transmission systems. Even the signals of competing long-distance 'carriers' often use the same physical systems. Typically the direct effect of a cable cut is immediate loss of a hundred thousand or more calls and all data connections and other services in progress. Indirect effects may include overloads on distant switching machines, loss of 911 service, loss of credit card verification services, shut down of banking machines and financial clearing networks, failure of airline and travel reservation networks, shutdown of data processing companies, and loss of Internet access and information services. Several travel company and 1-800 business failures have been directly attributable to such outages. One cable cut even shut down a major air traffic control network [1,2,3].

In the near future restoration technologies and restorable network design solutions will virtually eliminate the service impact of such failures. The same cable cuts as above will cause only a 'click' - or at most a pause - in a voice conversation, and data connections will experience several packet retransmissions. The busy life of the information society will go on uninterrupted, disaster having unknowingly been averted for hundreds of thousands of users.

Historical Perspective

Manual Restoration: Until the mid-80's restoration was generally handled by manual rearrangement at digital carrier cross-connect (DSX) patch panels. These DSX panels look similar to the 1920's style operator patch boards, but the signal on each of these patch cables contain 672 simultaneous transmission paths. Manual DSX patching operations were coordinated over multiple sites (yes, usually by phone) to reroute the carrier signals on the failed facility over the unused

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Network survivability has become a topic of serious concern for both telecommunication customers and network operators. At present, Self-healing Rings and Self-healing mesh networks are the two main approaches under development for service protection in the SONET fiber optic transport network. The SONET equipment market is already in the multi-billion dollars per year range and growing at over 25% per annum. The ability to efficiently restore, as well as design and manage, survivable SONET transport networks is therefore a strategic area for Canadian industry and University research.

Les problèmes de "survie" de réseaux sont en train de devenir très importants pour les clients et les opérateurs de réseaux de télécommunications. Parmi les méthodes de protection du service dans le réseau de transport de fibre optique SONET, on retrouve des systèmes d'auto-rétablissement de type anneau et maille. Le marché pour l'équipement SONET atteint déjà plusieurs milliards de dollars par année et il est en pleine croissance. La possibilité de faire face efficacement aux pannes et de concevoir et gérer des réseaux de transport SONET constitue un créneau stratégique pour l'industrie et la recherche universitaire canadienne.

capacity of other fiber, radio or coaxial cable systems, or via the automatic protection switching (APS) channels on other systems. Network operators would also sometimes arrange emergency use contracts with satellite operators. Whether by land or satellite, restoration by manual patching typically took six or more hours of coordination effort to establish and did not generally provide 100% service recovery.

Automatic Protection Switching: A partial form of automated restoration has been built into most digital transmission systems since the '70s. When a transmission system experiences only a single electronics or fiber failure, a hot-standby channel - built into the same system - is rapidly switched in. These APS subsystems are engineered on either a 1:1 or 1:N basis (1 'spare' for N working channels) to enhance the basic system availability \ddagger in the absence of any external damage to the system. This kind of designed-in redundancy is extensive in telecommunications equipment. Redundant power supplies, processors, tape drives, frequency allocations, antennas, lasers, etc. All this goes in to achieve basic operational availability levels that are exceeded only in space and nuclear applications. The APS system spare channel is one such a measure. But when the spare channel is co-routed with the working channels it protects in a fiber optic transmission system, it is of no help when the whole cable is cut. This is the context in which network-level restoration strategies must back-up the built in redundancy of most transmission systems.

From Radio to Fiber: Changing topologies: When an entire cable is severed, restoration can only be achieved by re-routing the affected carrier

\ddagger The technical meanings of availability and reliability are often confused. Availability is the probability that a repairable, maintained, system will be in the operating state at any time in the future. Reliability is the probability that a system or component will operate without any failure for a specific interval of time when starting from a no-fault state.

signals over physically diverse surviving systems. Physically diverse routes must therefore exist. Before the widespread deployment of fiber, however, long haul networks were largely based on point-to-point analog and digital microwave radio. APS systems routinely combated transient fading from multi-path propagation effects but network restoration - in the sense of recovery from a hard failure of a transmission span, was a rare requirement. The radio towers themselves were highly robust and you can't easily "cut" the free space path between the towers. National scale networks consequently tended to have many singly connected nodes and roughly approximated a minimum length tree spanning all nodes. With fiber optics we have been forced to 'close' these topologies into more mesh-like structure where no single cut can isolate any node from the rest of the world. The evolution this implies is illustrated in Figure 1. This is an essential first step to enabling the current survivability mechanisms. Note that this topological evolution itself has nothing to do with the speed of restoration. It is just topologically essential to have at least two points of connection for every node for restoration by diverse routing to even be an option.

