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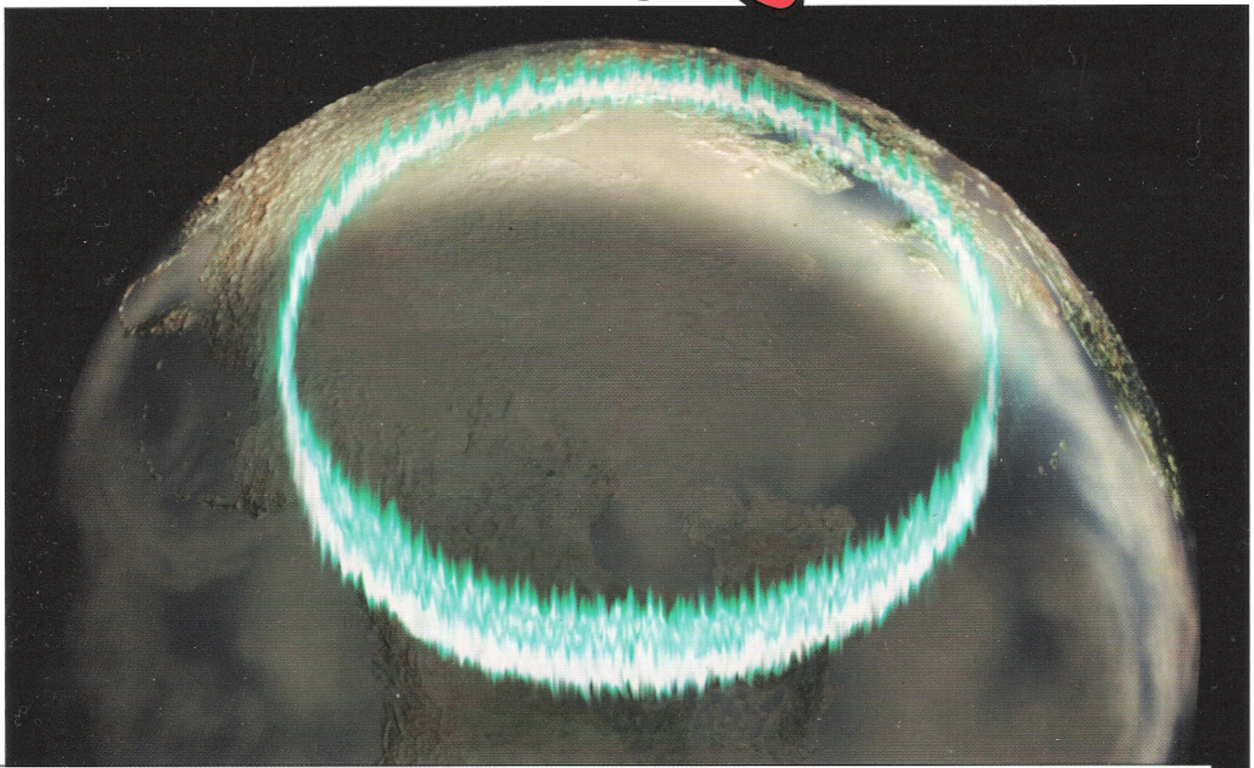

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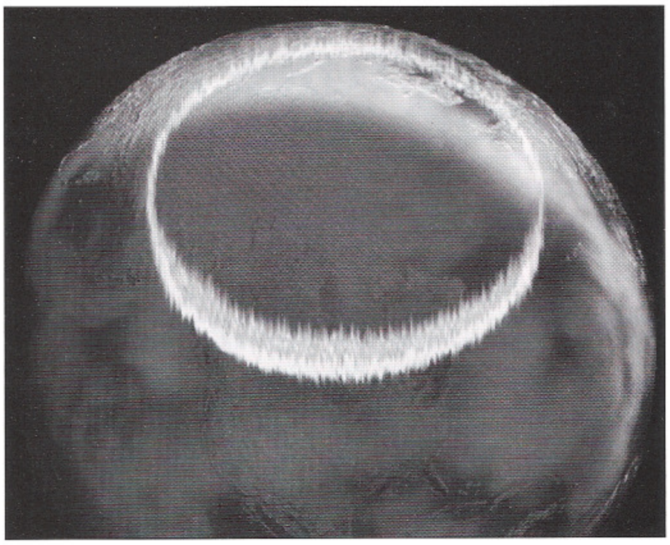
Auroral electrojet currents flow in a la rge oval in the ionosphere over the north magnetic pole. The Auroral Oval is popularly referred to as the Northern Lights by residents in the northern hemisphere.



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DIRECTOR'S REPORT/*RAPPORT DU DIRECTEUR*

Linda Weaver

Focusing on the Member

Just like most business of the 1990's, the IEEE is going through a process of change and growth. Over the last few years, this process has been both invigorating and frustrating - for IEEE members, those volunteers who act in the organization, and for IEEE staff. A major part of this process has been a refocusing on learning the real needs of the members and finding ways to improve IEEE services in areas that the members feel are important. We have all "seen" some part of this growth - either in the frustration with the transition to a new information system or in improvements in the services that we receive.

One of the initiatives undertaken by the IEEE corporate office is to conduct member surveys on an ongoing basis. The First Quarter Member Opinion Survey polled members and volunteers on their perceptions of quality, level of awareness, and satisfaction with the IEEE's products, services and processes. The survey was designed to provide a baseline measure of performance and will be used for assessment, continuous quality improvement, and to provide satisfaction measures to IEEE staff.

Overall, both members and volunteers reported high satisfaction levels with 94% indicating a high level of satisfaction with their IEEE membership. Areas registering the most positive results were: IEEE Spectrum; periodicals (transactions, magazines and journals); Standards publications and books; IEEE conferences and conference proceedings; and IEEE Press books. Communications, career guidance for students, promotion of the career interests of members and provision of career education information were areas where satisfaction levels were lower.

A complete copy of the First Quarter Member Opinion Survey and the survey results can be obtained by contacting the Strategic Planning and Institutional Research Office of IEEE at 1-908-562-3987/3988 or 3978. These documents are also available on the web at "htpp://www.ieee.org/opinion". Please ask for a copy and give your opinions - the IEEE is interested in them. Or feel free to contact me at l.weaver@ieee.ca. or by phone or fax at (902)434-2484.

Place aux membres,

Comme la plupart des entreprises des années 1990, IEEE subit un processus de changement et de croissance. Durant les dernières années, ce processus a été vivifiant, aussi bien que frustrant pour les membres, ces bénévoles qui ont fait converger leurs efforts à connaître les besoins réels des membres et à trouver des moyens d'amélioration des services IEEE, dans les domaines jugés importants par les membres. Nous avons tous vécu une partie de cette croissance, soit par une frustration pendant la transition à un nouveau système d'informations ou l'amélioration des services que nous recevons.

Une des initiatives du siège social de IEEE consiste à faire régulièrement des sondages auprès de ses membres. Le sondage d'opinion, tenu au premier trimestre auprès des membres et volontaires concernait leur perception de la qualité, leur connaissance et degré de satisfaction des produits de IEEE, ainsi que des services et des procédés. Ce sondage avait pour objectif d'obtenir une mesure de base sur la performance , l'évaluation, l'amélioration continue de la qualité et la satisfaction des employés.

