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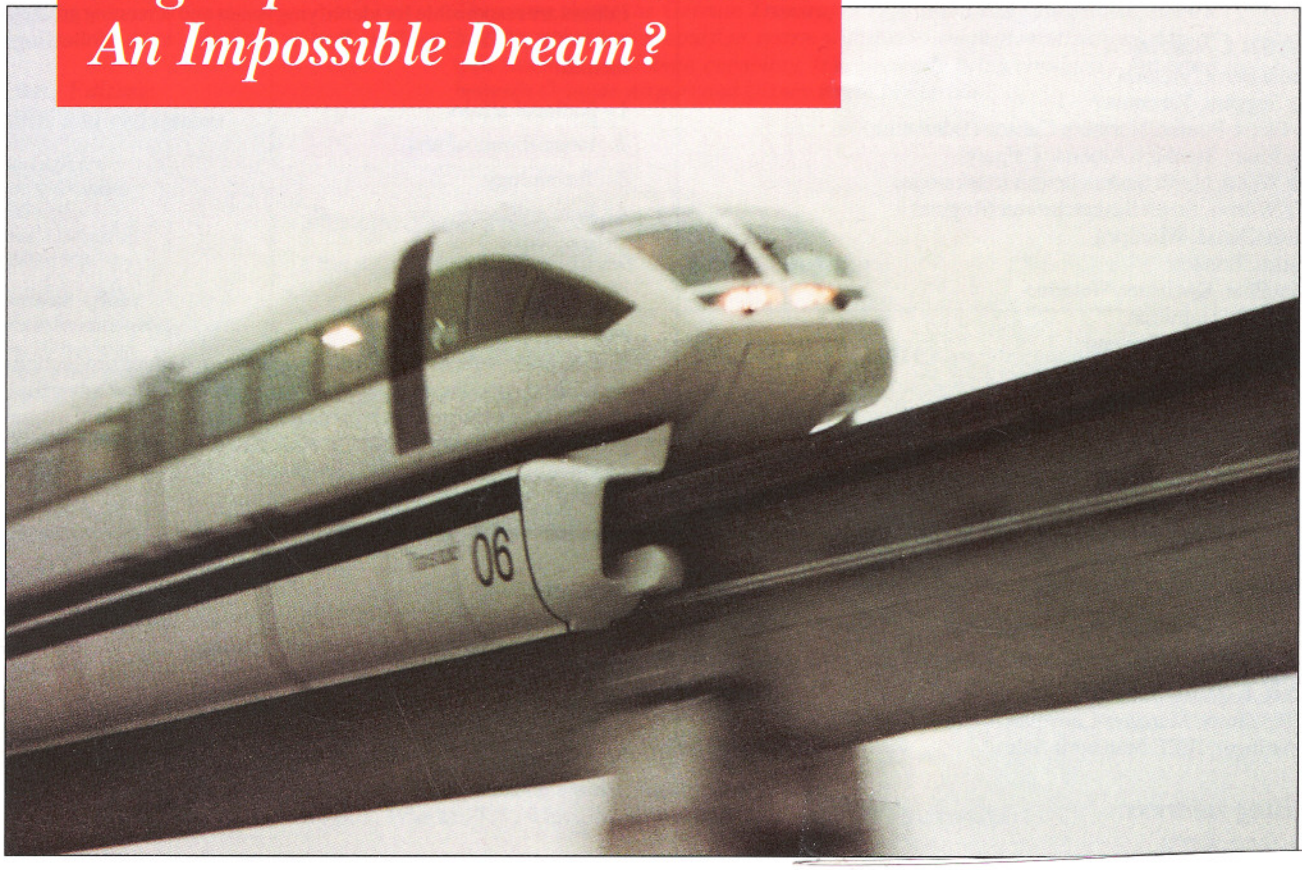
IEEE Canadian Review

High Speed Rail in Canada: An Impossible Dream?



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IEEE Canada

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IEEE Canadian Review General Information

The *IEEE Canadian Review* is issued quarterly - in March, June, September and December. The *IEEE Canadian Review's* principal objective is to project an **image** of the Canadian electrical, electronics, communications and computer engineering professions and their associated academic and business communities to :

(i) Canadian members of IEEE;

(ii) Canadian members of the profession and community who are non-members of IEEE;

(iii) the associated academic (i.e. universities, colleges, secondary schools, etc.), government and business communities in Canada.

In this context, the *IEEE Canadian Review* also serves as a forum to express views on issues of broad interest to its targeted audience. These issues, while not necessarily being technologically-oriented, are chosen on the basis of their anticipated impact on engineers or their profession and the augmented academic, business and industrial community, or even the community at large.

To ensure that the *IEEE Canadian Review* have the desired breadth of issues and that the required depth of analysis be achieved, five Associate Editors are responsible for identifying issues and screening articles submitted to the *IEEE Canadian Review* according to the following general themes:

1- National affairs

2- International affairs

3- Technology

4- Industry scene

5- Education

Advertising Policy
It is the policy of the *IEEE Canadian Review* to reduce production costs by inviting reputed organizations to place corporate-type advertising in the *Review*. For information regarding rates and mechanical requirements, please contact JEAN BONIN, *SOGERST*, 2020 University St., 14th floor, Montreal, Quebec H3A 2A5. Telephone: (514) 845-6141. Fax: (514) 845-1833

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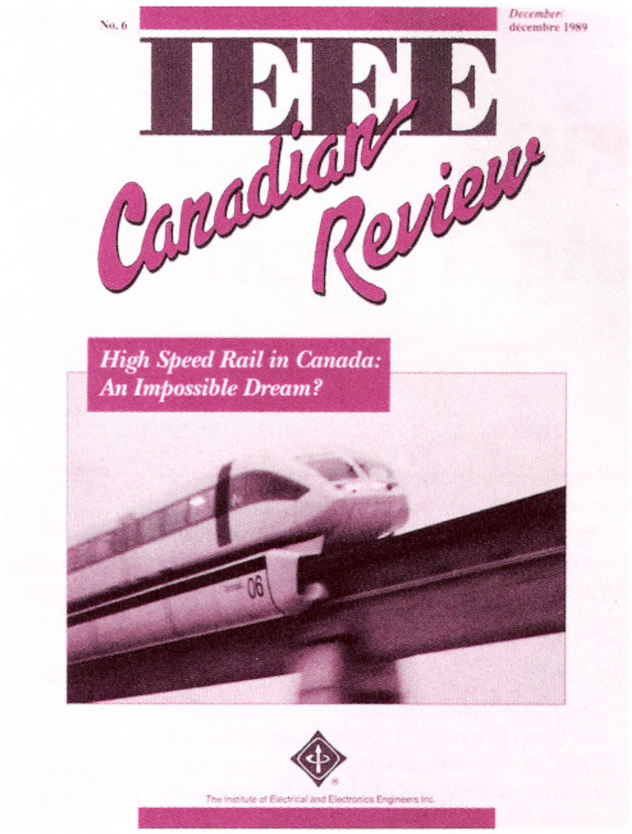
Information for Authors
Authors are invited to contribute to the *IEEE Canadian Review*. To this end, please contact the appropriate Associate Editor or IEEE Canada.

- The Managing Editor



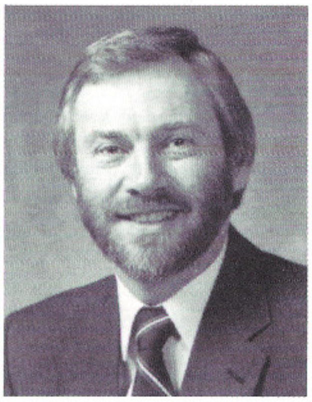
*The cover shows the German **Transrapid** high speed rail system. This electric linear synchronous propulsion system with electromagnetic (attraction) suspension has 400 - 450 km/h capability. It is presently being considered for a link between Orlando Airport and Disney World in Florida.*

CONTENTS / SOMMAIRE

IEEE Canadian Review is published quarterly by IEEE Canada. IEEE Canada is the Canadian Region of the Institute of Electrical and Electronics Engineers, Inc. **Address:** 7061 Yonge St. Thornhill Ont. L3T 2A6 Canada. Responsibility for the contents rests upon the authors and not upon the IEEE, or its members. **Telephone:** (416) 881-1930. **Annual Subscription Price:** Free of charge to all IEEE members in Canada. For IEEE members outside Canada: $16 per year. Price for non-members: $24 per year. **Advertising:** For information regarding rates and mechanical requirements, contact Jean Bonin, *SOGERST*, 2020 University St., 14th floor, Montréal, Québec H3A 2A5. Tel. (514) 845-6141.**Reprint Permissions:** Abstracting is permitted with credit to the source. Libraries are permitted to photocopy for private use of patrons. Instructors are permitted to photocopy isolated articles for non-commercial classroom use without fee. For other copying, reprint or republication, write to Manager of Canadian Member Services at IEEE Canada. Printed in Canada. Postage paid at Montréal Canada. **Postmaster:** Send address changes to *IEEE Canadian Review,* 7061 Yonge St., Thornhill, Ont. L3T 2A6 Canada.

Changing Times - Exciting Times!

by Dr. Robert T.H. Alden
Director, IEEE Canada



This is my last time to write in the *Canadian Review* as your Director. In reflecting on my two-year term, I am pleased to see lots of positive changes. These are due to the efforts of many IEEE members and, in particular, those who volunteer to serve on Section, Region, and related committees. Let me mention a few volunteers who have helped to break new ground and create a heightened sense of our identity as a unique Canadian partner and contributor within the IEEE family.

With Richard Marceau as Managing Editor, we have this new magazine that has already earned respect and is now on a sound financial footing. Some articles and some aspects have generated critical comments, some have stirred up violent passion (in engineers yet!). But you as members are reading and discussing these articles. That means it's working.

Thanks to Marty Bince for our successful membership drive (our first ever), to Harry Prevey for creating such a high quality program for our new direction in Canadian conferences - the recently held State of the Art Symposium, and to Gerald Karam and Mark Vigder for enthusiastic student activities including an electronic mail network linking 21 of our student branches with additions every month, it seems. Many, many thanks to the volunteer custodians of the IEEE conference surplus funds in Toronto and Montréal who support our activities (membership drive, office equipment, awards programs, etc). This past year, alone, IEEC Inc. contributed over $50 000 to McNaughton Centres and Scholarships.

And special acknowledgement to our superb staff, Pam Woodrow and Sandy Artinger, who with phone, fax, electronic mail (even Canada Post), span our huge country and provide the professional assistance to help you with IEEE matters, and run training sessions, tutorials, conferences and the Section, Chapter, and Branch meetings that typify Canadian IEEE activity. Don't forget to call them if you need help.