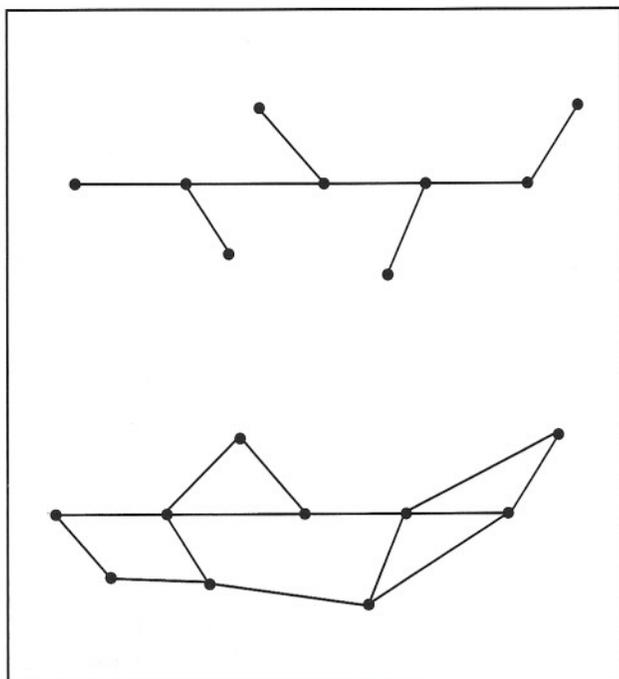


Figure 1: Topological evolution of networks to support survivability

Real-time Restoration Goals: Once the topology of a network is inherently restorable we can focus on two issues central to the choice of restoration scheme: speed, and the amount of spare capacity required. The speed and coverage objectives that are adopted have a significant influence on the capital outlays that will be required by network operators. The impact of various outage times has therefore been studied by several organizations. A summary from one such study is presented in Figure 2. Under 200 ms there is a low probability of connection loss in switched services and minimal impact on the network's own internal signalling and control sub-network (CCSN STP links in Figure 2). Up to about 2 seconds the service impact is essentially proportional to the outage duration itself in terms of data volume to be retransmitted etc. At 2.5 seconds, however, a quantum change arises in terms of the service-level impact: all circuit-switched and private line (PL) connections are dropped. Above 10 seconds all

types of data session are at high risk of session disconnection. If the outage goes on to last 5 minutes or more, the congestion experienced by digital switching machines can be severe due to re-routing by other switches and massive reattempt dialing by users. Beyond 30 minutes the outage may be reportable to regulatory agencies and the general societal and business impacts are considered to be of major significance. Two restoration time targets have therefore emerged as prospective objectives: either 50 ms or 2 seconds. The 50 ms target effectively specifies self-healing rings or diverse-routed 1:1 protection as the only viable technology at present. Many argue, however, that the 2-second goal has very little extra service impact because call dropping is avoided, but permits a potentially far more efficient mesh-based self-healing network concept for restoration. This choice of objectives is therefore a hot topic amongst vendors, operators, and researchers.

