Real-Time Generation Control

by *Patrick Toner, Jean Pierre Turgeon, Alain Verreault*
SNC-Lavalin ECS, Montréal, QC

Abstract

Generation scheduling and control is an important component of daily power system operation. The overall objective is to control the electrical output of generating units in order to supply in an economical manner the continuously changing customer power demand. Much of this functionality is provided by Automatic Generation Control (AGC) and related functions operating within a utility control centre Energy Management System (EMS).

This article describes the generation control functions developed by the SNC-Lavalin Energy Control Systems Inc. as part of its EMS product line. This Generation Management Subsystem (GMS) has been designed and implemented for efficient and reliable operation in real-time, allowing real-time monitoring and hierarchical control of generation resources.

Sommaire

La planification et le contrôle de production d'énergie est une partie importante de l'exploitation quotidienne d'un réseau électrique. L'objectif général est de contrôler la puissance fournie par des unités de production d'énergie afin d'alimenter de façon économique l'appel de puissance, en continuel changement, de la clientèle. Une grande partie de cette fonctionnalité est fournie par un Contrôle de production automatique (Automatic Generation Control - AGC) et des fonctions connexes opérants sous un Système de gestion d'énergie (Energy Management System) d'un centre de contrôle. Cet article décrit les fonctions de contrôle de production développées par SNC-Lavalin Systèmes de contrôle de l'énergie Inc. dans sa ligne de produits EMS. Ce Sous-système de gestion de production (GMS) a été conçu et mis en oeuvre pour une exploitation en temps réel efficace et fiable, permettant une surveillance en temps réel et un contrôle hierarchique des ressources de production d'énergie.

1.0 Introduction

Power system loads are sensitive to frequency and following system frequency changes the aggregate load change follows the frequency deviation. When a generating unit is tripped or additional load is added to the system, the power mismatch is initially compensated by an extraction of the kinetic energy from the system inertial storage (the spinning masses) that causes a system frequency drop. As the frequency decreases the power consumed by loads also decreases. Equilibrium for large systems can be obtained when the frequency sensitive reduction of loads balances the power output of the tripped unit or that delivered to the additional load resulting in the new frequency. This effect could stop the frequency decline in less than a couple of seconds. However, if the mismatch causes the frequency to deviate beyond the governor deadband of the generating units their output will be increased by governor action. For such mismatches, equilibrium is obtained when the reduction in power consumed by loads plus the increased generation due to governor action compensates the mismatch. Such equilibrium is normally obtained within a dozen seconds of the frequency incident.

Governor droop is the percent change in frequency that would cause unit generation to change by 100% of its capability. Typical speed droops for active governors are in the range of about 4%. With this level of frequency sensitivity and at the expense of some frequency deviation, generation adjustment by governors provides ample opportunity for follow up manual control of units.

This automatic adjustment of generation by free governor action is known as primary frequency regulation. The objectives of the follow up control especially under normal changes of load, are to return frequency to schedule, to minimise production cost, and to operate the system at an adequate level of security. Automatic Generation Control (AGC) (also known as secondary frequency regulation) is a closed-loop control system that partially replaces this manual control.

This form of generation control has become essential to the real-time operation and control of interconnected power systems and operates in widely varying power system control environments ranging from autonomous to strongly interconnected systems with hierarchic multi-level control.

Compared with generation based frequency control, generation based reactive power or voltage control is less standardised and less automated. Primary voltage control involves keeping generator terminal voltages at their setpoint values by means of controls, automatic voltage regulators, which operate as part of the generating unit excitation system. This automatic correction compensates against random variation in the transmission network within a few seconds.

Few countries in the world have semi-automated, secondary voltage control of generators. The main objective of the secondary level voltage control is to update the set points of generator exciters to maintain voltages at critical points within pre-defined deviations as reactive power demand and generation deviate from their scheduled values. These scheduled values can be provided by tertiary voltage control i.e. Real-time Optimal Power Flow applications.

Figure 1: Ningxia Autonomous Region Generation Control Centre, China.

Automatic Voltage Control (AVC) is an implementation of secondary level voltage control at the generating plant level. The objective of this plant control also known as Joint Voltage Control is to maintain the high-side voltage of the step-up transformers equal to specified values while avoiding reactive power interchange among the plant units.

SNC-Lavalin ECS has supplied generation control software integrated with SCADA as part of its “GEN-3” EMS product line to a wide range of customers throughout the world.

In 1995, the first “GEN-3” dispatch-level EMS was commissioned at the Ningxia Autonomous Region Generation Control Centre in China (Figure 1).