Turning to the activities of the IEEE Board of Directors and worldwide services and the Institute level, I can report a similar sense of change, and revitalization. Many good changes have been implemented or are being examined. The headquarters staff (about 500 people) is being reorganized to reflect the growth in membership and activities. New equipment is being installed to take advantage of electronic publishing technology. Offices are being developed outside North America to handle the increase in worldwide activity. The third "Sections Congress" and the annual IEEE awards ceremony will be held in Toronto next fall. The next May meeting of the Executive Committee will be held in Europe for the first time.

Use of electronic mail is being expanded. Plans are underway to link the IEEE Service Centre into the "internet", "bitnet", and other interconnected electronic mail networks that literally span our globe. I hope that many of our members (including you!) will take advantage of "our technology" and, thus, be able to cummunicate (worldwide) with each other and the IEEE in minutes or a few hours instead of weeks. These are exciting times. Our Institute is building on its reputation and its technical strength. It is moving ahead and becoming even better suited to serve you - the member. You have the opportunity to use these services, and to help shape the future. Come on board as a volunteer and join in the fun and satisfaction. I have enjoyed the last two years immensely. Thank you for my opportunity. Welcome Tony, it's your turn. Enjoy.

About the IEEE

The Institute of Electrical and Electronics Engineers, Inc. (IEEE), with headquarters in New York, is a transnational organization with 300,000 members in 137 countries. The world's largest engineering society, its objectives are technical, professional and societal.

The IEEE's technical objectives center on advancing the theory and practice of electrical, electronics, communications and computer engineering and computer science. To meet these objectives, it sponsors conferences and meetings, publishes a wide range of professional papers and provides educational programs. In addition, the Institute works to advance the professional standing of its members. It also has a mandate to enhance the quality of life for all people through the application of its technologies, and to promote a better understanding of the influence of these technologies on the public welfare.

Today, the IEEE is a leading authority in areas ranging from aerospace, computers and communications to biomedical technology, electric power and consumer electronics. When it began its second century in 1984, it rededicated itself to Innovation, Excellence, the Exchange of information and the quest for improved Education. In so doing, it underscores the initials IEEE.

IEEE Canada is the Canadian entity of this transnational organization, with approximately fifteen thousand members. The Canadian Region is divided into twenty Sections, each centered in a Canadian city, from Victoria, B.C., in the west, to St. John's, Newfoundland, in the east. For information on whom to contact in your area, the many IEEE products and services available, or how to join IEEE, write, phone, or fax our IEEE Canada office (page 2).

Your IEEE Needs You!

by Dr. Tony R. Eastham
Director-Elect, IEEE Canada

The end of a year is always a time for reflection and, perhaps, change. Thus it is with IEEE Canada. Bob Alden, after two years of energetic leadership as Director, is passing on the baton to yours truly. I will try not to drop it and to offer the same commitment and guidance that Bob and his predecessors (Gordon English, Wally Read, Fred Heath et many alia) have maintained over recent years. It's good to note that these past Directors are still around at many IEEE functions - I'm going to need their wise counsel in the months ahead.

While the IEEE Officers in New York and Piscataway are staffed by many professional persons, the Institute at the Regional, Council and Section levels is very much a volunteer organization. IEEE Canada (Region 7) has but one full-time and one part-time employee: Pam Woodrow, our Manager, is ably assisted by Sandy Artinger in our Regional Office in Thornhill. IEEE Canada relies on volunteer effort and could not be effective without the dedication of many engineers and technologists who give their time to their profession by participating on local executives, by organizing conferences and meetings, and by assisting in the administration of the many IEEE activities that are offered to our members.

The IEEE needs volunteers. We all have a primary responsibility to those who employ us, but we also have a secondary responsibility to contribute to the health and vitality of our profession. We should not expect the same people to do the work all the time - we need to have the new ideas that new people bring to maintain a dynamic organization. Your IEEE needs you!

How can you help? By attending your local IEEE meetings and/or making your willingness to contribute known to members of your Section executive. There are also opportunities to assist in many regional and technical activities. One particular way in which I need your help (and here's my pitch) is related to this publication - the *IEEE Canadian Review*. This is the sixth issue. Do you like it? I can appreciate that it is but one more chunk of paper that comes across the desk of busy professionals. Is it serving a useful function as our primary means of communication to electrical engineers in Canada?

The *IEEE Canadian Review* was initiated, nursed and developed by the dedicated efforts of its Managing Editor, Richard Marceau. Richard has worked tirelessly to make this *Review* a success. Richard is an IEEE volunteer and now wishes to pass the editorial gavel on. Is there anyone out there in the true north with the enthusiasm and journalistic flare to pick it up?

We also need contributors to the *Review*. We need more articles summarizing the state of the technology in such areas as computer engineering, communications, microelectronics, control techniques, artificial intelligence and robotics. I would also like to seek the occasional historical article on the contributions of one of the many leaders in the EE profession that Canada has produced. Any offers?

If you would like to offer an idea for an article, don't hesitate to call one of our Associate Editors, whose phone numbers are listed on page 3. If you're not sure which Associate Editor you should talk to or wish to contribute to this *Review* editorially or in other ways, please write (briefly in the first instance) to either Richard Marceau or myself:

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It remains for me to hope that you have or have had (depending on when this issue hits the streets) a very pleasant Christmas and New Year holiday season. I look forward to working with all in IEEE Canada as Director over the next two years.

All the best,

Tony R. Eastham

Smart Buildings: An Emerging Reality?

The technological basis for such systems is readily available, but there is yet much to be done.

What is a smart building?

A smart building should not be considered a "gadget" house or a central computer system to control specific functions (e.g. lighting). Many attempts have been made to accurately define a smart building. For instance, some people have tried to give a building an intelligence quotient or IQ much in the same way we define the intelligence of a person. Some have defined a smart building as one with particular features: integrated building automation, fire and security systems or shared tenant services. But there is no set threshold which a building must meet to be called "smart". In fact, all buildings are on a continuum of capabilities ranging from the least to the most intelligent.

The most important aspect when considering a smart building is to keep in mind that the role of a smart building is to serve human needs, not to be an example of technology for technology's sake. It is generally built around three main thrusts:

- a system that fulfills complex needs of any given individual or community,
- an integration of numerous automated functions,
- a system based on communications between devices.

This concept is applicable to residential homes, commercial buildings and the industrial environment.

In the residential sector, a smart home will fulfill the needs of security and safety, ease of living for the handicapped or elderly, energy consumption or energy bill management, entertainment or various services of data and information. A characteristic of a smart home is that the infrastructure has to be capable of evolution in order to answer the changing needs of the individuals. But this should be transparent to the end user: you should never require a degree in communications or in computer science to operate a smart home!

In the commercial and industrial sectors, smart services can be grouped into three categories: building automation systems, building services and shared tenant services.

The building automation system (BAS) includes energy management and control, fire protection, building security, elevator control and lighting control systems. Usually, each of these five systems is managed by a dedicated controller and interfaced with the building security system which is monitored at all times.

Building services are affected both directly and indirectly by information technologies: directly by the addition of extra equipment meaning increased wiring, heat generation, noise and space standards and indirectly by changing organizational structures. For example, information technologies introduce more complex forms of decision-making but allow flexibility of working hours and locations. Four major considerations are retained in smart building design: flexibility in overall building design, air conditioning, special machine rooms and wiring.

Shared Tenant Services (STS) provide economic, high technology services to small and medium size companies without the high capital cost burden.

by Yves Langhame
Chairman, Special Projects Committee, CABA
Gerry Meade
Executive Director, CABA

The smart building: ever heard about it?

It is the kind that manages your house's energy bill, it links your television set to your computer, your stereo system, the door bell, the telephone and the toaster. It polishes your shoes and serves the coffee at 7h05 a.m. Well, almost.

Le bâtiment intelligent, vous connaissez?

C'est celui qui règle votre chauffage, qui relie télévision, ordinateur, chaîne stéréo, sonnette d'entrée, téléphone et grille-pain, c'est lui qui cire vos chaussures et chauffe votre café à 7h05 le matin. Enfin, presque.

The users usually pay a competitive rental fee to the service provider. STS may include part or all of the following services: a private branch exchange digital telephone switch, personal computer rental and services, word and text processing, voice mail, electronic mail, computer networking, on-line databases, facsimile, audio conferences, etc.

Who Will Profit?

The success of these smart buildings will be based on how they answer the expectations of the groups involved in or concerned by them.

For architects and builders, the drive is to put construction back on the track of a technical edge in a highly competitive market. The projected image of progress in a traditional and aging building world should however be balanced by financial returns like simplification of wiring or access to new markets. For the manufacturers of equipment, the interest is obviously more straightforward: a new, rapidly expanding market for "smart products" with a target of tapping the new "smart needs" or of replacing "dumb products" could be a real incentive to move ahead.

But no one should forget that the market trend is in the hands of the end user whose attitude and response will be conditioned by the perceived trade-off between costs and returns. Various market studies have been conducted for the residential sector both in North America and Europe. They all show a high degree of expectation for security and safety, energy management, entertainment and access to information.

Public utilities will also be concerned by smart building expansion since massive changes in the end user environment will in turn modify the expectations for electric, gas or telephone services. Electric utilities will be hit first; in a positive way, due to the higher perceived value of electricity, but also in a negative way, due to higher dependence of end users on

Customer preferences	Professional Builder Magazine	John Morton (Smart House)	Institut Français du Bâtiment
Security / safety	69 %	60.4 %	
Energy management	66 %	62.2 %	
Entertainment	43 %		
Technical & risk management			56 %
Security			51 %
Comfort / convenience		62 %	48 %

Figure 1 The top three preferences according to three different surveys.

electricity. This could lead to increased pressure for both continuity of service and quality of the delivered product: electricity.

This concern has been clearly expressed by Richard Balzhiser, EPRI President and CEO at the 1989 World Energy Conference. "The combination of smart buildings, smart meters, automated distribution and an integrated communications protocol has the potential to revolutionize the business relationship between the homeowner and the electric utility".

The Technology

The technology is the back-bone of any smart building. At this point in time, most of the work has been done to develop and test concepts, communications protocols and hardware rather than to run up installations to test functionality and demonstrate the anticipated benefits or public responses. This technological world is vast, fast changing and associated with numerous niches in the market; as such, the state-of-the-art of smart building technology is a masterpiece of complexity. One common statement is that the technology is ready and available in terms of electronic devices, transmission media (with copper or fiber optics), and information management and transmission systems to name a few. The challenge is to organize this expertise and knowledge in order to market systems and products that fulfill end users' needs.

The North American domestic market is coveted by the Smart House Limited Partnership and the Electronic Industries Association (EIA) CEBus-related technology. They have in common a group and consensus approach that limits the probability of major technological errors occurring.