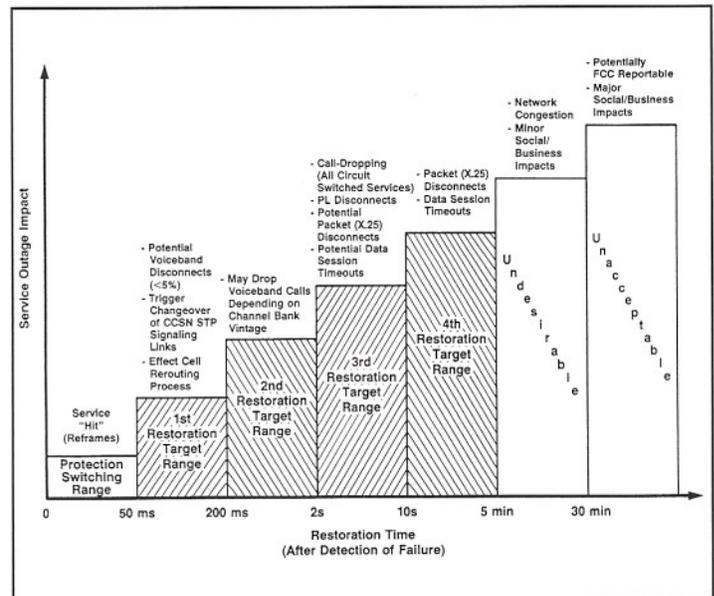


Figure 2: Impact of service outage duration on customers and society (from [3])

Self-healing Rings and Diverse-Routed Protection

One of the simplest measures for fast recovery from a cable cut is to use 1:1 APS with the protection channel on a physically diverse route. The diverse routed signal copy is always present at the receiver in which case the speed of restoration is essentially limited only by the failure detection time at the receiver. A 50 ms switchover can be achieved. In rare applications, the differential delay between the signal feeds can also be adaptively equalized to permit switching from one signal to the other within a bit time for so-called "hitless switching". The 1:1 diverse routed protection (1:1 DP) arrangement is costly, however, because there is over 100% investment in redundancy, relative to a single path on the shortest route. Nonetheless, for some heavy point to point demands in metropolitan applications 1:1 DP can be the most economic solution. A 1:1 DP arrangement is in fact the simplest type of Self-healing Ring (SHR).

Self-healing rings (SHRs) can improve on the economics of 1:1 DP where a number of smaller, roughly equal-sized, demands can be transported within one ring. The two basic types of SHR are illustrated in Figure 3. In the bi-directional line switched ring (BLSR), nodes adjacent to a span failure (or an intervening node failure) sense the receive signal loss, test the status of the protection channel, and (if free) switch their transmit signal to the protection channel in the reverse direction from the failure.

(A span is the section of transmission system including all its working and spare channels between adjacent nodes.) Each of these nodes also looks in the reverse direction on the protection channel to receive a replacement signal copy for their receiver input. Since any two nodes can make similar use of the standby capacity around the ring, the BLSR was originally called the Shared-Protection Ring (SPRing) [4]. In the uni-directional path switched ring (UPSR) each point to point demand is duplicated at its origin and permanently routed both ways around the ring. This establishes a 1:1 receive selection situation for each receiving point, equivalent to a virtual 1:1 DP system for each individual tributary signal. The nodal elements of SHRs are add-drop multiplexers (ADMs). An ADM has only two optical line-level (eg. OC-24, or OC-48 say) terminations and can originate (add) or terminate (drop) any of the tributary payload signals (eg. STS-1 or DS3) from the line signal passing through it.

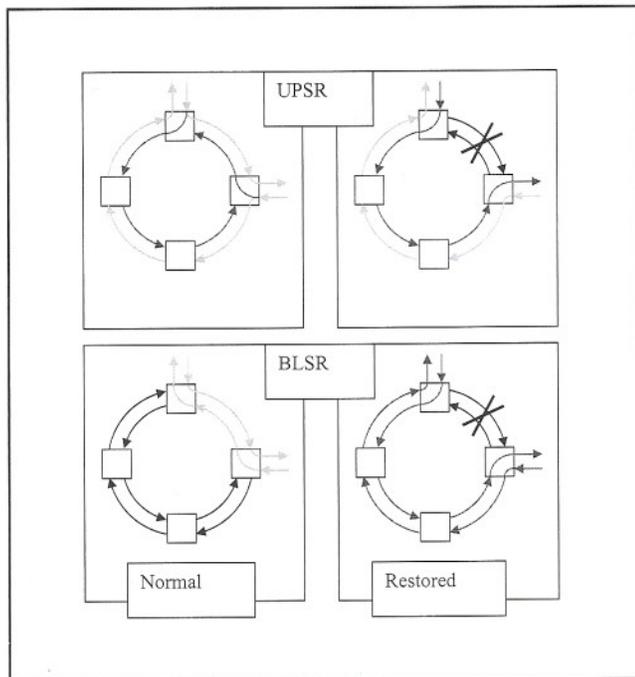


Figure 3: Operation of UPSR and BLSR self-healing rings (SHRs)