More recently, both AGC and AVC were delivered as part of a “GEN-3” Hydro GMS recently commissioned at the 10, 000 MW Guri Hydroelectric power plant on the Caroni river in Venezuela (Figure 2).

This article describes the generation control functions and related software architecture developed by the SNC-Lavalin Energy Control Systems Inc. as part of its EMS product line.

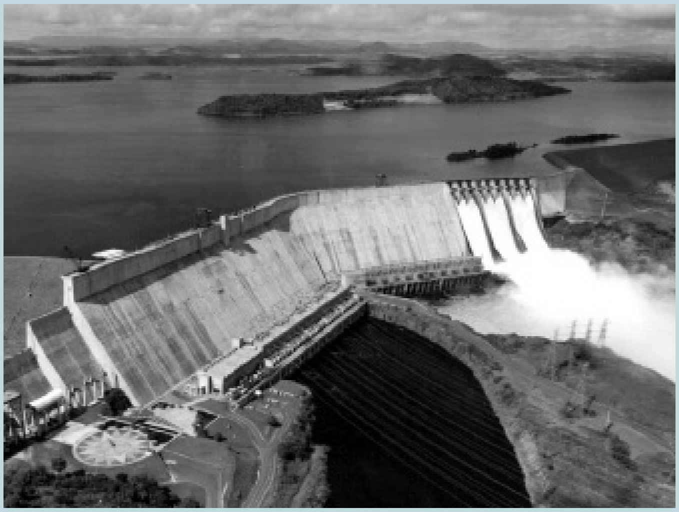

Figure 2: Guri dam, Venezuela.

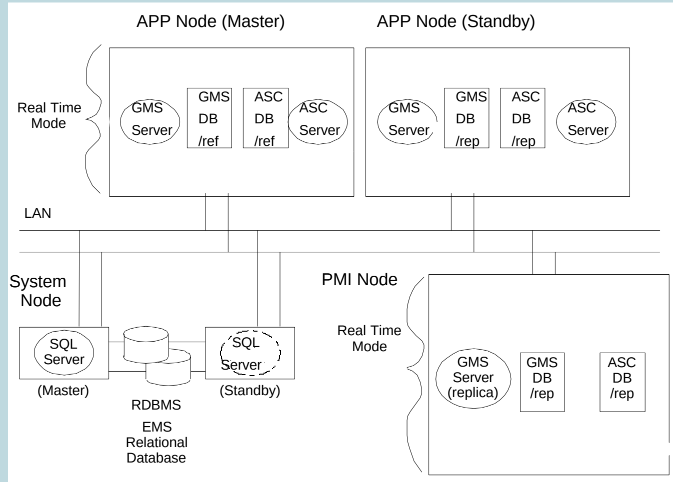

Figure 3: System Architecture Configuration.

2.0 ECS Software Architecture

The ECS system comprises a Supervisory Control and Data Acquisition (SCADA) subsystem, and advanced application subsystems such as Network Analysis and Security (NAS), Operational Planning and Scheduling (OPS) and the Generation Management Subsystem (GMS).

The system is implemented with multiple processing units (nodes) that are connected together by a Local Area Network (LAN). The system uses a homogeneous hardware/operating system (Unix) platform for its processors.

The Figure 3 below presents the consolidated EMS configuration consisting of the System (SYS), Data Acquisition (DAC), Application (APP), and Person-Machine-Interface (PMI) nodes.

SCADA executes on redundant Data Acquisition (DAC) nodes that have special hardware interfaces for communication lines to the Remote Terminal Units (RTUs) to perform the data acquisition tasks. RTUs are data acquisition units placed at various locations throughout the power system to collect data and perform remote control.

The advanced application such as GMS can execute on the DAC nodes or more usually on a redundant pair of Application (APP) nodes. Data processing and application calculations are performed on the different server nodes, for example DAC and APP, and results are distributed to the other server nodes and the operator workstations, known as PMI nodes.

The SYS node contains the EMS relational database tables.

2.1 GMS Software Architecture

The GMS architecture is characterised by application programs such as AGC, Economic Dispatch, AVC and Spillway Gate Control, a GMS server process and a memory-resident database. The server process schedules and executes all of the GMS applications and provides remote access from the PMI nodes.

The GMS memory-resident database (GMS/m) and related services are responsible for storing all GMS data i.e. static data, application control parameters and application results. The GMS/m provides a central data storage and retrieval mechanism for data that is used very frequently and allows many processes to access the information at the same time.