The Smart House project, a business venture that was launched in November 1984, was the first company organized under the National Cooperative Research Act of 1984 in the United States. The Smart House is a proprietary for-profit organization. Funded by the building community, especially the National Association of Home Builders, it regroups manufacturers with significant activity in the new construction market place.

The Smart House approach is to develop and license a new closed-loop energy distribution and communications infrastructure for the new home market. This concept requires a fundamental redesign of the traditional wiring format, assuming that only a new design can handle the sophisticated consumer benefits. The core system - the energy distribution and communications infrastructure that every Smart House will have - is built around a multi-function hybrid cable and microprocessor-based convenience centers and service center. To obtain the full benefit of the system, Smart House-attached products will be required. These are the Smart House versions of everyday appliances that will have the capability of taking advantage of the closed-loop system.

The 16-conductor flat ribbon cable handles traditional power connections, control signals, telephone and intercom signals and low voltage DC power. Each plug offers the full service: for example, the single cable that connects a Smart House TV set to the wall also conveys 120 VAC, 24 VDC, the signals from antenna and from the VCR, and provides communication with outside speakers as well as with other audio-video equipment.

Each convenience center is responsible for providing power to the attached products based on the rules of the Smart House closed-loop power system. As such, it takes care of communications between the attached products and the service center. The service center is the main piece of equipment that makes a house a Smart House. It is connected to the external services like electric power, gas, TV cable and telephone, and manages and distributes these services in the house. While the communications protocol is proprietary, some details have been disclosed: Time division multiplexing, using a clock signal, was chosen for the control channel access. 32 baseband time slots are present for each branch circuit, each of them providing a virtual full-duplex circuit to each node, with a communications rate of approximately 350 kbps.

The various Smart House components have been developed by the licensed manufacturer and the venture has begun the construction of five prototype homes in order to test the functionality of the entire system. Two are now complete, two are presently underway and one has yet to be started. As this latter program winds down in 1990, Smart House is planning to start a 100-demonstration home program in 20 markets throughout the United States and possibly in Canada. These homes will be used mainly for promotional purposes and will be followed closely by the commercial introduction of 3,000 homes. This program will start in late 1991 and continue in 1992.

The Consumer Electronic Bus (CEBus) committee was formed in 1984 to develop an interproduct communications standard targeted at home automation applications. This group, sponsored by EIA, contrary to the Smart House Venture, is a committee and not a business; no profits will be made on the standards, no licence will be sold and no discussions relate to the end products. The CEBus design starting point is the wiring used in today's North American homes on the basis that evolutionary progress is the only progress possible in an established market. However, some communications media, like coaxial cables or fiber optics, will require new wiring and thus will target new construction or remodelling.

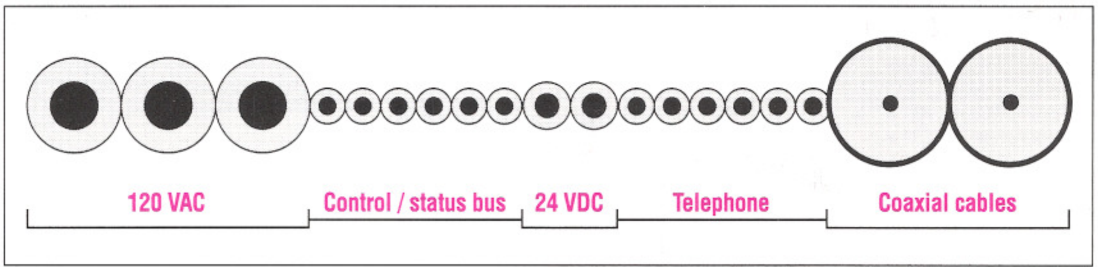


Figure 2 The Smart House hybrid branch (courtesy of Smart House Limited Partnership).

The EIA home automation standard is made up of any combination of the following physical media: infrared carrier, radio frequency carrier, existing house electrical wiring, twisted pairs, coaxial cables and fiber optic cables. The communications resources serve two purposes: the first one is to provide a means for products to exchange application commands and the second is to allow products to request and use other services.

The exchange of meaningful information implies the use of a Common Application Language (CAL). Language tables are being developed for various product types on the basis of functional blocks that can be addressed on the bus. For example, a TV might be defined using four blocks (e.g. tuner, video monitor, audio and time) with a number of "services" for each one (e.g. volume, time edit, feature switch, etc.). Each service element is then subject to allowable operations (e.g. increment, load, etc.). The committee will be completing such tables for the most common products before the standard is published. The generic and the powerline carrier standards were scheduled for release in November 1989 for review and comments. The other standards will be issued in 1990.

As we have seen, these two smart home systems do not compete in an absolute way, from a technological point of view. However, they do compete for expertise and investment from interested companies as well as for the customers' attention and dollars. The Smart House target market is approximately 1.5 million new constructions per year, while CEbus will be applicable to the entire base of roughly 100 million existing homes in North America.

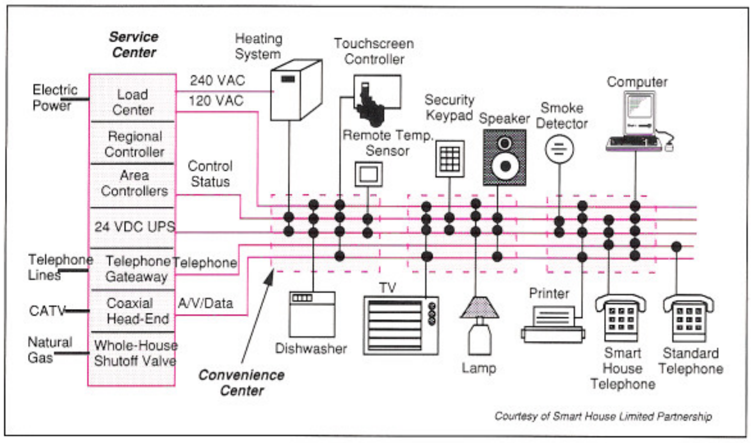


Figure 3 A typical Smart House branch circuit.

Conditions For Success

Some conditions are a generic prerequisite for the success of the smart building industry as a whole: coordination and standardization.

As a general rule, but especially in the commercial domain, coordinated focus amongst organizations involved in building automation is weak, and in Canada, the industry seems to be more dependent on activities in other countries than on its own capabilities. However, a trend has recently emerged around the world whereby expertise and resources coordination are sought for commercial smart buildings development. In 1988, several industrial ventures were born in France: IBM France and Bouygues (an important commercial builder) formed IB2 Technologies; Bull, Spie Batignoles and Jeumont-Schneider formed Ositel; and EDF and the Caisse de dépôts formed GIE Intelbat 2000. In Japan, IBM Japan, Sumitomo Electric and insurance companies have united in their efforts to tackle the smart commercial building market. In the United States, similar moves have taken place: United Telecommunications with Olympia and York, TEL Management with Wiortham Van Liew for the commercial sector while the Smart House Limited Partnership covers the residential market.

The issue of standards is another critical key factor to both the residential and commercial markets. Standards can occur in one of two ways: one company can establish a defacto standard (like IBM did in the PC industry) or a group of companies can agree on an industry standard. At this time, there are no accepted building automation standards in the residential or commercial market. In the United States, there are virtually two incompatible communications protocols for the residential market: the Smart House closed protocol and the EIA CEBus open protocol.

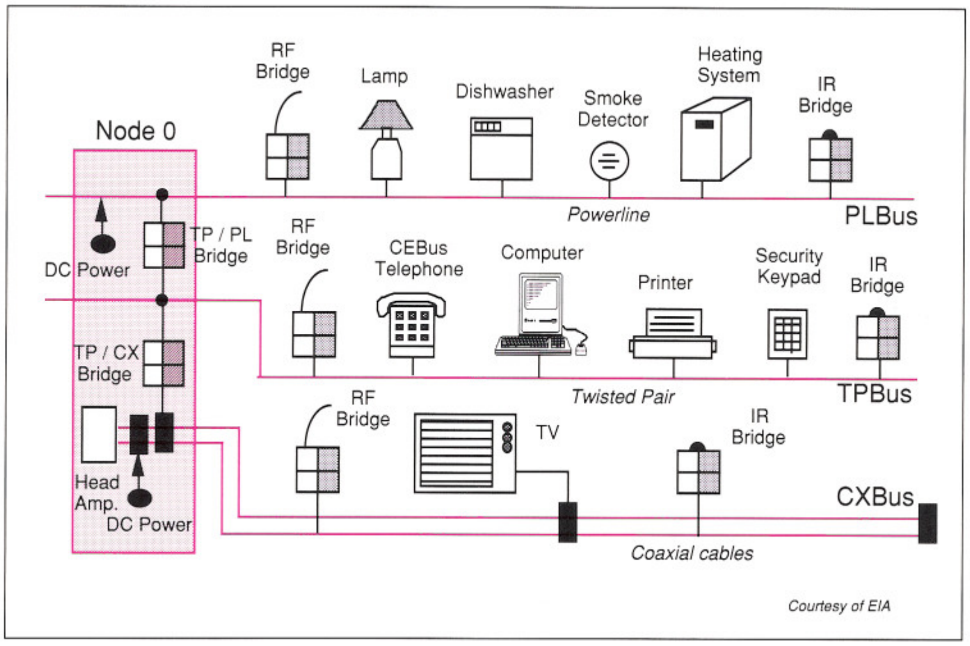


Figure 4 Typical CEBus topology.

The concept of open protocol means that any company can manufacture products which will function on the system. There is also the J-bus standard that was developed in Japan in 1987 and the D2B standard that is presently being developed in Europe. The intent is to have a European standard in place by 1992 when all trade barriers fall in western Europe. And, not to be forgotten, the existing array of housing automation products which are predominantly based on the X-10 power line carrier system.

The commercial market has similar problems. A large number of companies have their own independent systems for automating buildings - Johnson, Honeywell, Powers, Robertshaw, and Transalta to name a few. In the United States, IBI, with potential funding from the Federal Government, is considering a study to develop a standard for building automation to avoid having to deal with incompatible products.

On top of these two major issues that have to be addressed quickly, some pitfalls have been identified. In the residential market, the delays involved in introducing the Smart House concept to the market (after a launch with much fanfare), have left many people feeling frustrated with the concept and not anxious to hear more about it until products are available. In the commercial sector, anyone can learn from the abandonment, in 1986, of Share Technologies by its mother companies, AT&T and United Technologies; its approach to the smart building environment was too technical. The human dimension must remain a major driving force.