Somme toute, les membres et volontaires indiquaient un niveau de satisfaction élevé, aussi 94% étaient satisfaits de leur adhésion à IEEE. Les points les plus positifs étaient: "Spectrum", les périodiques, (transactions, magazines et revues), les publications et livres sur les normes, les conférences IEEE ainsi que leurs recueils de publications, les éditions IEEE. Les points suscitant un bas niveau de satisfaction étaient les communications, les conseils aux étudiants sur leur choix de carrière, la promotion des intérêts de cheminement de carrière des membres, ainsi que l'information sur l'éducation continue.

Une copie complète du sondage incluant les résultats (premier trimestre) peut être obtenue
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Demandez une copie du sondage et donner votre opinion. C'est important pour IEEE. Vous pouvez aussi me contacter par e-mail: l.weaver@ieee.ca, par téléphone ou télécopieur (902)434-2484.

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A Vision of the Access Network of the Next Century

by Rolando Oliver, Bell Canada.

This paper presents a vision of what the telephone access network could look like in the first ten years of the next century.

The current structure of the telephone network is based on historical optimal sizes of switches and, most importantly, the loss characteristics of the copper loop. The advent of fiber and optical cross connects will have a significant impact by changing the number, size, and composition of the existing central offices.

Building the new access is a tough project since the number of options are numerous. First the building blocks of such a network are described. It also puts in context the possible role of wireless for broadband access.

The possible structure of the future network will have two key components: the infrastructure and the opto-electronic systems. Since the infrastructure is the most expensive part of the network, it should be planned with the future vision in mind to insure the coexistence of different generations of access systems.

On présente la structure du futur réseau d'accès. La structure actuelle des réseaux se base sur les capacités historiques des commutateurs, et surtout sur les carctéristiques électriques du circuit métallique. L'arrivée de la fibre et les brasseurs optiques aura un impact significatif en changeant le nombre, la taille, la composition, et la vocation des bureaux centraux actuels.

Dans le futur des télécommunications, la modernisation du réseau d'accès sera un projet complexe.

Malgré le nombre croissant d'options disponibles, le coût demeure élevé. C'est pourquoi, chaque firme recherche le cheminement optimal, qui lui donnera un réseau concurrentiel et différencié et qui lui assurera sa survie dans le siècle à venir.

L'accès aura deux composantes de base: l'infrastructure et les systèmes optiques-électroniques. L'article insiste sur le fait que l'infrastructure, étant l'élement le plus coûteux du réseau, requière que la topologie des conduits, câbles, et points de fléxibilité soient planifiés avec la vision du réseau futur en tête. Dans ce cas l'infrastructure assurera la coexistence des différentes générations de systèmes d'accès à venir.

Introduction

Probably the most challenging task that telephone companies face at the end of this century is the re-build of their access networks. Costs will be high. Even more, it will be difficult to recognize the precise optimal timing of the required investments, as decisions will be taken in the middle of a turmoil of competitive action, regulatory intervention, quick and uneven technological development, and market uncertainty. The complexity of the problem is compounded by the fact that the market will not develop itself if an infrastructure is not made available beforehand. There will be at best many sub-optimal implementations. Careful planning will be required to cope as much as possible with this challenge.

A journey always starts with a good reason to depart, a destination, and a route to follow. As telephone companies initiate their voyage towards the access network of the next century, they need to understand why they have to move at all, to have a clear vision as to how they want their networks to look like, and to be aware of at least some of the intermediate steps that they would possibly take to implement it.

We will explain our current vision of our network ten years from now. The steps to get there will be part of subsequent work. As a start, we will explain the reasons why we have to undertake such a perilous march.

Requirements of the Access Network by Year 2005

There is a strong consensus in our industry, that the access network as we have been building for over a hundred years will not sustain our operations in the near future. This network lacks the attributes that users will expect and will obtain from new entrants to the local telecommunications business. These attributes are continuously evolving as technology becomes available. We know that customers will expect to obtain from a communications network at least similar capabilities as they can obtain today from local information systems (LAN, (Local Area Network) PC, Entertainment System, etc.). A partial list of these attributes is:

-CAPACITY. Both small businesses and consumers will require bi-directional transmission capacity in excess of what is possible today for Home Working and entertainment applications. This means capacity in the order of at least 52 Mb/s per household. Even if capacity sharing is envisaged, it is not difficult to imagine the large capacity that will have to be accommodated.

-RELIABILITY. The network will have to prove extremely reliable. It will have to be able to absorb failures caused not only by its own components, but also outages originated by exogenous systems. This means that it should be robust in the case of cuts and power outages.

-SERVICEABILITY. The future access will have to be easy to repair in case of failure, easy to up-grade, easy to provision, easy to test. Required human intervention should be minimal.

- CONNECTIVITY. It will have to be easy to connect to. This means that, once installed, it should be able to handle many transmission systems and applications without specific interface devices either at customer premises or central locations. This means it will have to be protocol independent.

-VERSATILITY. It will have to be able to carry all applications that its owners will want. This includes applications for business and consumers, narrowband and broadband, fixed and mobile, voice and data.

-EVOLVABILITY. It will have to sustain the evolution of market conditions and technology without major re-construction. The key thing is that in an access wired network more than 50% of the cost is in the construction of the civil engineering infrastructure. Therefore, it is not so important that the system is the ultimate one or that it lasts for 30 years. More important is that the infrastructure has all the flexibility to handle all types of systems - HFC, (Hybrid Fiber-Coax) FTTC, (Fiber to the curb) DLCs, (Digital Loop Carrier) FTTH, (Fiber to the home) wireless, etc.