Because one or the other signal copy of each demand appears in every span of the UPSR, the UPSR system bandwidth must exceed the sum of all demands in the ring. In contrast, the protection bandwidth of the BLSR must only exceed largest sum of demands routed over any one span. The BLSR is thus more capacity efficient than the UPSR. However, the cost-effectiveness of both SHRs derives largely from the aggregation of a number of smaller demands (i.e., at the STS-1 level) to take advantage of available Gb/s SONET transmission technology (i.e., at the OC-n level). This is an economy of scale effect in the cost of bandwidth. A rule of thumb is that it costs about twice as much to obtain four times the capacity with modern fiber systems. A second form of efficiency is also achieved in the BLSR. This is the reuse of ring bandwidth in subsequent spans of the ring when several point-to-point demands can be served by different segments of the ring. All the demands served effectively share the single ring-wide protection channel of the BLSR rather than requiring duplication around the ring for each demand, as in the UPSR. On the other hand, the UPSR uses simpler recovery and operational mechanisms than the BLSR. As a result we tend to see UPSRs economically employed in access network applications and lower capacity inter-office metropolitan applications. BLSRs are used in higher capacity metropolitan or regional backbones.

Neither type of SHR has been very widely deployed in long haul transport applications. A historical note for the Canadian IEEE community: the patent for the BLSR was awarded to Tom Flanagan of Nortel for work done in the BNR Edmonton laboratories circa 1986/87.

Designing Networks of SHRs

SHRs use extremely simple routing principles. It is perhaps ironic, therefore, that the optimized design of networks with even a few rings is an astronomically complex problem. To appreciate this, consider just some of the variables to be simultaneously specified in a complete ring-network design:

- The number of rings to use,
- The topological layout of each ring on the network graph,
- The type of each ring: UPSR, BLSR or 1:1 DP,
- The size (OC-n bandwidth) of each ring,
- The location of active terminals and passive 'glass-through' sites on each ring (a SONET ring may pass through any number of sites but can have at most 16 active ADMs.),
- The subset of the demand flows to be routed through each ring,
- The locations at which each demand segment should transit from one ring to the next when more than one ring is traversed in the end to end path.

As a simple example, consider a case of 6 nodes and 8 spans in a network in which there are also only 6 distinct cyclical routes on which a ring could lie. If 4 ring technologies are available (say two OC-n rates of BLSR and UPSR) then it is worked out in [6] that there are 2^{512} distinct multi-ring network configurations possible. It is with good justification, therefore, that the practical design of multi-ring networks is being approached through heuristic strategies, although exact methods are being applied to certain sub-problems such as the optimal loading of an individual ring candidate within in a developing design.

One widely used ring network planning system is Nortel's SONET Network Planner™ and SONET Transition Planner™ [7]. These tools provide a graphical user interface through which planners enter and revise locations and types of SHR systems. Software automatically routes demands over the proposed ring set and reports the network total cost and the extent of any un-served demands. The planner iterates, applying a number of principles, and considerable human insight such as, for instance, visualizing the communities of interest in the demand patterns. The system is thus an analysis tool with the synthesis function coming from an experienced human in the feedback loop. There is a serious shortage, however, of planners who are experienced in developing designs using this method: There are far too few to meet the planning needs of the many new private and public SONET-based networks being deployed world-wide.

A next step in aiding the network design process is being taken collaboratively by Nortel and TR Labs, with key inputs from Telus, MCI, and SaskTel members of the TR Labs consortium. TR Labs has developed an automated design synthesis program called RingBuilder™ [8]. In several studies since 1994, RingBuilder™ has demonstrated an increasing ability to design ring based networks, of up to 150 systems, which are highly cost effective. At this scale of network design, the differences between alternatives can be tens or hundreds of million in capital cost. But human insight and manual design development is extremely difficult in these larger designs. Figure 4 shows a screen display from a TR Labs tool called X-Ring™ that allows detailed visualization and inspection of a large RingBuilder™ network design.