Canadian Activity

In the past, automated building technologies were developed outside Canada and imported into this country without Canadian input. One of the Canadian answers to this fast changing environment was the founding of the Canadian Automated Building Association (CABA). CABA was formed in 1988 to address the governing issues of the smart building environment and to provide a focal point for proactive agencies interested in Canada. The partners at the origin of this organization were Bell Canada, EEMAC, Hydro Québec, the Ministry of Industry, Science and Technology, the National Research Council of Canada and Ontario Hydro. Canadian activities in smart buildings are disjointed, and thus opportunities for Canadian companies depend on a focal point for them to come together and cooperate. CABA is an independent, non-profit organization whose mission is to lead the development, promotion and adoption of advanced technologies for the automation of homes and buildings. CABA deals with all market sectors as many of the technologies overlap several sectors. This also permits the cross-pollenization of ideas.

The objectives of CABA are, firstly, to create an environment that will encourage Canadian industries to develop new business opportunities and, secondly, to promote the compatibility, integration and synergy of technologies and regulatory requirements.

Lastly, CABA will demonstrate the benefits of smart homes and buildings. CABA could take a leading role in managing this effort but would certainly need the support of home builders, architects and engineers. Therefore, CABA will be the focal point for interaction and exchange of information among manufacturers, utilities, telcos, builders, building owner/managers, government departments/agencies, and buildings and systems designers.

Four committees are taking care of the projects, namely the membership and information, the standards, the special projects and the research and development committees.

The membership and information committee is responsible for responding to and soliciting membership inquiries. CABA does not want to be an association of thousands but rather to represent as many sectors as possible. This committee is also responsible for keeping members informed of CABA activities and of developments in automated buildings throughout the world. The standards committee will be looking into the need for standards and the way in which standardized and open protocols can be implemented for use by all companies. Closed protocols are a possible dead-end in that only a few companies have the right to manufacture those products.

Some progress has been made in Canada in relation to approvals. The Canadian Standards Association has approved a new clause in the Canadian electric code which will allow the concept of closed-loop power to be used in Canada. The special projects committee is considering a demonstration project to promote automation. CABA may also arrange a conference on automated buildings in Canada. This could be a joint effort with the Intelligent Buildings Institute of the United States. Finally, the R&D committee will promote and support research and development in Canada, coordinate research studies which address the needs of CABA's members and assist members to work together towards common goals.

No one sees a Canadian smart building technology unique from any other, but no one wants to be left as an add-on to American or Japanese thinking. As an example, Canada has already a world-recognized expertise in communications which can be applied to this market. Therefore, Canada intends to play an active role in this new, fast growing business. Some Canadian organizations have taken the lead.

For instance, the new emerging standard of communications protocol, the CEBus, has found a Canadian manufacturer, AISI, to market the first development chip that follows the EIA standard. This British Colombia-based company had toured Canada and some international exhibitions to demonstrate the feasibility of this Canadian technology to perform smart functions within residential premises. The technology uses either infrared, twisted pair or telephone lines, coaxial cables, fibre optics and radio communications media.

Research and development is also a major thrust in Canadian smart building activities. The Canadian Institute for Building information and Network Technologies (CIBINT) at the University of Regina is actively working on applications of fiber optics for building communications and control. The Institute is carrying out a project with the objective of establishing competence in telecommunications networks and associated systems for intelligent buildings, and is working with the industry to develop components for a "fourth utility" in intelligent buildings communications. CIBNIT is also providing a test facility, at the University, for component development and testing with emphasis on fiber optics.

Public Works Canada has developed a communications protocol specification following the ISO seven-layer model. The specification deals initially with energy management control systems, and the incorporation of other building automation services will be dealt with as a second, separate step. The specification uses a standard LAN to provide communications between the operator workstation and the energy management field panel. Public Works Canada is striving to have a working demonstration by March 31, 1990.

In adopting a pragmatic approach to the environment-control of its buildings, specifically to systems and protocols issues associated with different manufacturers' products, Bell Canada decided to create a new communications interface langage. From a centralized control center, using the Bell Control Langage (BCL), an operator can monitor and control, on a real-time basis, a number of manufacturers' building control systems. BCL is marketed through INFOPRO Ltd.

Conclusion

As long as they are aimed at overcoming present buildings' inefficiencies and at helping people to live and to work better, smart buildings will be developing very fast once the consensus on standards is reached.

In the residential sector, the owner will enjoy a higher quality of life if his/her smart home remains intelligent but not exceptionally gifted, and cooperative but not restrictive.

In the commercial sector, anticipated benefits will be measured in terms of flexibility, longer building life, lower installation costs, reduced energy costs, lower life cycle costs, higher space efficiency and greater productivity to name a few.

For Additional Information...

Interested parties wanting to probe further should contact The Canadian Automated Building Association (CABA), 10 Carlson Court, Suite 500, Rexdale, Ontario, M9W 6L2

IEEE Canada Newsflash

Dr. Ashok K. Vijh, Fellow IEEE, has recently received the Thomas W. Eadie Medal.

This medal is given in recognition of a major contribution to any field through engineering or applied science. The award is funded by Bell Canada in honour of its past President (1953-63) and Chairman of the Board.

Dr. Vijh has been called one the best electrochemists of our time. Electrochemistry is experiencing a renaissance in its purely scientific significance and in its industrial application, and Dr. Vijh is considered one of the main architects of this renewal.

His research contributions to electrochemistry are immense and span an enormous range - from long-term studies to the concrete applications of these investigations in industry.

Dr. Vijh's best known work is his monograph, published in 1973, entitled *Electrochemistry of Metals and Semiconductors* which won the Lash Miller Award of the Electrochemical Society that same year. This work is acclaimed by scientists around the world.

Modern electrochemistry is an enormous field dealing with mechanisms of chemical reactions accompanying the transfer of electricity across charged interfaces. Dr. Vijh's original and extensive research has contributed to the knowledge of processes involved in the electrochemical industries (production of aluminium, copper, zinc, caustic soda, chlorine and fluorine) and in the conversion and storage of energy.

The quality of his work has been recognized by several awards and its originality is illustrated by the more than 40 papers which mark the first announcements of significant discoveries.

Dr. Vijh was born in India in 1938. He received his B.Sc. (1960) and M.Sc. (1961) from Panjab University, and his Ph.D. (1966) from the University of Ottawa. He joined the Hydro-Québec Institute of Research in Varennes, Quebec, in 1969 where he is currently Research Master.

High Speed Rail in Canada: An Impossible Dream?

Does high speed rail transportation make financial and economic sense in Canada?

by W. J. Hurley, J. Jones and A. R. Eastham
Kingston, Ontario

An idea whose time has come?

The concept of high-speed rail (HSR) in Canada has attracted considerable media attention. Given the success of high speed rail in Japan, France and elsewhere, the technical feasibility of such a project is not seriously in question. But is such a project economically viable in Canada?

Le temps est-il mûr?

L'idée d'un train à grande vitesse au Canada a attiré beaucoup d'attention ces derniers temps dans les grands médias. Étant donné le succès de différents types de trains à grande vitesse au Japon, en France et ailleurs, on ne met plus en doute sa faisabilité technique. Toutefois, un tel projet est-il économiquement viable au Canada?

Much media attention has recently been given to the possibility of an electrified high speed rail system (HSR) between Montréal, Ottawa and Toronto. This discussion occurs against a backdrop of cutbacks and uncertainty regarding the future of VIA, the Crown corporation responsible for rail passenger transport in Canada. The Canadian government is planning to reduce the subsidy to VIA to $350 million, a cut of 45%, by 1993. In this climate of budgetary restraint, it seems unlikely that the federal government would make a major investment in HSR. Yet, our estimates suggest that it may be possible to move people in the Montréal-Ottawa-Toronto corridor more cheaply by HSR than by air transportation (Air).

The Relative Cost of HSR and Air

Let us first consider the basis on which costs are to be compared. Currently, there is no high speed rail; there is only an air system. It is appropriate, then, to compute the savings in discounted cost that would result if a given level of traffic is moved by HSR rather than by air. Costs are discounted over the life of the HSR infrastructure, which is assumed to be 40 years.

The total cost for each system comprises three categories: direct fixed costs; direct variable costs; and indirect costs.

- Direct fixed costs for HSR are the costs of providing the right-of-way and track. For Air, they consist of two major elements: the cost of airports, terminals and related fixed plant; and the cost of the air navigation system.
- Direct variable costs include all other direct costs exclusive of infrastructure costs. For HSR, direct variable costs would include: operations; rolling stock maintenance; maintenance of way; overhead; and an amortized capital charge associated with the rolling stock investment.
- For Air, direct variable costs would consist of comparable items.
- Indirect costs include the cost of travel time, pollution and other such items which are not borne directly by the providers of the transportation service.

Indirect Costs

On indirect costs, HSR compares favourably with Air. For instance, consider the cost of travel time. Table 1 compares the total time of travel - including time spent traveling to and from the terminal and waiting at the terminal - for the three major corridor trips. Between Ottawa and Montréal, HSR is faster; for the other two, HSR times are competitive.

Other aspects of indirect costs are convenience and comfort. HSR and Air come out roughly equal. A TGV-type HSR service would be more comfortable than Air. On the other hand, Air would generally offer more departures.

A final category of indirect costs are "externalities" like noise, air pollution and congestion. Since TGV-type service is electric, it is both quieter and cleaner than Air. With the existing congestion at Pearson International Airport in Toronto and the prospect that it will get worse, HSR is an alternative to airport capacity expansion.

Direct Costs of High Speed Rail

To get a high speed rail system operational between Toronto and Montréal will require approximately $2.6 billion, consisting of $2.3 billion for infrastructure (see Figure 1 for breakdown) and $300 million for rolling stock.

We take $2.3 billion, the total infrastructure cost, to be the direct fixed cost of the high speed system. We estimate that it will take 6 years to put the infrastructure in place and, once in place, it will last for 40 years with normal maintenance. Rolling stock is not included as a fixed cost for reasons to be discussed below.

There are two items of direct variable cost. One is a period charge which includes operation, overhead, maintenance of rolling stock and maintenance of way. The other is rolling stock. We estimate the period charge to be $.052 per passenger-kilometer, calculated as shown in Table 2.