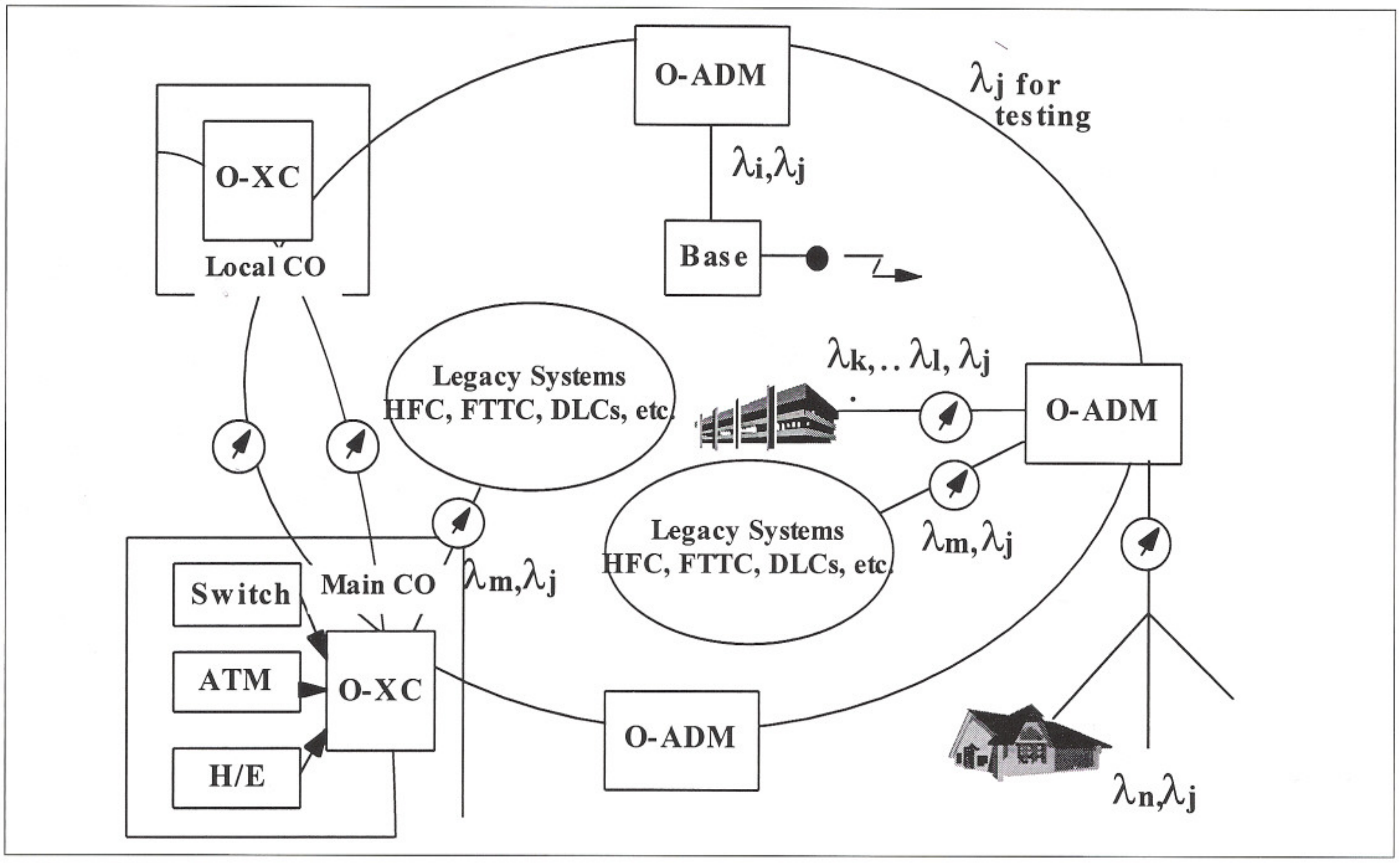

Figure 1: Access Vision using Optical Bandwidth Management.

PROBABLE TECHNOLOGICAL BUILDING BLOCKS

There seems to be a consensus in the industry that the backbone of the Access Network will be a mixture of fiber and wireless. Fiber is the only technology known today capable of providing the capacity that will be required for interactive multimedia applications. Wireless will be a strong support technology, as it will allow for quick and rapid coverage of users at a minimum risk. It will also be ideal for mobility applications. Some contend that wireless systems have the possibility of handling as much bandwidth as fiber. This will be virtually possible only in the cases where wireless architectures are based on very small cell design, and thus radio will be used only for the last hundreds or tens of meters. Base stations will still require a solid fiber interconnection system. Therefore unless major surprises appear, the fiber and wireless technologies will probably coexist and complement each other to provide the required versatility and evolvability.

Given the current pace of technological development, ten years is a long time. It is expected that both wired and wireless systems will quickly evolve. Fiber is expected to develop into a large capacity monster. Systems in the order of 10 Tb/s are assumed to be possible. This is 10 million megabits per second! Obviously, it will not be possible to manage the bandwidth in such a system with electronic chips. As well, to transmit all that information with a single laser would result in an extremely low energy per bit. Therefore, the systems will be made of different light beams operating in different ranges of the light spectrum that will be combined, routed, extracted, and switched in optical form. Thus a key requirement for this to become reality is the development of optical bandwidth management systems.

The possibilities of optical bandwidth management for the access are tremendous. As an analogy we can say that optical bandwidth management is to fiber systems what digital channel banks and cross-connects are to digital switches. By handling the bandwidth optically, access nodes will be simplified. Today, a SONET (Synchronous Optical Network) system in the access has to receive a signal from a fiber, convert it to an electrical bit stream, process it, and route it to the appropriate system. The information that is transmitted through fiber systems has to be converted to optics again. The optical access systems will not only be much simpler and cheaper, they will also require much less power and there will be a definite trend to passive systems.

The different technology pieces that are needed and are being developed are, amongst others: Optical ADMs (Add Drop Multiplexer) (a splitter can be considered a very simple ADM), Optical Cross Connects, tunable receivers (to be able to extract specific light carriers), Optical Amplifiers (to be able to restore the energy lost in splitters and switches), and narrow multi-wavelength lasers. All this technology is expected to become available within the next five years. It will be certainly mature by the year 2005.

We can expect to see wireless access systems for mobile bi-directional applications up to 1 Mb/s. Most of this technology will be applied for mobility purposes, especially outside of homes and in the office environment. The question will be how much capacity will technologists be able to squeeze out of the band in the 1.8 GHz range that is currently being made available. However, it could be expected that if wireless systems for the final user really take off, more bandwidth could be made available in the band under 10 GHz where most of the radio microwave systems are licensed today. Some of these systems could become obsolete because of the use of fiber. Certainly wireless has a lot of potential within office buildings and maybe homes. By using wireless techniques, the inside wiring could be eliminated. Office buildings will have their own micro-cells. Each home could be one micro-cell, potentially transmitting large capacities between a central controller or base station and different entertainment or work terminals disseminated in the customer premises.

Broadband wireless will also be used in places where it will be too expensive to re-build with fiber. However, the main thing about wireless for bi-directional broadband applications is that beyond Near Video on Demand, wireless encounters severe limitations. True video on demand, where a customer has full VCR capabilities, and home working applications at rates of 10Mb/s at significant take rates - probably beyond 20% - will be only possible through a wired or more precisely a fiber network. The only exception will be the inside wiring, where we can conceive the idea of a wireless broadband system. Because of this, telephone companies will not be able to compete against cable companies if they base their broadband capability only on wireless.

The Access Network of Year 2005

A vision of the access network using these concepts appears in Figure 1. It is obvious that the fiber based solution will not be the only alternative. It will be the preferred solution only if the market demand for work at home and true video on demand materializes. Wireless solutions (Satellite, Cellular Vision, etc.) have a not so rich service set as fiber, even if combined with a copper network.

ADSL (Asymmetric Digital Subscriber Loop), ISDN (Integrated Service Digital Networks) and other copper based technologies will not resist in the long run the competition against fiber systems. Furthermore, these technologies will rely on fiber to extend their reach.

Thus, the capacity requirement will be best addressed by a fiber network. A fiber network will also be the only alternative that will be fully versatile, which means that it will be capable of serving all applications. As we describe this network, it will become apparent how the key requirements of the access network listed at the beginning will be met.

CHARACTERISTICS OF THE ACCESS FIBER NETWORK

In order to have a network that is as reliable as possible, simplicity will be most important. This favors pure optical paths, and passive components as much as possible. Opto-electronic conversions will not be required and will have to be avoided. Flexibility and concentration points in the access will all be purely optical. Optical ADMs could in certain conditions operate even in cases of power failure as glass through devices. During black-outs only the maintenance routines will be impaired. This will have tremendous advantages. Local power could be used, reducing the need for power hubs and copper conductors.

One important source of operations costs today is the large number of termination points that are required in the Central Office (CO). By using wave length multiplexing and PON (Passive Optical Network) systems, high degrees of fiber sharing will be achieved. This will lead to significant operations savings.