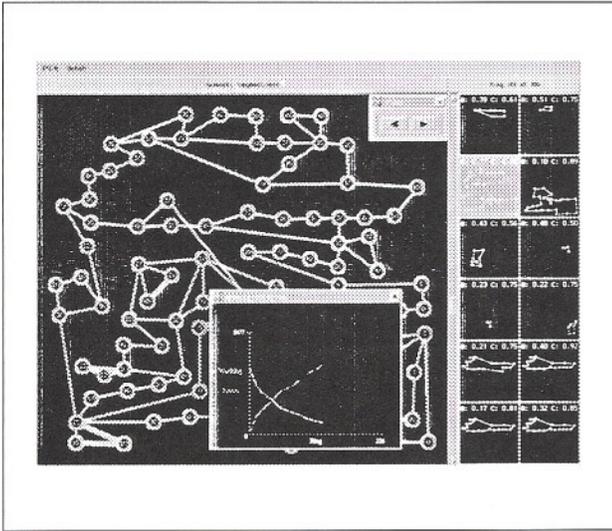


Figure 4: Screen capture from X-Ring™ design viewer tool for RingBuilder™

In smaller test cases where human designs can be compared to RingBuilder™ designs, RingBuilder's™ totally automated results are doing as well or better than time consuming manual designs. But the ideal overall capabilities will come when human insight and oversight is coupled with an automated synthesis system such as RingBuilder™. TRILabs and Nortel are now collaborating on a system employing these strategies. The combined system will exploit RingBuilder™ as an expert assistant to suggest one or several 'next moves' - or suggest a whole design - to the planner as he/she proceeds to develop a new design or do evolution planning of an existing network. In this way specific network circumstances and considerations of which the human is aware can be reflected in the design while retaining confidence that the overall design is near the theoretic minimum cost. The scarce and experienced human planners will thus be able to increase their throughput of design studies for customer networks. TRILabs is also collaborating with other sponsors and outside licensees of RingBuilder™ to develop an advanced graphical user interface for RingBuilder™ in stand-alone applications.

The Self-healing Mesh Network Alternative

"Mesh" restorable networks work on a more general rerouting principle than that seen in rings. In a mesh-restorable network, signals that traverse a failed span spread out as individuals or subgroups and follow many diverse paths through smaller amounts of spare capacity than is present in ring-based networks. Each unit of spare capacity in a mesh network is reusable in many different ways, depending on which failure occurs. In a ring, the spare bandwidth protects only spans on the same ring. The mesh architecture is primarily based on digital cross-connect systems (DCS) embedded in a mesh-like set of point-to-point transmission systems. For cost savings, ADMs can also be used in place of DCS at sites that have only 2 spans. The generalized rerouting in mesh restoration requires a more complex restoration process but the payback can be a reduction of 3 to 6 times relative to BLSRs in the total spare capacity needed for survivability. Mesh networks therefore tend to be the leading candidate for long haul survivable architectures where

network cost is more strongly correlated to the total bandwidth-distance product for transmission. Ring networks tend to be more cost-efficient in metro areas where total network cost is dominated by terminal costs, not distance-related transmission cost.

At TRILabs, we have been working towards the vision of distributed self-organizing control for restoration of mesh networks. Today, mesh-survivable networks are centrally controlled. In a centrally controlled system, a database image of the network is maintained from which restoration rerouting plans are continually pre-computed as the network changes, or they are computed on-demand when a failure arises. In either case the instructions for cross-connecting spares and rerouting working signals are downloaded from the central site to each DCS: the process is conceptually the same as manual restoration where the DCS nodes function as remote-controlled DSX patch panels. AT&T's FASTAR™ system was the first fully automated large-scale centralized mesh restoration system. It represents the state of the art in centralized restoration control and can restore 100 DS3's in about 5 minutes [9].