Table 1 - Air and HSR Trip Times for Selected City Pairs

City Pair	HSR	Air
Toronto-Ottawa	3 hours 20 minutes	3 hours
Toronto-Montréal	4 hours	3 hours 20 minutes
Montréal-Ottawa	2 hours 10 minutes	2 hours 20 minutes

Table 2 - Annual Operating and Maintenance Costs for High Speed Rail ($ millions)

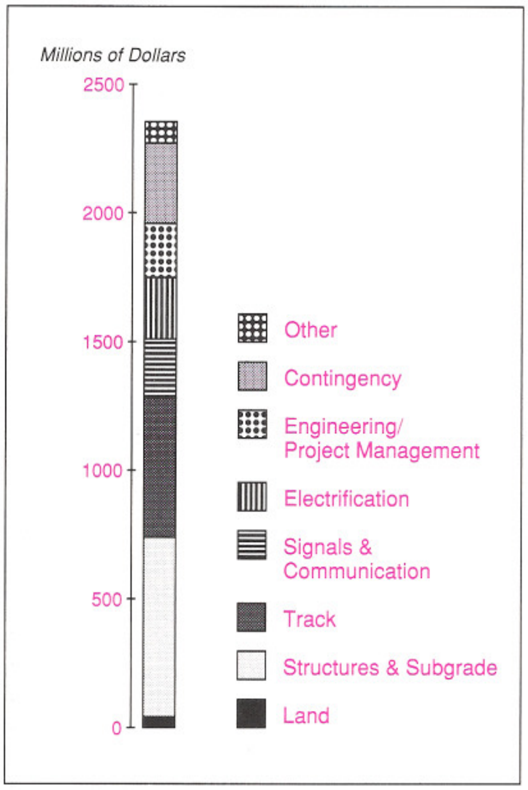
Crew and On Board Services	24.4
Equipment Maintenance	22.8
Stations and Sales	18.0
Train Control	1.5
Track and Facilities Maintenance	12.5
Insurance	3.0
Corporate Offices	5.5
Total	87.7
Total passenger-kilometers (millions)	1 679
Cost per passenger-kilometer (cents)	5.2

These costs have been developed under the assumption that the operator of a Canadian high speed system would not be constrained by traditional railway industry workrules. In particular, it assumes that the crewing levels practised on the French TGV could be implemented here. Also, the cost per passenger-kilometer is for the forecast level of demand. For higher levels of demand, this cost would fall.

To check that 5.2 cents per passenger-kilometer is reasonable, we examined the TGV Southeast accounts over the years 1981-1985. These indicated that the average costs decreased from 5.4 cents in 1981 to 3.9 cents in 1985, therefore supporting our cost analysis.

The other variable cost is the capital cost of the rolling stock. We have chosen to amortize the capital cost over a 15 year period. An equipment analysis based on 65% occupancy factors and an annual workload of 350,000 km per trainset indicated that 15 trainsets will be required, at a cost of $300 million in 1988 dollars. This translates into 1.5 cents per passenger-kilometer over the useful life of the equipment. Thus, we calculate the total direct variable cost to be 5.2 + 1.5 = 6.7 cents per passenger-kilometer.

Figure 1 Breakdown of infrastructure costs for High Speed Rail.



There is one additional cost, and that is the cost of capital. We have assumed a required real rate of return of 5%.

To get a total direct cost, we discount the annual variable cost over the 40 year life of the high speed infrastructure and add to it the cost of the infrastructure. The total net present cost of the HSR then becomes $3.8 billion.

Direct Costs of Air

We take a different approach to estimate the variable direct costs of the Air mode. Airline fare data for major origins and destinations across Canada was obtained as well as the distance in kilometers between each. With this data set, we regressed price on distance. The resulting regression equation is as follows:

$$P(d) = 89.3 + 0.135\,d, \quad R\text{-squared} = 0.997 \qquad [1]$$

where P(d) is price (i.e. in dollars per passenger) and d is distance. The high R-squared indicates that the data fit the linear relationship quite well.

We take this as the airline cost function for several reasons. First, North American airline companies have not been exceptionally profitable since deregulation, even with substantial increases in traffic. Table 3 presents the breakdown of operating profits for US airlines on domestic services between 1970 and 1985 for selected years. With the exception of 1985, revenues are just enough to cover operating expenses. Even in 1985, the margin is only about 2%. Second, the theory of contestable markets applied to air passenger transport suggests that, given the mobility of capital in the industry, airline prices may be close to competitive prices. Table 3 provides evidence in support of this contention.

But there are obvious objections to this approach. First, it may be that there is a cross-subsidy between long and short-haul flights. If short-haul subsidizes long-haul, the true airline cost function may be flatter that [1]. Hence, if [1] is used to estimate the cost of short-haul flights, the resulting cost will overestimate the true cost. Second, if [1] is the true cost function, it will also include a provision for capital payments to airline shareholders and bondholders. If yearly unit costs are developed from [1] and then discounted for comparison purposes with HSR, capital costs will be double counted, thus biasing the comparison towards HSR. Airline costs would also include landing fees. We do not net these from Air costs for two reasons: they are a small fraction of airline costs; in our analysis, we are not going to charge any of the capital and operating charges of the airport and air navigation system against the Air alternative.

With these qualifications noted, we proceed as follows. For a trip length of 539 kilometers, the distance between Montréal and Toronto, the cost from [1] is $162 or 30.1 cents per passenger-kilometer. However, as noted above, this cost includes all airline costs as well as capital charges to the various stakeholders. To take out these capital charges, the data in Table 3 are used to estimate the percentage of total expenses which are made up by capital charges. We take the expense item "depreciation and amortization" to be a suitable proxy for capital charges. In 1970, the depreciation and amortization constituted 10% of total expenses. For 1975, 1980 and 1985, it averaged 6%. To be conservative, we use 10%. Therefore, the direct variable cost adjusted for capital charges is:

$$30.1 - 10\%(30.1) = 27 \text{ cents.}$$

To this point, the analysis indicates that HSR has a significantly lower variable cost. Now to the problem of direct fixed cost for Air. As mentioned above, this cost has two components: airports, terminal and other fixed plant; and the air navigation system. Adoption of the new microwave landing system and maintaining the existing infrastructure will require approximately 6 to7 billion dollars over the next 20 years for the country as a whole. This expenditure does not include any provision for expansion at Toronto. Whatever these planned expenditures, the key number is the savings in Air capacity cost which would result if a high speed rail system were implemented.

Some Background on High Speed Rail

The Japanese were the first to introduce high speed rail. The *Shinkansen* or *Bullet Train* (Figure 2) began operation in 1964. Since then, other jurisdictions have introduced high speed service through heavily populated corridors. In the United States, high speed rail is being considered in Pennsylvania, Ohio, Florida, Michigan-Illinois, Nevada-California, Texas and New Mexico.

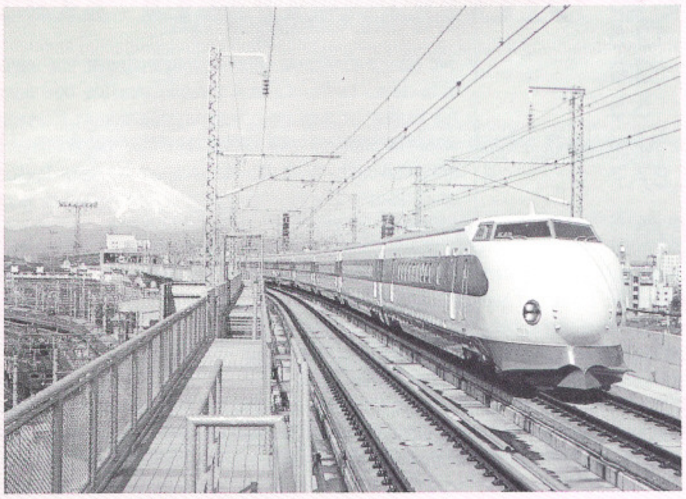


Figure 2 The Japanese *Shinkansen* or *Bullet Train*, in operation since 1964.

The TGV (Figure 3) began operation between Paris and Lyon in 1981. Construction of a dedicated line was begun in 1976 and completed in two sections, the southern in 1981 and the northern in 1983. Approximately 425 kilometers long, this line is designed for speeds in excess of 300 kilometers per hour. The TGV has a top speed of 270 kilometers per hour

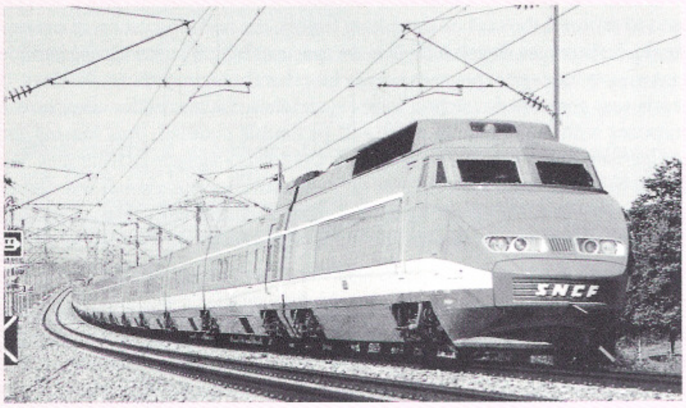
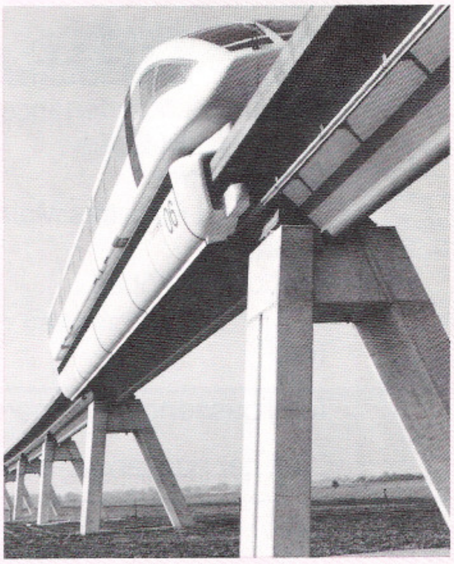


Figure 3 The French Paris-Lyon Train à Grande Vitesse (TGV), in operation since 1981.

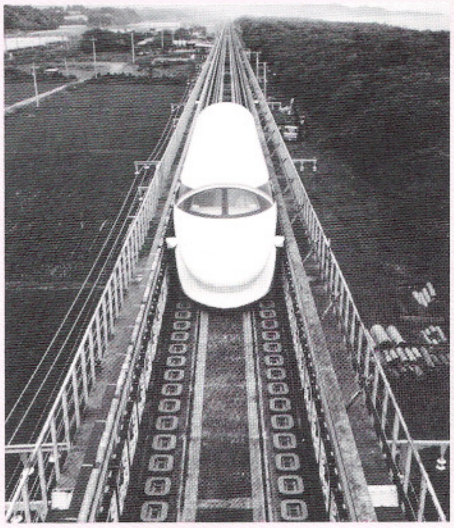
and averages 213 kilometers per hour on the Paris-Lyon route, for trip time of about 2 hours. In comparison, the existing line between Toronto and Montréal is some 539 kilometers long. Existing service on this route is supplied by Bombardier's LRC equipement which is designed to run at speeds of 190 kilometers per hour. However, freight interference, limitations of the roadbed and the LRC itself restrict the best time to 4 hours 30 minutes for an average speed of 120 km/hour. In contrast, the TGV is capable of a Montréal-Toronto trip via Ottawa in under 3 hours (on new dedicated right-of-way).