Wave-length multiplexing will allow the transport of different applications over the same fiber. For example, Fiber-To-The-Home (FTTH) systems could use one wave length and PCS systems could ride on another. Optical Add-Drop Multiplexors (O-ADMs) will route the different wave lengths to the different devices. O-ADMs don't have to be very complex devices. Actually the simplest O-ADM system is a star splitter-combiner.

Using wave-length multiplexing has great advantages with respect to connectivity. In fact this technique is transparent to most protocols and thus can insure that almost all services run on the network as though they were running on their own fiber. This is very important as it is expected that the terminals evolve much quicker than the rest of the network. Today this requires a lot of dark fiber from the side of the telephone company.

Business applications will be able to share at least the feeder part of the fibers with residential applications. One single building could be fed with a reduced number of fibers if the different applications use different wave-lengths. Thus LAN (Local Area Network), voice, teleconferencing and other systems could run on their specific wave length. At the office building an optical ADM similar to the one used for the outside plant will be economical.

The layout of the network will be a hierarchical ring system. Feeder rings will be built straddling at least two central offices in most cases. Only the least dense parts will run on tree and branch systems or folded rings. This will be the case of the FTTH systems in their last kilometers. The rings will not be SONET but fully optical rings. SONET will slowly ease out as the main ring management standard, as it will be too inefficient to convert the signal from optical to electrical at every intermediary node. SONET, together with ATM (Asynchronous Transfer Mode) or other bandwidth management standards will be more and more relegated to the edges of the network. At this points the conversion will be required to access servers and terminal equipment.

Unobtrusive testing can be achieved by using a specific wave-length. Many testing techniques are being developed that allow to differentiate terminals attached to a shared fiber system. Techniques using etching at the remote fiber provide results analog to a transponder and do not require too many wave-lengths.

THE FUTURE OF THE CO

The current structure of the telephone network is based on historical optimal sizes of switches and, most importantly, on the length of copper loops. Actually the maximum loop length that is advisable in the case of 26 gauge copper is 3 Km. Thus the size and coverage of central offices in urban centres is on average below 100 thousand homes passed in an area of about 9 square Kilometers. Cable companies in the UK have demonstrated, that for a starting company that has access to fiber technology, central office sizes don't have to respect these limits. Indeed in the UK, cable companies pass areas from a single head end or central office about 4 times as large as central offices in Canadian urban centres.

Thus, it is expected that telephone companies will try to consolidate their switches. Therefore only certain offices will be equipped with all the required servicing gear. The large capacity of fiber systems will allow to back-haul traffic from several local COs. In most cases an Optical Cross Connect (O-XC) will be the only thing that will be located in the local CO. From this O-XC, the management and maintenance of the facilities could be handled, obviously through remote access. The smallest COs will not even require full cross connect capabilities but will be handled by O-ADMs.

POWER

Powering of the consumer phones could still remain an issue. However, the most favorable scenario would be that as consumers move to more advanced terminals (wireless and display phones), the need for CO power will be reduced.

WIRELESS

Wireless will be a good complement to this network. Wireless will be very attractive for mobility applications for narrowband and wideband. The tremendous number of microcells that will be required by PCS will benefit from being integrated to the fiber access network. Satellite and broadband wireless will definitely gain market share as they will be unbeatable for low take rates, scattered users, and broadcast type applications with limited interactivity.

Talking about simplicity, it is possible that inside wiring be eliminated in most cases by using wireless techniques. Each living unit could thus become a microcell. Indoors it will be possible to achieve extremely high frequency re-utilization factors. Several cells will be established within a single office building. Significant operations savings will thus be obtained.

THE ACCESS NETWORK WILL NOT BE HOMOGENEOUS

Finally, the access network will never be a very homogeneous network. It has never been so. At all times there have been different access technologies. Loaded and unloaded pairs; access points, Jump Wire Interfaces, and other types of boxes; Digital Loop Carriers, (DLCs) Remote Switch Concentrators, and Channel Banks; different types of cables; copper, and fiber. Furthermore, as we introduce new technology, the systems of tomorrow will be the legacy systems of the day after tomorrow, and there will always be a system better and cheaper than the one we just installed. So the legacy systems will always be present. However it will be possible to incorporate at least their feeder and interoffice part into the new scheme of things.

The Transition to the Network of the Next Century

Life is transition. Even the approach presented in this paper will be a transition to something else. Thus, given the time that it takes to build the access we will never be able to do it once for all. It will be quite important to have a network that evolves gracefully. This can be achieved by installing an infrastructure that is flexible enough.

Stentor uses guidelines for laying fiber in the urban areas that will carry them well into the future. Flexibility points will be planned so that as much as possible they will coincide with future O-ADM locations. Telephone companies will win if they can do the hardest thing in the most economical way. When putting an access network in place this means construction.

Most of the access systems contemplated for deployment in the short term will not be able to ride on this vision without modifying the optics. As fiber re-enforcement will be required, there will always be the possibility to install new optics in the existing system instead of building new facilities. Thus, a slow migration to the new wave-length multiplexed scheme for the legacy systems will be achieved. In those cases where this will not be economical, an uglier solution could be implemented. It consists of dedicated fibers to the legacy systems that will by-pass the O-XCs and O-ADMs.

CONCLUSION

To summarize as some form of conclusion, the access network of the future will have to address the following requirements. It will have to have a large bi-directional capacity. It will have to be reliable and easy to maintain. It will have to be able to connect to all the systems that the customer will want without requiring special interfaces. Finally, it will have to be capable of evolving.

Although wireless and wired architectures seem to be competing with each other, actually they will be complementary. A pure wireless access network will not have the possibility to address all the discounted applications. A company with a pure wireless network will always be a niche company. Wireless will be quite successful for mobility, inside wiring, and rural applications. The full service set can only be provided with fiber architectures.

The fiber access network of the next century will be a pure optical network for its most part. Fiber will be led directly to the customer location through a set of fiber rings and PONs connected through optical cross connects and optical add-drop multiplexors. Although an optical time division multiplexing scheme is under study, today wave length multiplexing seems more promising.

It will be impossible to build the final network from the start. The key thing will be to build initially the civil infrastructure, so that it can accommodate all the transitional systems that will come. The most successful company will be the one that learns to do this best.

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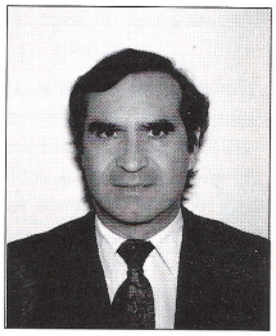
Glossary of terms used:

ADM	Add Drop Multiplexer
ADSL	Asymmetric Digital Subscriber Loop
ATM	Asynchronous Transfer Mode
CO	Central Office
DLC	Digital Loop Carrier
FTTH	Fiber to the Home
FTTC	Fiber to the Curb
HFC	Hybrid Fiber-Coax
H/E	Head End
ISDN	Integrated Services Digital Networks
LAN	Local Area Network
O-ADM	Optical Add Drop Multiplexer
O-XC	Optical Cross-Connect
PCS	Personal Communication Services
PON	Passive Optical Network
SONET	Synchronous Optical Network
WDM	Wavelength Division Multiplexing

About the author



Rolando Oliver obtained a Bachelor's and a Master's degree in Electrical Engineering from the Ecole Polytechnique de Montreal and a MBA from McGill University.
He joined Bell Canada in 1975, where he was initially involved with software systems development. Later he moved to network engineering activities where he was involved with the initial deployment of on-line banking. He also worked in the introduction of Packet Switching and Cellular radio in Canada. As well he has done substantial consulting work in Africa and S. America on behalf of Bell Canada International. He has also been responsible for Engineering Economics for Bell Quebec. As Director of the Access Network Engineering group of Stentor, he planned the modernization of the access network for the Canadian telephone companies.