Distributed, autonomous reaction to the failure is, however, thought by many to be a technical necessity to achieve split-second restoration in a mesh-restorable network. First proposed in 1987, with patents issued in 1990 [10,11], several independent studies world-wide have now confirmed claims that the TRILabs SHN™ protocol can spontaneously form such multi-path re-routing plans in under 2 seconds. The SHN™ does not require centralized computation or a real-time database of the network. In effect the network itself -at the moment of failure- is the database that the SHN™ uses. The SHN is a rapidly-acting self-organizing process embedded within the network. Each node operates in isolation, with no global knowledge of the network, and no stored pre-plans. It follows simple rules for the origination and reaction to signalling "statelets" embedded on the links surrounding it. All nodes are thus indirectly coupled in a highly parallel way and influence each other. As a system they converge rapidly to a reconfigured state where the network spare links are recruited into the required pattern of replacement paths for the given failure. Interactions occur asynchronously in parallel amongst nodes at the physical signal level, without inter-processor message handling stacks, and with only the delays of physical propagation. Although no SHN™ node knows of the actions of other nodes, the independent decisions of each node collectively constitute efficient re-routing plans on the network as a whole.

Figure 5 shows a panel of illustrative test cases for the SHN™. Each tile shows the result of the self-organizing assembly of spare links into efficient restoration path-sets for a different failure. These are test case results obtained from the TRILabs Self-healing Network emulator on a small test network where the complete restoration path-set can be easily visualized. Real networks will not always require restoration path-sets in patterns as complex as these, but there may be many more paths over each distinct route in the pattern. The point in this particular test network was to validate the mechanism against theoretical efficiency limits in a richly connected test case. All the path-sets shown are formed in well under 2 seconds with conservative assumptions about DCS speeds and inter-nodal propagation delays. Figure 5 conveys the extent to which each spare link can be re-used differently, depending on the failure. This is the key idea and source of the high capacity efficiency of a mesh restorable network. In contrast, in a ring or 1:1 network, each spare link is dedicated to covering only a subset of the possible failures.

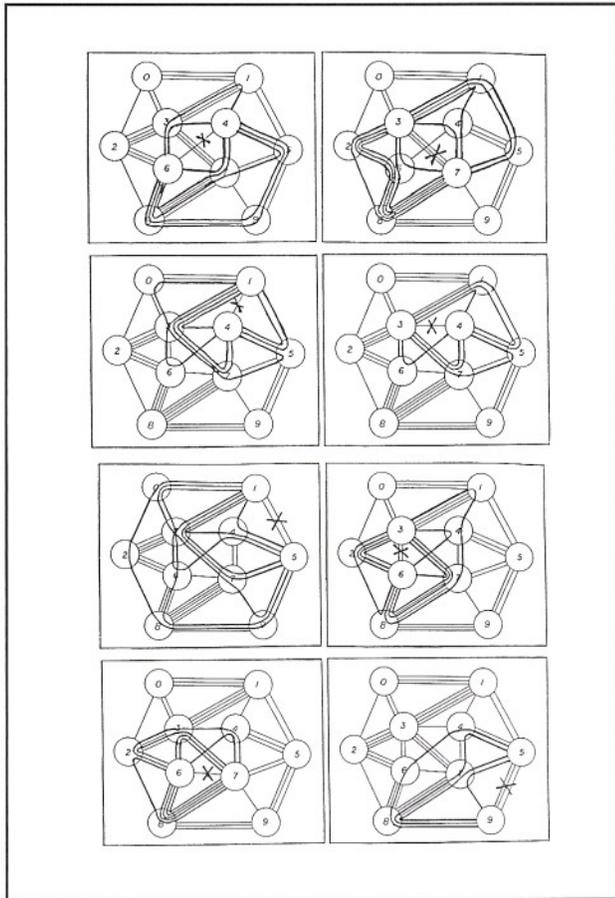


Figure 5: Examples of real-time mesh restoration path-sets self organized by the SHN™ protocol

At present, the SHN™ restoration paths are formed between the end-nodes of the span failure, as illustrated in Figure 5. While this allows network redundancy (total spare to working capacity ratio) to be brought down to 60% to 80% for full survivability, our current research is developing an equivalent process that will collectively organize end-to-end rerouting for each signal affected by the cut. This is called path restoration. At the time of writing, a path-level self-organizing restoration process is undergoing patent protection. With a fully developed path restoration protocol the prospect is of networks that are fully survivable, in less than 2 seconds, with as little as 20% to 30% redundancy [12].

In deployment, a distributed restoration systems serves only as a real-time assistant to centralized administrative systems. It does not replace them. "After-action" reports from each node involved in a restoration event give a central site the overall picture of the failure, and the network reaction. Central control can then take over, either to ratify or to alter the restoration path-set through its normal means of remote control of the DCS nodes. Other details about the engineering of distributed restoration are addressed in [13].