Figure 4 The German *Transrapid*, in final phase of prototype test and demonstration (electromagnetic attractive suspension, linear synchronous propulsion).



TGV traffic has grown 500% since its inception and the train has captured 56% of pre-TGV air traffic between Paris and Lyon. Table 5 shows the growth of the Paris-Lyon route between 1981 and 1985.

Figure 5 The Japanese *Linear Express*, planned for the turn of the century (electromagnetic repulsive suspension, linear synchronous propulsion).



Looking to the future, high speed non-contact magnetic levitation systems are likely to become available in the nineties. The German *Transrapid* (Figure 4) with 400-450 km/h capability, using controlled electromagnetic (attraction) suspension and linear synchronous propulsion is now in the final phase of prototype test and demonstration. This vehicle system is planned for a link between Orlando Airport and Disney World in Florida. The Japanese *Linear Express* (Figure 5) with 500 km/h capability, using superconductive electrodynamic (repulsion) suspension and linear synchronous propulsion is also under development. This technology should be ready for implementation by the turn of the century, after thorough testing on a new 47 km test track to form part of a Tokyo-Osaka line.

Table 5 - Selected Traffic Statistics - Paris-Lyon

	1981	*1982*	*1983*	*1984*	*1985*
Passengers (thousands)	1 014	3 227	4 025	4 819	5 318
Passenger-kilometers (millions)	511	1 885	2 040	2 460	2 822

For our purposes, it is enough to assume that the savings in Air capacity cost as a result of HSR are zero.

Based on the variable direct cost of 27 cents and zero fixed direct cost, the net present cost of Air is $5.8 billion. To arrive at this number, we have made the same traffic assumptions that we used for HSR: there is no traffic for 6 years; after 6 years, the traffic is a constant 1.7 billion passenger-kilometers per year.

In summary then, HSR is some $2 billion cheaper that Air over the 40 year period.

The Investment Value of HSR

We have shown that it is more efficient to move people by HSR than by Air. However, this does not mean that the returns will be sufficient to justify private sector investment. For this assessment, we need to test the profitability of HSR at various revenue levels.

Table 4 presents the Net Present Value of the high speed rail investment at levels of revenue ranging from 15 to 25 cents per passenger-kilometer.

Table 3 - Operating Income of U.S. Airlines on Domestic Operations (1970-1985, $ millions)

	1970	*1975*	*1980*	*1985*
Total Revenues[1]	7 131	11 911	26 404	37 629
Expenses:				
Flying Operations	2 098	3 869	11 029	12 684
Maintenance	1 127	1 595	2 758	3 604
General Administration	3 157	5 050	10 545	17 324
Depreciation and Amortization	745	883	1 560	2 318
Transport Related	n/a	383	517	681
Total Expenses	7 127	11 780	26 409	36 611
Passenger-miles (billions)	104.1	131.7	200.8	270.6

[1] Revenues include freight and other revenues which range between 12% and 15% of total revenues.

Source: Statistical Abstract of the United States, 1988, 108th edition.

At a fare level of $0.20 per passenger-kilometer, which is about 70% of the current Air fare between Montréal and Toronto, the HSR investment has a positive Net Present Value using a discount rate of 5%. However, the net present value calculation is sensitive to the revenue assumption. If fares are raised 25% to $0.25 per passenger-kilometer, the net present value increases by about 350%. Thus, given the structure of our analysis, profitability is very sensitive to the revenue assumption made.

This sensitivity suggests a role for the public sector. High speed rail profitability turns on the level of fare that can be charged. Since the initial investment is quite large, it is doubtful whether a private company or consortium of private companies would be willing to take the risk. However, if a government (or a group of governments) undertook to supply a sufficiently large part of the initial investment, the private sector risk of the project could be reduced to the point where the project would be attractive.

Table 4 - Net Present Value of the HSR Investment ($ millions)

Revenue per passenger-kilometer	*Net Present Value*
0.150	-661
0.175	-153
0.200	354
0.225	861
0.250	1368

An interesting issue related to public sector involvement is the structure of this involvement. One alternative is to have the government supply a fraction of the infrastructure cost. This will have two effects on the private sector investment. It will increase profitability and reduce the payback period. For example, suppose the fare level is fixed at $0.20 per passenger-kilometer. With no public sector involvement, the payback period is 16 years; if the public sector were to contribute $1 billion, the payback period would be reduced to 6 years.

Conclusions

The main finding is that, for a given level of demand over the Montréal-Ottawa-Toronto Corridor distances, high speed rail is cheaper than air transportation. However, our profitability study suggests that HSR may be too risky for private sector investment alone. This suggests a role for public-private sector cooperation to reduce these risks to acceptable levels and enable the benefits of HSR to be reaped.

There are also other benefits which have not been included in the economic analysis:

1. Bombardier has the North American manufacturing rights for the TGV. If high speed rail is adopted by other North American jurisdictions, Canada is well positioned to supply this market.
2. There will be economies from CN and CP's increased capacity to move freight.
3. The high speed option has the potential to reduce the congestion which currently plagues the air mode, especially at Pearson International Airport.

A final benefit is related to our ability to predict the future. Our analysis does not include the modeling of shocks to the economy over the next 40 years. Yet, in the transportation industry, shocks such as the OPEC oil embargo can have substantial effects. By way of example, suppose the price of oil were to double at some time in the next forty years. Under the existing corridor transportation arrangements, this would cause significant difficulties because of our reliance on the automobile and airplane and the energy costs incurred thereby. In a sense, the HSR investment, which is much less energy intensive, is a form of insurance against such adverse movements.

IEEE Canada Newsflash

Dr Robert T. H. Alden, outgoing Director of IEEE Canada, has just been named Vice-president of the IEEE Regional Activities Board (RAB). Dr. Raymond Findlay, a long-time active member of IEEE Canada, has also just been named Student Activities Committee (SAC) Chairman for all of IEEE. Congratulations to Bob and Ray!

Obituary

Mrs. Margaret (Peggy) Armitage, wife of George Armitage, the first Manager of IEEE Canada Region Office, died on November 9. Peggy was very well known for her support of George's activities with IEEC Inc. and the International Electrical Electronics Conference from 1959 until quite recently. We wish to extend our condelensces to George and family at this time.

In Memoriam

In the first week of December, an armed young man broke into École Polytechnique de Montréal. Before committing suicide, he shot and killed fourteen young women engineering students and wounded, at the time of printing, approximately fifteen other students.

The engineering profession as a whole is appalled by this violent act and mourns the loss of these future colleagues. On behalf of all Canadian members of IEEE, the *IEEE Canadian Review* wishes to express its deepest sympathy to the families touched by this ordeal.

IEEE Canada Snapshot

McNaughton Gold Medal

The 1989 McNaughton Medallist is John S. Foster. Dr. Foster was presented with the McNaughton Gold Medal at a special ceremony held on Monday, October 23, 1989 at the State of the Art Symposium Banquet at the Royal York Hotel in Toronto. Presentation of the Gold Medal and certificate was made by Dr. Robert Alden, Director, IEEE Canada and Mrs. Leslie McNaughton Sykes, daughter of Gen. A. G. L. McNaughton. Dr. Foster was joined by his wife, his daughter, and other friends for the presentation.

John Foster, Chairman of the World Energy Conference and a former President of Atomic Energy of Canada Ltd., was born in Halifax, Nova Scotia in 1921. He attended Dalhousie University and Nova Scotia Technical College, graduating with a B. Eng. (Mech.) degree in 1943. Following graduation, Dr. Foster served in the Royal Canadian Navy to the end of the war, after which he returned to Nova Scotia Tech. where he received his B. Eng. (Elec.) degree in 1946, together with the Governor General's Medal.

Mrs. Leslie McNaughton Sykes, Gen. McNaughton's daughter, and Dr. Robert Alden, Director, IEEE Canada present the 1989 McNaughton medal to Dr. John S. Foster.

Dr. Foster joined Montreal Engineering Co. Ltd. and worked on the engineering for thermal power plants in the Maritime Provinces, Western Canada and Central and South America.

In 1953 Dr. Foster assisted with the rehabilitation of the NRX reactor at Chalk River and Became one of the members of the Nuclear Power Group which produced the feasibility study on the Nuclear Power Demonstration Station (NDP), Canada's first nuclear-electric generating station. When design work for this station was started by Canadian General Electric in 1955, Dr. Foster joined that company to take up the appointment as Head of the Design Engineering Group.

The Nuclear Power Plant Division of AECL was formed in 1958 to carry out the design of a full-scale power plant. John Foster was selected as Deputy Manager and became Manager later the same year. As the undertakings and staff increased, the Division grew into the Power Projects Organization with Dr. Foster as General Manager. He was appointed Vice-President of AECL in 1966.

Under his direction, these organizations performed the engineering for the nuclear part of the commercial prototype 200 MW Douglas Point Station, Ontario Hydro's Pickering A and Bruce A stations with 4-500 MW and 4-750 MW units respectively, and for a power plant in India. Work was also begun on the 600 MW units for Quebec, New Brunswick, Argentina and Korea. John Foster was responsible for the management of the engineering and construction of the Bruce A Heavy Water Production Plant and the first 1000 MW phase of the HVDC Nelson River Transmission facilities in Manitoba.

In 1974, Dr. Foster was appointed President of Atomic Energy of Canada Ltd. where he served until 1977.

Dr.Foster has long been associated with the World Energy Conference and is a Past Chairman of the Canadian National Committee. For several years, he has held offices in the world body and has been Chairman of its international Executive Council since 1986.

Dr. Foster has honorary doctorates of engineering from the Technical University of Nova Scotia and Carleton University. He is a Fellow of the Royal Society of Canada, the Canadian Academy of Engineering, and the Engineering Institute of Canada (Julian C. Smith Medal 1987) and was appointed by the Lieutenant Governor to the Council of the Association of Professional Engineers of Ontario in 1970 (Gold Medal 1984). He is an Honorary Director and Past Chairman of the Canadian Nuclear Association (W.B. Lewis Medal 1989).

The McNaughton Gold Medal is the Region's most prestigious award and is given to outstanding Canadian engineers in recognition of important contributions to the profession. It was struck in 1969 and honours General A.G.L. McNaughton, electrical engineer, diplomat, soldier and politician of national and international fame. The 3-volume biography of Gen. McNaughton was presented as part of the award. Dr. Foster's citation reads:

"For leadership and initiative in the fields of Power Generation and HVDC Transmission Systems, and for Service to the Profession and to the Country."