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To be eligible for consideration, a landmark should be at least one of the following:

- a recognized engineering achievement in itself
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- illustrative of a major technological advance
- associated directly with the work of a renowned Canadian engineer or master builder
- an engineered, clearly defined, geo-cultural area of national importance - a cultural landscape formed (or transformed) by an engineering project.

To nominate a landmark, please send its name and a brief description - including its location, relevant dates, and names of engineers involved - and a short explanation of why it is an outstanding achievement. A photograph would be appreciated, as well as references to known written material.

Please send nomination to:

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A few words from the Managing Editor

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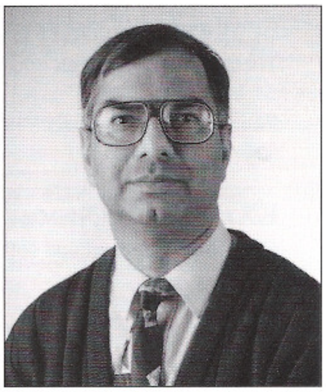

It is with pleasure that I present the Fall issue of the Review. I hope that some of the teething mistakes of the last issue have been ironed out (thanks to Eileen Dornier) and it should be plain sailing from now on.

Some changes in the editorial staff have taken place since the last issue, and Mr. J. Mariconda is no longer on the staff. I thank Brunilde Sanso and Paul Freedman for their on-going assistance. Since there is a vacancy for an Associate Editor, I will entertain applications from members wishing to serve as an Associate Editor; I would particularly encourage a member from Western Canada to apply. It is a voluntary position and the rewards are nil, but the experience is great.

In August 1996, I had the pleasure to attend the IEEE Power Engineering Society (PES) Chapters Congress'96 in Denver, Colorado. This presented an opportunity to meet face-to-face some of the hard-working volunteers functioning as PES Chapter Chairs from across Canada. If any of them are reading this, "Greetings!". IEEE is a growing institution, and sensitive to the needs of members and the changes taking place in the work environment. Some 40 recommendations were passed at the meeting to improve communications, and provide services on the internet.

In November 1996, the executive committee of IEEE Canada will be meeting at the Sections Congress'96 and I hope to report on this in the next issue of the Review.

At time of going to press, we had contacted Clearnet Communications in Toronto, and Newbridge Networks in Ottawa for future articles. As always, if you or your company have a Canadian success story to tell, please do get in touch with any of the editorial staff. We are always open to receiving classified advertisements for the Review, and for interesting news items.

Geomagnetically induced currents: - Causes, Effect, and Mitigation

by Tom Molinski - Manitoba-Hydro

Geomagnetically induced currents (GIC's) that can flow in power systems are caused by geomagnetic storms. Geomagnetic storms are originated by solar flares from the sun. The GIC's and the corresponding harmonic currents may cause detrimental effects to power systems such as equipment damage (eg. to transformers, generators, capacitor banks), improper relay operation, and even system shut down. This article summarizes various research efforts studying the cause, effect and mitigation of GIC's in power systems.

Les orages géo-magnétiques induisent des courants dans les réseaux électriques qui peuvent perturber leur fonctionement . Non seulement peuvent-ils endommager les équipements tels que transformateurs, génératrices et bancs de condensateurs, causer un déclenchement intempestif des relais de protection, mais aussi entrainer à la limite, une panne de réseau. Cet article résume les recherches en cours sur les causes des courants géo-magnétiques, leurs effets sur les réseaux et les moyens de mitigation envisagés.

Geomagnetically induced currents (GIC's) have been known to occur in power systems for more than 50 years, and were considered harmless. However, in the last 25 years it was realized that large GIC's can flow in power systems and become problematic. Utilities susceptible to GIC do not want to rely on luck, that the geomagnetic storm will not affect them, or if it does, the loading conditions at the time will allow enough margin to ride through it. This is precisely why utilities today are studying the cause, effect and mitigation of GIC's.

It is because of the excellent co-operation of the scientific community involved in this research that we have the understanding that we have today; and it is necessary to continue this co-operation for a more thorough understanding of these immensely complex phenomena. Several institutions (Canadian Electrical Association (CEA) in Canada, and Electrical Power Research Institute (EPRI) in USA, among many others) are actively involved in this research.

The effect of GIC's on electric utilities has been the topic of research and discussion for many years. However, it was the "great storm" of March 13, 1989, causing a blackout of the entire Hydro-Quebec system, that prompted utilities to realize that a better understanding of GIC's was necessary.

CAUSE OF GIC's

Geomagnetic storms are the root cause of GIC's, which flow into the grounded neutral points of power systems. The source of geomagnetic storms is the Sun, which is 150 million kilometres (93 million miles) away from the earth. Some understanding of the physics involved will assist the reader to appreciate how difficult it is to predict geomagnetic storms and why today's predictions are only about 15-30 percent accurate. This makes it difficult for utilities to take precautionary measures (usually costly) when many alerts are false alarms. It is noteworthy that five or six utilities do take some action on this basis, typically reducing line or transformer loadings.

More frequent and more intense geomagnetic storms occur when sun spots, which are dark areas on the surface of the sun, cause large ejections of charged particles (solar flares) or coronal mass ejections from the sun's outer atmosphere (corona). Charged particles are always flowing from the sun toward the earth, creating what is called the solar wind. During solar flares, the stream of charged particles that flows towards the earth significantly adds to the existing ambient solar wind. These charged particles are mostly made up of hydrogen ions, helium ions, and electrons.

Sun spot activity and thus geomagnetic storms are cyclic, with peaks (intensity and frequency of occurrence) transpiring about every 11 years. The eleven-year cycle is thought to relate to reversal of the main magnetic (dipole) field polarity of the sun. Should a geomagnetic storm occur then there will likely be anotherone 27 days later when the solar flare is again in line with the earth (the sun makes a complete rotation on its axis every 27 days). The last peak period of geomagnetic storm activity occurred between 1989 and 1992. We are presently in a solar minimum and anticipate another peak around the year 2000. It has been observed that there is a three-year time lag from the peak sun spot activity to the peak geomagnetic storm activity. The current thinking is that certain large activities on the sun are only visible by X-ray imaging and these activities are causing geomagnetic storm peaks after the telescopically visible sun spots disappear.

There are presently two theories that rationalize the occurrence of solar flares. The first and most widely accepted is that the sun's corona, made up of a hot shroud of gases, is usually enslaved by the sun's magnetic field. At times the field weakens allowing some of these gases to escape. The second theory is that the sun's magnetic field is disrupted and actually catapults these gases outward. Both these theories suggest changes that are occurring to the sun's magnetic fields, for which the reasons are unknown at this time.