Like the BLSR, the SHN™ (and its extensions to path-restoration) are also Canadian inventions [10, 11]. As evidence for the practical significance and value of this technology, MCI Telecommunications Corp. recently completed a \$5.5 million licensing and sponsorship agreement to acquire non-exclusive rights to TRILabs technology and know-how in this area [14].

Design of Mesh- Survivable Networks

While the re-routing mechanism for mesh restoration is more complex than that of rings, the corresponding network design problem is actually easier to formulate and solve exactly. The main problem is to specify the spare capacity quantities for all spans so that the total capacity is minimized while for every span, taken one at a time as a failure span, there is a suitable number of simultaneously feasible replacement paths through the surviving spares of the network. For span restoration, the placement of spares must be sufficient to support the required replacement paths between the nodes adjacent to the failed span, i.e., recovery is by a rerouting around the break directly. The problem for span restoration was first solved exactly by Herzberg and Bye in 1994 using linear programming methods [15]. For 'path restoration', exact solutions to the spare capacity optimization problem and related aspects of the joint planning of working and spare capacity were obtained in 1996 [12]. However, the exact solutions to both these problems take enough computation time that research is continuing on heuristics for efficient but approximate mesh network design studies. For instance, a fast heuristic for the mesh-sparing problem will be a key step towards enabling large scale searches for new span addition strategies aimed at topology growth planning in rapidly-growing fiber networks. In Canada this work is primarily based at TRILabs Edmonton, and at INRS - Telecommunications and at Ecole Polytechnique in Montreal.

Summary, Long Term Vision, and Continuing Research

Automated restoration mechanisms, and network design techniques that incorporate survivability, have become an essential adjunct to the deployment of large-scale fiber optic transport networks. Self-healing ring technology is filling the need economically today in metropolitan network applications. With the advent of WDM it is expected that ring based technology will continue to lower in cost and that wavelength-switching DCS systems will also emerge to support the mesh networking architecture. Due to their much greater capacity-efficiency, mesh based networks tend to be more economic in long haul networks. Centrally controlled mesh restoration systems are operational today but do not achieve the split-second restoration times needed to protect users from significant failure effects. Research on self-organizing real time mechanisms for mesh restoration has matured and recently been licensed to industry, where it is under further development. At about the turn of the century we may see the first operational real time Self-healing mesh network deployment. In any case the size and growth rate of the SONET equipment market -whether deployed in ring or mesh configurations- is so significant that TRILabs has made research related to the planning and design of such networks a strategic priority for our research program.

Looking further out, the flexibility, autonomy and robustness of a self-organizing mesh restoration process seems to offer a road ahead with exciting future spin offs. The same mechanism that self-organizes path-sets for restoration can be used in a traffic-adaptive transport network that manages the logical size of inter-switch trunk groups in a time-varying way [16]. This goes beyond, but is complementary to, today's dynamic call routing techniques. The ultimate vision is of transport networks that react organically, as a whole, self-organizing their resources to accommodate failures, unforeseen traffic shifts, mass user mobility effects, and integrating new facilities into its operation when made available. These networks will be self-healing and self-configuring and may also be self-testing, self-auditing, and self-planning. The elegance of their internal operation will be more or less invisible to the public. Indeed, such invisibility is a measure of success for a successful transport network technology.

To probe further: Ongoing research is even more vibrant than when this topic first 'took off' in the mid '80's. A few of the important questions we are working on today are:

- Improved theory and algorithms for ring network design and evolution
- ATM network restoration strategies and capacity planning.
- STM / ATM hybrid network design and restoration strategies
- Optimized design of Ring - Mesh integrated transport networks,
- Optimal topology growth planning for ring and mesh based networks,
- Self-organizing traffic adaptive networks,
- Obtaining ring-like restoration speeds in mesh-based networks.