We congratulate Dr. Foster for his achievements.

Canadian Developments in Power System Simulation

Canadians are driving the state of the art in power system simulation technologies.

by R.P. Wierckx, T.L. Maguire,
D.A. Woodford (Manitoba HVDC Research Centre)
G.K. Rosendahl (University of Manitoba)
Winnipeg, Manitoba

Getting a handle on power systems ...

For many years, power systems engineers have relied on the simulator or transient network analyzer (TNA) to provide insight into the dynamic behaviour and characteristics of the large electrical networks.

An overview is made of the types of simulation tools that are commonly used by power systems engineers. Recent developments in the area of power systems simulation relating especially to "transients simulators" are highlighted.

Pour en arriver à une meilleure représentation des réseaux ...

Depuis longtemps, les planificateurs des réseaux de transport d'énergie s'appuient sur les simulateurs analogiques afin de prédire le comportement dynamique des réseaux et d'en déterminer les caractéristiques électriques.

On retrouve ici un survol des différents types d'outils de simulation les plus répandus. On y discute également de développements récents quant à l'évolution des moyens de simulation transitoire.

As electrical power transmission systems continue to expand and interconnect, the requirement for tools to study the ever-increasing system complexity grows too. The introduction of complex components such as HVDC converters and static var systems into the power system only serves to place further demands on the tools necessary to study the system.

Power System Simulation Tools

Depending upon the nature of the study at hand, various types of simulation tools are available to the power systems engineer. The three major classes of these tools are the load flow simulation, the power system stability simulation and the simulation of transient phenomena.

Load-Flow

A load-flow study is performed to determine the steady-state power flows within the power system grid. The addition of new components, such as a transmission line or compensation device, requires a load-flow study to be performed. The effects of the new components on the existing power system with regard to the distribution of power can be observed.

Load-flow studies typically model large portions of a power system using relatively simple models of the power system components. A steady-state phasor solution is employed.

Stability

Stability (or transient stability) studies are performed to determine a given system's ability to return to a relative state of equilibrium following a disturbance. Various types of faults may be applied to the modelled system, and the "swing" between the various generators and machines connected to that network may be observed. The stability program normally calculates the system's responses for many seconds after the fault to ensure that no portion of the network loses synchronization with respect to the rest of the system.

Component models used in transient stability studies, especially models of rotating machines and their associated control blocks, must represent the physical component's transient characteristics.

Transients

The most severe stresses on power system components usually occur immediately following a disturbance. Components connected closest to the point of the disturbance will bear the brunt of the impact. Transients simulation is performed in order to determine the stresses that are seen by the power system components due to particular faults. The results of a transients simulation study will help the power systems engineer ensure that component ratings are sufficient and protective devices are in place to prevent damage to the components in case of a fault.

In order to accurately model the power system's response to a disturbance (i.e. for the first few milliseconds after the fault) requires that the component models represent accurately the transient behaviour of the physical device. Typically, transients studies are used to model only a limited portion of the overall network under study.

Transients Simulators

Development of devices which perform the simulation of power system transients has been an on-going task for the past three decades. Due to the severe consequences that can result from improper design or protection of power system components, the considerable effort that has been expended in the past and that is currently being dedicated to transients simulators is justifiable. Two distinct types of transients simulators are commonly used today: the analog simulator and the software-based digital simulator.

Analog Simulator

Analog simulators, or transient network analyzers (TNAs) as they are often referred to, use scaled power system components to model the physical power system. The system model is constructed using components which operate in the range of 10's to 100's of Volts, with current levels on the order of a few Amps or less.

Since analog simulators operate at system frequency, the immediate advantage of real-time operation is realized. The interfacing of physical controls to the analog simulator can be easily accommodated in order to determine their performance and ability to control various aspects of the power system under study. System quantities such as voltages and currents can be observed and used as inputs to the devices under test.

There is also a number of disadvantages associated with the analog simulator. Technical problems such as unrealistically high losses in the modelled network must be countered with negative resistance boxes. The accurate modelling of devices such as power transformers, long transmission lines and machines also presents technical challenges.

The analog simulators are large, bulky devices that may occupy an entire floor of lab space. They are owned and operated almost exclusively by large manufacturers and research institutes. Time shares to use the simulator may be rented by third parties. As setting up the system model may take a week or more, once the allocated time is over it is very difficult to return (i.e. after absorbing the simulation results) to perform a number of follow-up tests. The lack of quick, general accessibility of the analog simulator is a major disadvantage.

What About Real-Time?

The term *real-time* when used in the context of simulators refers to the capability of the simulator to generate the system's response at the same rate that the physical system would respond. Analog simulators inherently operate in real-time.

Digital simulators determine the power system's response to a disturbance by solving mathematical equations representing the system under study at discrete time steps. In order for a digital simulator to achieve real-time operation, all of the equations representing the power system must be solved in less than or equal to the time step which is being used. Time steps on the order of 50 microseconds are typical. Hundreds of millions of floating point operations must be performed each second (MFLOPS) to digitally simulate a realistic power system in real-time.

Software-Based Digital Simulator

Many disadvantages of the analog simulator can be eliminated by using a software-based digital simulator. Using mathematical models of the components making up the power system and an algorithm to solve the network equations, a digital computer may be used to study power system transients. The algorithms necessary for software-based digital simulators were first described by Herman Dommel in his now classical paper of 1969 entitled "Digital Computer Solution of Electromagnetic Transients in Single and Multiphase Networks." The basic concepts outlined by Dommel were incorporated into the most widely used software-based simulator, known as the Electromagnetic Transients Program (EMTP).

The algorithm used in EMTP is referred to as a time domain solution: the equations that are solved are functions of time. To properly represent the higher frequency components of the power system transients, the software simulators must solve the state of the system in very small discrete time steps. Depending upon the type of disturbance being applied to the network, time steps ranging from 1 to 100 microseconds may be used. Even today's fastest computers could not solve all of the equations representing a typical power system in real-time. This lack of real-time operation of the software-based simulators means that the interfacing of physical controls, with feedback, into the network solution cannot be accomodated. To overcome the problem, mathematical models of the controls can be developed and integrated into the solution algorithm.

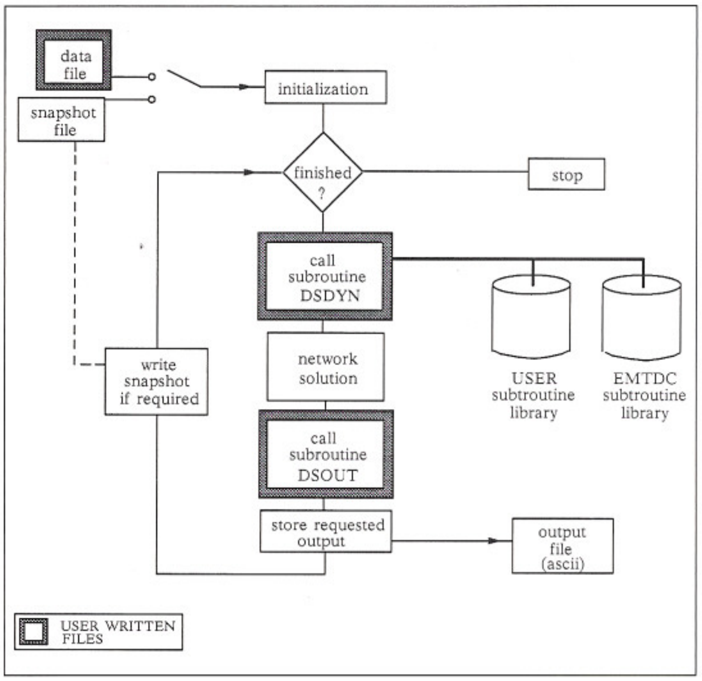


Figure 1 Flow chart of the algorithm used in the EMTDC software.

The major advantage of the software-based simulator over the analog simulator is its accessibility. The relatively low cost of high speed computers today means that utilities, consulting firms, manufacturers and educational institutions can provide mass access to the simulation tools.

Another tool with promising applications is the Frequency Domain Transients Program (FDTP). The advent of the Fast Fourier Transform algorithm and reduced cost of computer storage has renewed interest in frequency domain analysis as a complement to time domain analysis. Current activity on FDTP is being sponsored by the Canadian Electrical Association and the Manitoba HVDC Research Centre under Dr. L.M. Wedepohl. As the FDTP simulation tool develops, an increased scope of analysis will become available to the power systems engineer.

Analog or Digital: Getting Down to Business

Use of either the analog or software-based digital simulator requires a high degree of skill and experience on behalf of the power systems engineer. Knowledge of the limitations associated with the component models is essential if accurate results are expected. When using analog simulators, a team of engineers dedicated to the operation of the device is usually on hand to help in setting up the power system model. When using a software-based simulation tool, it is up to the user to construct and test the system model. However, the ease of use of transients simulation software has fallen far behind that of the software available to the designers of integrated circuit chips.

Consequently, a significant portion of the work done at the Manitoba HVDC Research Centre over the past number of years has focused on the development of modern digital transients simulation tools for power systems engineers. The work has resulted in a very flexible and easy-to-use software-based simulation package and a novel real-time, fully digital transients simulator.

Modern Software-Based Digital Simulators

The elegance and simplicity of Dommel's algorithm has been incorporated into a software transients simulation package initially developed at Manitoba Hydro. The software simulator was designed especially to allow the time domain simulation of power system networks which included HVDC converters and their controls. Figure 1 shows a flow chart of the algorithm used in the software, known as EMTDC.

In order to simulate a given system, the user must describe both the system's component interconnection as well as the system's dynamics. By allowing the user access to a high level computer language when specifying the system dynamics, complex logic may be incorporated into the simulation with relative ease. Furthermore, subroutines that perform specific functions or model unique power system components can be assembled, placed into a library and revised many times. To ensure accurate interaction between modelled control and protection devices, and the power system under study, the monitoring of specific system quantities can be done using predefined models of transducers.

With the software simulators currently available, power systems engineers are able to model complex networks in detail. Some of the more interesting systems which have been modelled using software tools include the Nelson River HVDC System, the HVDC New Zealand interconnections between the South and North Islands (including the proposed upgrades) and the McNeil back-to-back HVDC system in Alberta. The concept of "Super Digital Simulation" whereby all the major AC and DC transmission lines, stations, generators and associated controls and protection devices in a provincial power system can be represented in a single model is fast becoming a reality. Transient response of such large systems can now be obtained in a reasonable amount of time using software-simulation tools, due primarily to the powerful workstation computers available in the marketplace.