The solar wind travels towards the earth at a speed of 500-1000 kilometres (300-600 miles) per second, taking 2-3 days to reach the earth's own magnetic field, called the magnetosphere. The solar wind also has a magnetic field associated with it. It is the orientation of the solar wind's magnetic field that determines whether or not a geomagnetic storm will occur. It should be noted that the orientation of the vertical component solar wind's magnetic field can be either northward or southward. The earth's magnetic field is oriented from south to north and tends to prevent the solar wind from entering the earth's magnetosphere. However, if the magnetic field of the solar wind is oriented from north to south (opposite to the earth's magnetic field) then the field lines of the solar wind and the magnetosphere "reconnect" [1], allowing the solar wind to enter the earth's magnetosphere, giving a possibility of a geomagnetic storm.

This effect may be compared with the attraction of magnets of opposite polarity while magnets of the same polarity repel each other.

The polarity of the magnetic field associated with the solar wind is a key missing link to predicting with certainty if the solar wind will cause a geomagnetic storm. To determine this and other information, NASA plans to launch a satellite in August, 1997, to monitor the solar wind. This satellite will travel in a halo orbit (elliptical formation) 1.6 million km (1 million miles) away from the earth towards the sun. This is the point where the gravitational forces from the sun balance those from the earth. This will provide information allowing the determination of about a 1-hour advance notice that a geomagnetic storm will occur with greatly improved accuracy. This is part of a program to eventually have 13 satellites [2] launched to monitor various aspects of space weather and the solar wind. Without the NASA satellite, making this prediction could be compared to trying to forecast the weather in Winnipeg when the closest weather station is in Vancouver. Recent information suggests that the solar wind's interaction with the earth's magnetic field is not random but chaotic. Random interactions, of course, can not be predicted; interactions for chaotic behaviour can be predicted for some duration into the future with only a few measurements (eg. from the NASA satellite). However, we are obviously still 5-10 years away from providing an accurate forecast as computer models that use the satellite information to predict geomagnetic storms have yet to be fully developed.

The physics of what happens once the solar wind enters the magnetosphere is very complex and beyond the scope of this article. The key point is that large currents (auroral electrojet currents) flow in a large oval in the ionosphere called the auroral oval. There is one oval over the north magnetic pole and a mirror image oval over the south magnetic pole. To those living in the northern hemisphere, the auroral oval can be seen as the Northern Lights. As the magnetic storm intensifies these auroral ovals expand in size and affect the lower latitudes, including the northern USA (Figure 1 and front cover). It is also important to note that the auroral oval remains "parked" with respect to the magnetic poles. As the earth rotates under the auroral oval, the rotation causes various areas of Asia, Europe, and North America to pass under it and be affected by the storm.

The brightness of the aurora is a good indicator of the strength of the geomagnetic storm. Geomagnetic storms can encompass tremendous power with estimates up to 109 megawatts of electrical power being associated with the electrojet currents which can be as high as 2 million amperes and extend 1,000 kilometres (600 miles) in width. This is comparable to the entire world's installed electrical capacity.

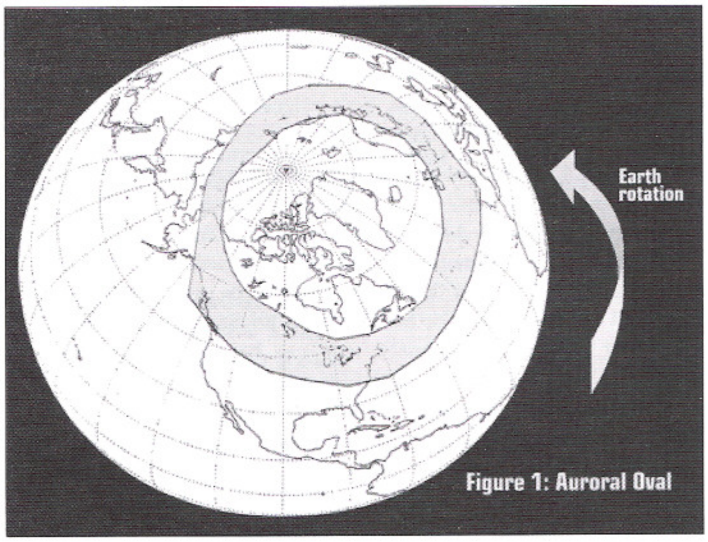

Figure 1: Auroral Oval

Figure 1: Auroral Oval

Currents associated with the electrojet system induce voltages in electrical transmission systems that drive the GIC to or from various system ground points. GIC is more pronounced for power systems located in northern latitudes, especially in areas of high earth resistivity. Although GIC tends to increase in areas of high earth resistivity, the reasoning is not as simple as once thought, as there are two opposite effects to consider. First, a high earth resistivity results in a larger electric field that can drive larger GIC's. Second, a high earth resistivity means that there is a large earthing resistance associated with the power system ground points, which tend to reduce GIC [3]. However, it turns out that, especially for long transmission lines, the larger earthing resistance is less important than the larger electric field, and the GIC's thus tend to increase.

Coastal areas are another region of high susceptibility to GIC. It has been proposed that the reason for this is due to charge accumulation at the coast. This is caused when GIC's flowing in the ocean enter the land and meet a higher resistance.

It is evident that power systems are becoming more vulnerable to GIC effects and that the levels of GIC occurring today in Canada and the United States are 2-3 times the levels occurring 15-20 years ago. This is due to power systems becoming more strongly connected by the use of long transmission lines which are more susceptible to larger induced voltages. A degrading effect is that larger transformers with lower reactance cores that are used today tend to saturate more easily from GIC's. Also, it should be noted that geomagnetic storms, on average, have been increasing in intensity for the past 125 years. The geomagnetic storm 11-year cycle is part of a longer-term cycle (80-250 years) of which the latest is predicted to peak sometime about 2010 (see Figure 2). Note that the shorter term 11-year cycle still can overpower the effect of the 80-250 year cycle.

It is now known that the horizontal electric field on the earth's surface is not always in an east-west direction and can be in any direction. This is important when doing computer simulations to test various electric field directions that produce the worst case scenario for GIC. However, statistically the electric field is predominantly in the east-west direction.

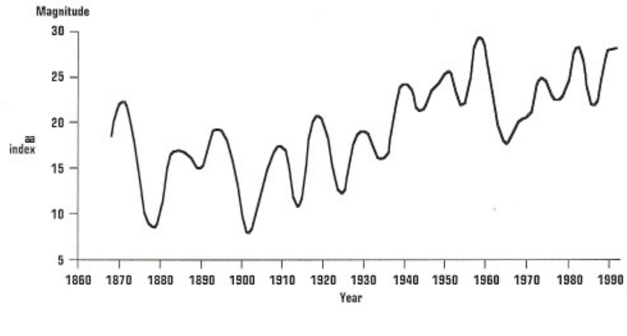

Figure 2: Relative increase in geomagnetic storm activity

An often-asked question by utilities in a particular geographic region is what is their susceptibility to geomagnetic storms that could cause large GIC's to flow in their power systems. As part of the work at the Geomagnetic Laboratory of the Geological Survey of Canada in Ottawa, and EPRI's SUNBURST Research Project into GIC's, a geomagnetic hazard