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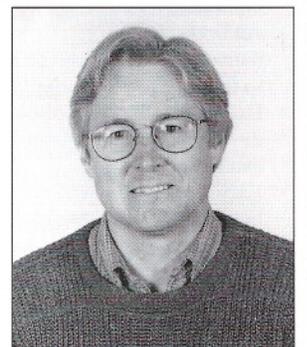
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Glossary of Terms

- ADM: Add-Drop Multiplexer
- APS: Automatic Protection Switching
- ATM: Asynchronous Transport Mode: A set of standards for statistical multiplexing and transport of all integrated broadband services based on fast packet switching of fixed size cells of payload information
- BLSR: Bi-directional Line-Switched Ring (also called the 'shared protection' ring)
- DCS: Digital Cross-connect System
- DS-3: Third level digital multiplex signal in the pre-SONET multiplex hierarchy. Contains 672 voice channel equivalents.
- DSX: Digital Carrier Cross-connect patch-panel
- INRS: Institut National de la Recherche Scientifique
- Linear programming: a mathematical technique used in operations research for optimization where the objective function is a linear function of the multiple variables to be specified
- OC-n: Optical carrier signal containing n STS-1 tributaries, or the equivalent
- SHNTM: The Self-healing Network protocol
- SONET: Synchronous Optical Network. A set of standards for multiplexing and transport of a range of payload types in a manner that is optimized for fiber optic transmission in -OC-n multiples of the STS-1 rate, up to over 40 Gb/s -CCSN7: The signalling and control network used between switches for call setup, tear-down and network control
- STS-1: The basic 51 MB/s building block unit for SONET multiplexing. May contain a variety of payload types through pre-defined multiplexing structures
- TRILabs: Telecommunication Research Laboratories <http://www.trlabs.ca>
- UPSR: Uni-directional Path-Switched Ring
- WDM: Wavelength division multiplexing

About the author

Wayne Grover obtained his B.Eng from Carleton University, an M.Sc. from the University of Essex, and Ph.D. from the University of Alberta, all in Electrical Engineering. He had 10 years experience as scientific staff and management at BNR on digital networks, fiber optics, switching systems, digital radio and other areas before joining TRILabs as its founding Technical VP in 1986. He now functions as Chief Scientist - Network



Systems, at TRILabs and as Professor, Electrical and Computer Engineering, at the University of Alberta. He has had patents issued on 17 topics to date, over half of which have found use in industry and in 1996 he received the TRILabs Technology Commercialization Award for the licensing of restoration-related technologies to industry. He is also the recipient of the 1996/97 McCalla Research Professorship in Engineering and completed a recent term as an Associate Editor for IEEE Transactions on Circuits and Systems. He is a P.Eng in the Province of Alberta and Senior Member of the IEEE.



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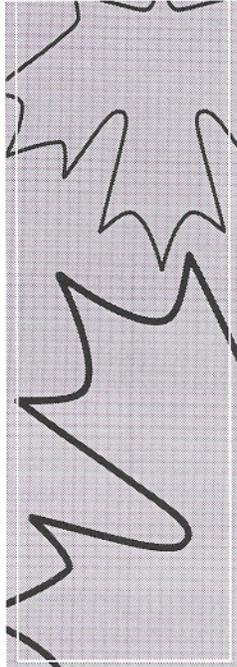
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Unveiling of the EIC plaque at the Confederation Bridge

The Engineering Institute of Canada (EIC) unveiled a plaque paying tribute to Canadian engineering during the official opening ceremonies for the Confederation Bridge on Saturday, 31 May 1997 near the PEI toll booth area.



In the photograph are members of the EIC who participated in the unveiling ceremony: (from left to right) J. Seychuk (President of EIC), V. Anderson (DELCAN), B. Burwash (GOLDERS), B. Montgomery (GOLDERS), B. Henderson (DELCAN) and M. Bozozuk (Executive Director of EIC).



A view on the Confederation Bridge



A view of the Confederation Bridge

IEEE Canada News

At the recent (24-25 May 1997) meeting of IEEE, Region 7 Executive in St. Johns, Newfoundland, awards were handed out to the following members:

Abdel Sebak (Western Council Chair),
Pierre Lesage (St. Maurice Section Chair),
Haran Karmaker,
Vijay Bhargava.



In the picture above are (from left to right):

Linda Weaver (Regional Director), Abdel Sebak (Western Council Chair), Pierre Lesage (St Maurice Section Chair), Haran Karmaker, Ray Findlay (Past Regional Director), Vijay Bhargava and Charles Alexander (President of IEEE).



In the picture above are (from left to right):

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