Workstation Applications for Power System Simulation Tools

Emergence of the computer workstation network provides an excellent platform for the use and development of software-based digital simulation tools. Simulation software has recently been integrated into such a workstation network at the Manitoba HVDC Research Centre. The primary advantage of the workstation network over the more conventional mini- or mainframe computer facilities (typically employed by the power system industry) is a division of workload. By dividing the computing power into many stations rather than having a single computer handle the entire load, a far more efficient computing environment is realized. The graphics capabilities and individual computing power available to the engineer using a workstation far exceeds that available when sharing a large computer with entire departments.

To demonstrate the flexibility and ease of use of the workstation-based simulation software, a short description of the primary modules comprising the software is presented. It is envisioned that integrated software packages incorporating all three types of power system simulation tools, including frequency domain analysis using FDTP, will operate from a single database and become the norm in the future. It will be necessary for the power system community to adopt a set of standards defining the way in which power system component models are defined and maintained in a database.

File Management System

An icon-based file management system has been included to aid the user in maintaining the large array of files that accumulate during the construction of a new network model. Since new models are usually constructed in stages, the file management system maintains a hierarchical structure of the users' various projects, cases and input/output files. Features are available to allow sharing of models and files between network users (Figure 2).

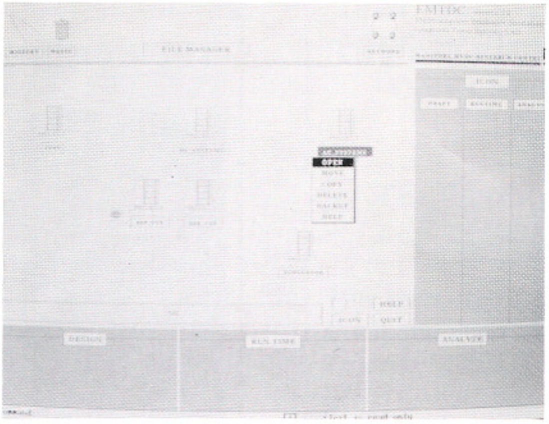


Figure 2 The file management system.

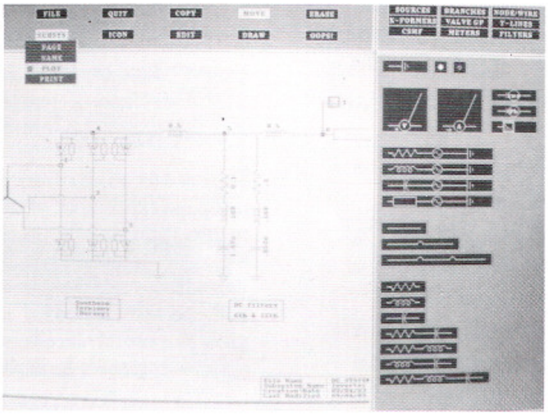


Figure 3 The graphic data input module.

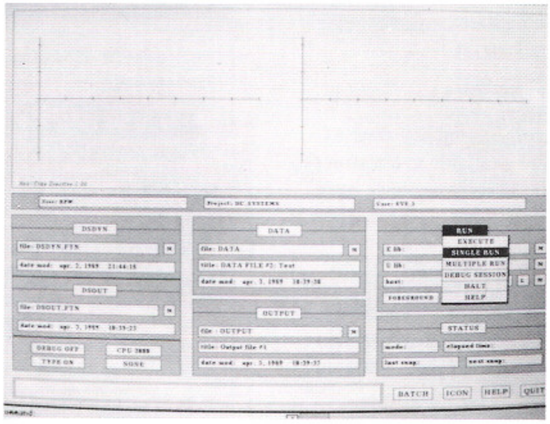


Figure 4 The runtime executive.

Graphic Data Input Module

The workstation's high resolution graphics capabilities have been used for the graphics input module. Instead of creating a text-based file describing the interconnection of the network under study, the user may now draw a circuit diagram of the system. Icons presenting power system components are chosen from a menu and may be placed onto a drawing surface. Once the circuit has been drawn, the necessary input files required by the software simulator are automatically generated. The user is warned of any irregularities in the model, and the software highlights potential problems that may be encountered if the system is simulated as is (Figure 3).

Runtime Executive

Once the input files for the software simulator have been created, the user may direct the simulation to be run on any computer accessible in the network. The advantage here is that there may exist machines of various computing capabilities within the network. The computer intensive simulation may be run on one of the faster machines available, thereby leaving the user's own computer free to perform other tasks.

The Runtime Executive is able to run numerous cases distributed over the network. Results of the simulation may even be shown graphically on the user's computer as they are being calculated (Figure 4).

Output Analysis Package

Plotting and analysis of the output produced by the software simulator can be observed using the output analysis package. Scaling and formatting of the results (for insertion into a report) is available. Fourier analysis of the plotted curves can be done on-line (Figure 5).

Real-Time Digital Simulator

The most exciting development in the field of power system transients simulation has been the successful demonstration of a digital simulator capable of real-time operation. Advantages of both the analog and software-based simulation tools are combined in the fully digital real-time simulator.

Due to the vast number of calculations that must be performed during each time step of the software-based simulator, it takes a lot more time to perform the calculations than the duration of the time step, say 50 microseconds. If a computer could be devised which could perform all of the necessary calculations within the given time step, then real-time would be achieved. The computer that was constructed at the Manitoba HVDC Research Centre to perform the calculations is based on parallel processing concepts. The machine's general architecture is shown in Figure 7. By limiting the interconnection of tightly coupled groups of parallel processing elements, the architecture mimics that of an electrical power system; larger and larger networks can be modelled by adding groups of processing elements without jeopardizing the simulator's real-time capabilities.

A first attempt to achieve real-time simulation using conventional microprocessor technology (Motorola 68000 microprocessors) ended with little success. It was only when digital signal processors appeared, with their immense floating point calculation speed, that realistic power system models could be simulated digitally in real-time. Unique schemes were devised which divided the network solution algorithm and calculation of the power system components amongst individual processors in an efficient manner.

Experience gained during the development and use of simulation software was used extensively in the development of the real-time digital simulator. The previously discussed graphical front end serves as the front end for the real-time simulator as well. A compiler has been developed which produces the executable code for the simulator's individual processing elements, based on data entered using a graphical data input module. The user need never see any low-level code or machine language.

Since there are only three distinct printed circuit boards which make up the simulator, the hardware costs are far less than that of the analog simulator. It is estimated that a simulator capable of modelling a bipolar HVDC system, with the associated AC networks at either end, would lessen the cost by 20% and occupy less than 20% of the space of an equivalent analog simulator (Figure 6).

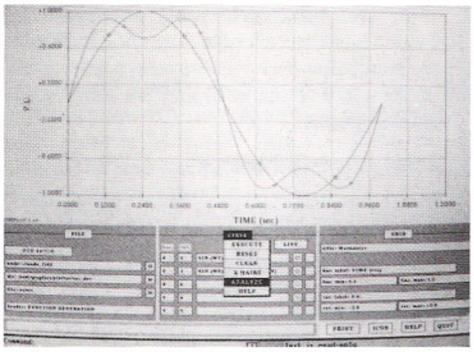


Figure 5 The output analysis package.

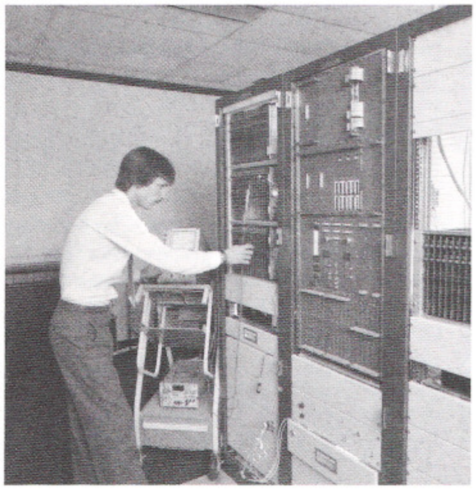


Figure 6 The real-time digital simulator with physical HVDC controller.

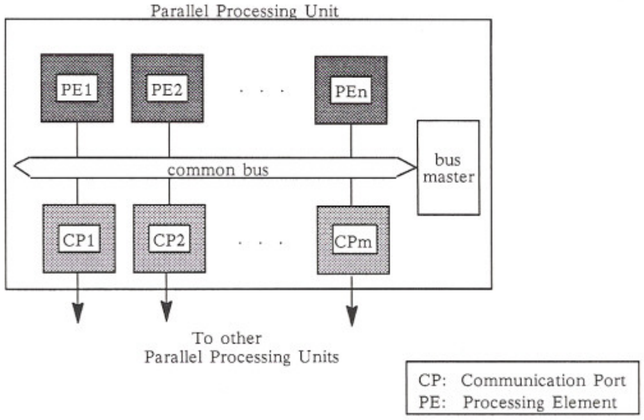


Figure 7 Real-time digital simulator architecture.

Conclusion

The need for more advanced power system simulation tools is being met by using the capabilities of the workstation computer network. For users that require the interfacing of physical controllers and protection equipement in the modelled power system, the fully digital real-time simulator is the tool that will provide the greatest flexibility in the near future. Capabilities of both the software-based and real-time digital simulators will continue to grow as more advanced computing devices appear, and especially as power systems engineers demand more sophisticated modelling capabilities.

Some of the applications of the real-time simulator which are currently being addressed at the Centre are as follows:

Alternating Current Transient Network Analyser (AC TNA)

In its most general form, the simulator operates as a fully digital real-time AC TNA. Typical power system component models are available to construct AC networks for study. Time steps on the order of 50 microseconds have been used in example cases run on the simulator.

Data generated by the simulator may be monitored using an oscilloscope connected to one of the digital to analog converters found on each processing element, or may be stored and downloaded to a host computer for analysis. The analog ouputs may also be used as inputs to a physical controller. Feedback from the controller into the simulator is done via input ports on each processing element.

Relay Test Simulator

Use of the simulator to test protective relays has received a great deal of interest. By having the real-time simulator model a network interfaced to a physical relay, the relay engineer may observe the relay's response to particular faults. Since the simulator operates in real-time, a relay could be used to trigger the opening and closing of breaker models when a simulated fault occurs. A particularly useful application is the testing of distance relays. A series of cases could be run where the fault location on a transmission line is moved successively closer to the relay. The relay's response could be checked for accuracy with the known location of the applied fault and the corresponding impact of electromechanical swings.

Dedicated Workstation Network Accelerator

With the simulator connected to a workstation network's high speed communications links, users are able to submit cases to the simulator and receive the results quickly. Whereas software simulation tools may require minutes or hours to perform a given simulation, the real-time simulator could provide results in seconds. In this mode, the simulator is shared among the users of the workstations network and acts like an accelerator.

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