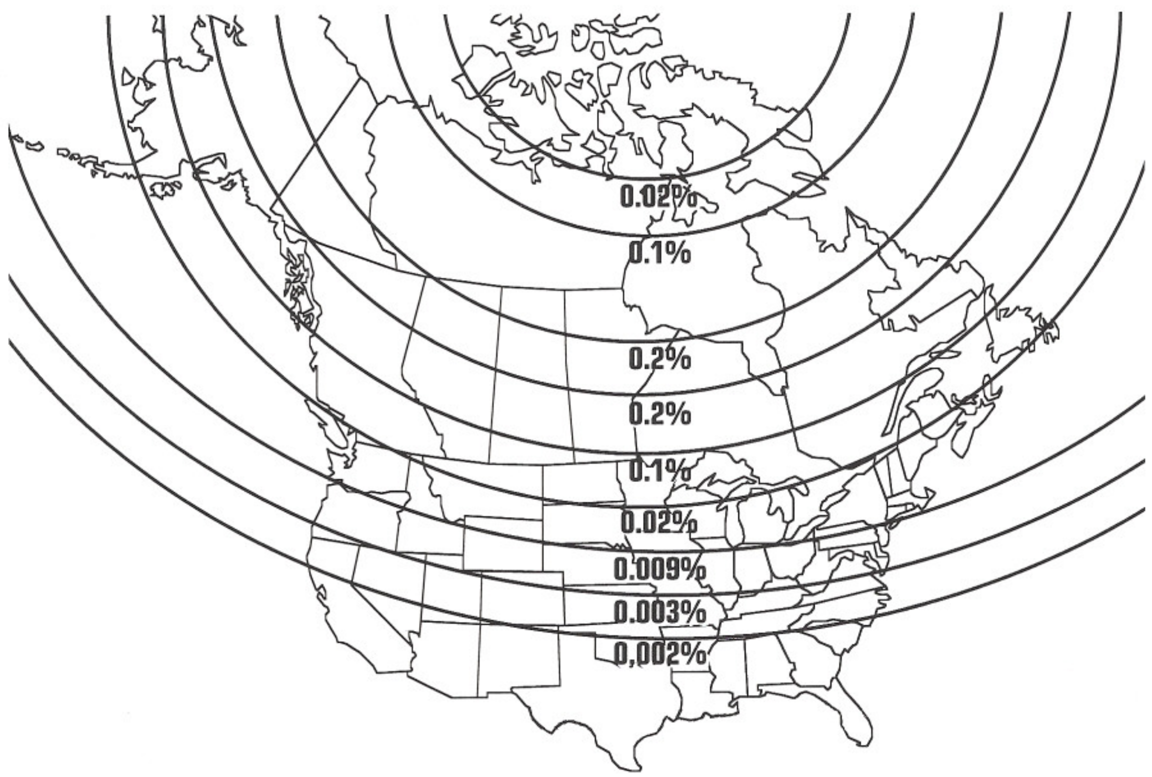

Figure 3: Geomagnetic hazard percentage of probability of occurrence

map of Canada and the USA was produced and is shown in Figure 3. This map indicates the percent probabilities of an occurrence of an hour in any given year where the dB/dt (variation in the earth's magnetic field) will exceed 300 nT/min., which represents a large storm. The significance of this is that the relative difference in these probabilities indicate that Canada is much more susceptible to GIC's than the United States. Note that there is no consideration given on this map for geological formation (high earth resistivity, oceans, etc.) or for system transmission line locations.

EFFECTS OF GIC'S

Several electric utilities are involved in a time-synchronized monitoring of GIC's in their power systems [4]. These systems have shown that GIC effects can be localized, or continent-wide. It has also been shown that the progression of a GIC event is more dependent on the magnitude of, and the expansion and contraction of the auroral oval than on the earth's rotation from west to east (which takes 3 hours for the North American Continent). The magnitude and size (expansion and contraction) can occur in minutes and can affect all of Canada and the USA simultaneously.

It is now known that a large variation in the magnetic field (B) does not necessarily mean that a large GIC will flow into the power system. Large GIC is caused by a large electric field (E) which is related but not directly proportional to the time derivative of the magnetic field (dB/dt). Therefore the present use of the K indices based on the quasi-logarithmic scale that ranges from 0-9, and determined by a 3-hour variation amplitudes of the horizontal magnetic field, is inadequate as a GIC severity index. Another severity index based on dB/dt plus other information is required and is being actively researched.

Geomagnetically induced currents (GIC's) are quasi dc in nature varying very slowly, typically less than 0.01 Hz. They can drive transformers into half-cycle saturation, resulting in harmonic currents in the power system. Harmonic currents are problematic for utilities in that they may cause resonances and associated over- voltages. It has also been shown that some transformers produce harmonic current spectrums unique to their construction type (eg. core or shell-type). These harmonic currents can overload capacitor banks, filters banks, and static var compensators. False or restrained relay operation may both occur. Relays that are not designed for harmonic restraint (eg. overcurrent relays for feeder protection) may false-operate. Other relays (eg. overcurrent relays on capacitor banks) may not be responsive to harmonics when they should be, and do not operate (restrained relay operation). Transformer differential protection that features second harmonic restraint will be reduced in sensitivity due to prolonged periods of second harmonic current that flows as long as the transformer is in half-cycle saturation.

The GIC flow in transformers can also cause stray flux heating intense enough to cause hot spots recorded up to 175 degrees Centigrade [5]. The susceptibility of heating is dependent on two factors. The first is that single-phase units are more susceptible than three-phase units. The second is that the three phase shell form construction type is more susceptible than three phase core form construction type. Severe GIC events can persist for periods of several hours. However, a large GIC with one polarity usually only lasts for a couple of minutes. These GIC can occur for several days in succession resulting in heating effects that are cumulative and damaging to the transformer's insulation. Over the course of exposure to several GIC events, it is surmised that the loss of life to the transformer could be significant. In fact, recent studies of base-loaded generator step- up transformer failures provide compelling evidence that GIC can result in long-term heating effects that reduce the life of these transformers by about 20 percent. It has been determined that low levels (10's of amperes) of GIC can place a transformer in deep saturation that could lead to failure.

As the GIC causes transformers to saturate, there is a substantial increase in MVAR consumption that if occurred system-wide, could lead to voltage collapse and system shut-down. This was a main reason why the Hydro-Quebec system collapsed on March 13, 1989 and must be taken seriously.

Significant generator rotor heating may occur in the rotor end rings of large generators due to the harmonics produced by GIC currents that drive generator step-up transformers into half-cycle saturation. In fact these levels can exceed the limits specified in the ANSI standard. The prime cause of the heating is the negative-sequence second harmonic and the positive-sequence fourth harmonic adding together on the rotor as third harmonic induced current in the rotor bars. These rotor heating currents increase approximately linearly with GIC in the neutral, and care must be taken to ensure adequate protection exists.
The good news is that distance-based impedance relays commonly used to protect transmission lines are insensitive to GIC effects. Also, there have been no proven effects degrading the performance of relay communications, and no significant threat to reliable current transformer performance was found.

MITIGATION

Power systems can be made more robust to the effects of GIC by utilizing transformer types (eg. three-phase core) and protective relay types that are not as adversely affected by GIC's.

System studies should be undertaken to determine the "worst case" GIC event. Because localized currents associated with the auroral electrojet are the most important driving sources, a uniform electric field occurring at the earth s surface is not a sufficient and satisfactory assumption when estimating GIC's in a network. The electrojet may be modelled by a line or sheet current, and to a good first approximation, the earth can be regarded as containing two layers: a perfect conductor beneath an insulating surface layer. This earth model permits the use of the mirror image concept making the computations easy and fast. A uniform field may be expressed as a potential gradient but it is extremely important to note that generally the electric field producing GIC's is not a potential field. It has been demonstrated that the incorrect use of potentials leads to false GIC values.

Further power system studies should be taken to determine the specific point of system voltage collapse due to the shortage of vars which are being consumed by the saturating transformers. These studies will provide the safety margin required for adequate var flow, necessary to avoid system voltage collapse during GIC events.

Although advanced warning that is nearly 100 percent accurate for predicting GIC events may be 5-10 years away, some effective action can still be taken when it is determined that a severe GIC event is underway. These actions would typically involve reducing "key" transformer loadings, allowing these transformers to operate at cooler temperatures to prepare for the onset of stray flux heating from GIC, and to have room for the added var loading. Other action would involve changing the equipment "set-points" (transformer taps, phase shifter angles, etc.) to free up more vars to provide larger margins to avoid the system voltage collapse effects. This action is costly and would have to be 100 percent certain that it is as necessary to avoid system voltage collapse or equipment damage. Additional action that can be taken involves insuring that series capacitors (for transmission lines) and neutral blocking devices (for transformer neutrals) are placed in service. These devices block the flow of GIC. However the GIC will probably be forced to take other paths that are not blocked and could cause problems elsewhere. Some utilities have installed series capacitors in transmission lines for the specific purpose to block GIC and not to increase the transmission line power transfer capability (surge impedance loading). Experiments with neutral blocking devices have proven to be successful in blocking GIC in transformer neutrals and safe for proper operation of the system during fault conditions.

CONCLUSION

More research work is required to develop and validate models that can use solar wind information (via satellite) to predict the ionosphere currents, and determine the horizontal electric field at the earth's surface that ultimately drives the flow of GIC in electric power systems, and is thus the key geophysical parameter. Other requirements are to study the impact of GIC on digital relays, investigate the accumulated loss of life of transformers from previous GIC events, develop simple techniques to measure GIC in transmission lines, and most importantly to establish appropriate operating guidelines.

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About the author

Tom Molinski holds B. Sc and M. Eng degrees in electrical engineering (1975 and 1985, respectively) from the University of Manitoba.

He was a member of the System Performance Department at Manitoba Hydro for twenty years, working mainly on the analysis of protective relaying systems. In 1995, he became the Supply-Side Enhancement Engineer with the same utility, responsible for overseeing supply-side efficiency improvements, as well as enquiries regarding non-utility generation proposals to Manitoba Hydro. He is a member of IEEE and has been Manitoba Hydro s representative on the EPRI SUNBURST research project regarding geomagnetically induced currents since 1990; and chairman of the SUNBURST utilities users group since 1994.

UBC'S FIRST NATIONS PROFESSIONAL SCIENCES ACCESS PROGRAM

University of British Columbia works to encourage students of aboriginal descent to pursue careers in forestry, agriculture and engineering

by Paul Freedman (Associate Editor)
Centre de recherche informatique de Montréal

The University of British Columbia has recently created a new program to encourage students of aboriginal descent to pursue careers in forestry, agriculture or engineering.

L'université de la Colombie-Britannique a dernièrement mis sur pied un nouveau programme destiné à promuvoir l'accès aux carrières en foresterie, agriculture et en génie pour des étudiants autochtones.

In the Winter 1995 (no. 21) issue of the IEEE Canadian Review, Jorge Campos described an initiative sponsored by Québec's Ordre des ingénieurs and Concordia University to help make university education a reality for First Nations students.

The University of British Columbia in Vancouver has also been active in this area.The First Nations House of Learning was established in 1987 to make UBC and its resources more accessible to BC's First People, and to improve the University's ability to meet the needs of First Nations. Through various processes of consultation with First Nations communities, the House of Learning aims to provide a quality post-secondary education determined by the philosophies and values of First Nations.

The First Nations House of Learning is located in the First Nations Longhouse which is the hub of First Nations activities on campus. The Longhouse serves as a "home away from home" where students can study and learn in surroundings which reflect their heritage and culture; and provides a place where First Nations people can share their knowledge and cultures with each other, with the University community and with the larger society. The traditional Salish-style Longhouse structure includes a Great Hall, an elder's lounge, child care facilities, a Sacred Circle, a student and staff lounge, kitchen, a library/resource centre and administrative offices.

The House of Learning promotes a number of initiatives designed specifically for First Nations students. These include: First Nations Health Careers, Native Indian Teacher Education Program, First Nations Law Studies and Ts"kel Graduate Studies. The House of Learning is committed to assisting First Nations students achieve their academic goals in all areas of post-secondary study.

The following text describing a new program to encourage students of aboriginal descent to pursue careers in forestry, agriculture or engineering, is taken from an article written by Shannon Horne and Treena Derrick, two students in that program, which appeared in the Winter 1995 issue of the UBC's alumni magazine, "The Chronicle".

First Nations Professional Sciences Access (FNPSA) is a five year program for students of aboriginal descent who wish to complete a bachelor's degree in forestry, agriculture or engineering. The goals are to instill in the students the skills necessary to fulfill university entrance requirements and provide a transition into each student's chosen faculty. Not only does the program provide academic upgrading, but it also acquaints each student with First Nations culture, history and ideals. Orignally, there were twenty-five students carefully selected to take part in the FNPSA. There are now sixteen, including one who has begun studies with the Faculty of Forestry. The coordinator of FNPSA, Cliff Grant, is dedicated to ensuring the success of his students.The program is funded by the B.C. Ministry of Skills, Training and Labour, B.C. Hydro, and various other organisations concerned with the advancement of aboriginal students.

The inaugural year of the UBC Access Program began with a four-week orientation in July and August, 1995. It familiarized students with their mentors and instructors, the UBC campus, and the city of Vancouver. The instructors assesed the educational background of each student, tested the students' knowledge, and prescribed personalized programs of study for the Access year.

Two months into the Access year, students were occupied with courses such as mathematics, chemistry, biology, physics, english, computer science, and First Nations studies; these will enable them to fulfill entrance requirements for the faculty of their choice. Many students are significantly challenged by their new academic lifestyle. In the midst of this challenge, students are still enjoying the opportunity that they have been given to enrich their minds and lives. They find many occasions to reflect on what this program has come to mean to them and their goals and aspirations. According to Gerald Nyce, a future forestry student, "I find this program to be a very challenging experience. All theses courses make for a very interesting life on campus, as well as in the Longhouse." Future chemical engineer, Treena Derrick, comments, "I like that I'm getting a full dose of academics, not only in a university setting, but also in a First Nations setting. It is great to be able to learn amongst some of the future leaders in the First Nations communities."

Six months later, students began their four year bachelor's degree programs, in September 1996. Students feel assured that the preparatory year will prepare them for the rigours they will face in the coming years and are confident that they will be capable of achieving their academic goals. In the minds of many students is the awareness that they are only at the beginning of a journey. In the words of Shannon Horne, future agriculturalist, "We, as students, are here not only to brighten the future for ourselves, but also for the whole Native community."