The EMS relational database (EMS/r) includes the static data description of the power system and organises data for specific uses, for example, GMS data. GMS interfaces with the relational database for the static population of the GMS/m and handling edits of GMS data in the relational database

Like all other ECS processes, the GMS server is a redundant process and maintains a reference copy of the GMS/m on one of the APP nodes, referred to as the reference node for this “reference” server. The server on the other available APP node acts as a standby “replica” for the reference server. The PMI nodes as well as the standby APP node have their “replicated” database maintained by data propagated from the reference APP node.

When the GMS reference server process fails or the APP node on which it is running fails, the standby server takes over from the failed reference server and thus becomes the new reference server. When the failed reference server recovers, the full database is downloaded from the reference and it starts as a standby. This “failover” strategy ensures high availability for application programs.

2.2 Real-time Data from SCADA

The SCADA subsystem includes telemetry scanning, data processing, output co-ordination (controls to RTUs, strip chart, mapboard updates and data links) and calculated point computation.

The data acquisition programs obtain measured data from the data links and RTUs, validates, converts and stores the data in the real-time SCADA database. This database is organised on a point (measurement) basis and analog, status (digital) and accumulator points are supported. GMS receives notification of selected point updates, for example unit MW generation, frequency, tie line MW.

Supervisory control applications provide the capability to control field devices associated to SCADA points. Discrete, incremental (raise/lower) and setpoint controls are supported. GMS interfaces with these supervisory control applications to send, for example, generator MW and generator Mvar setpoint commands and spillway gate position commands.

2.3 Alarming

One of the primary goals of GMS is to provide real-time monitoring of generation resources and to support dispatchers in taking corrective action. Using the standard ECS alarming services audible and visual indications are provided to the dispatcher when abnormal conditions arise. The dispatcher is also notified of other events occurring on the system, for example, dispatcher actions.

Presentation control allows priorities to be assigned to alarms and provides alarm acknowledgement and alarm inhibiting.

2.4 User Interface

Real-time displays present GMS data in variety of formats. Multi-headed, full-graphics consoles form the primary interface to the GMS applications. Standard input devices include an alphanumeric keyboard and a three-button trackball or mouse.

Each full-graphics console operates as an independent workstation, performing all display processing locally. Display data is maintained in local memory and on disk and as mentioned previously, real-time GMS database updates are continually provided to the workstation via the replicated database communication facilities. The data broadcast scheme provides continuous exception updates to the workstation

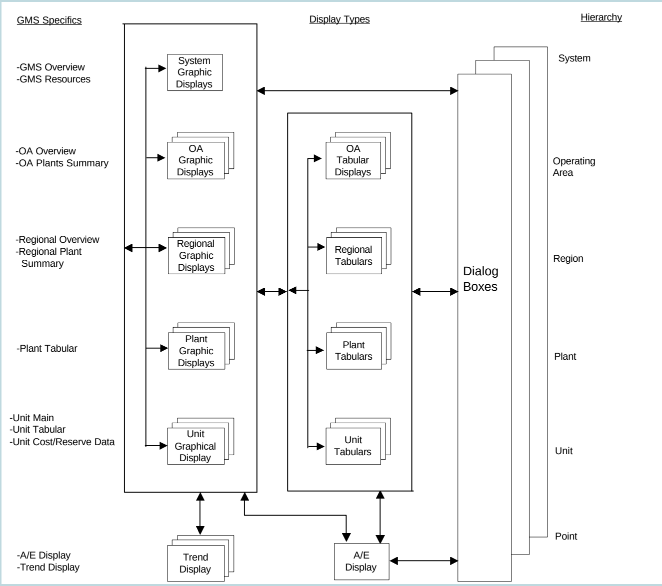

Figure 4: GMS Operational Displays Tree, Based on Power System Hierarchy Levels.

database.

All application user-interfaces are implemented in X-windows using the Motif widget set. These widgets provide standard user-interface objects such as push buttons, list, menus etc. Motif controls the display and handling of these widgets, thus ensuring a consistent “look and feel.”

Display types include graphical summary displays, dialogs and menus, tabular displays and trend displays (Figure 4).

3.0 Hierarchical Generation Control

3.1 Introduction

The principles of AGC are well known and relatively straightforward in terms of control theory. However, AGC implementation depends on the regulating strategy of the particular utility and its place in a well-defined national or international regulating hierarchy. GMS products have been developed for different levels in the control hierarchy.

The Dispatch-Level GMS performs real-time monitoring and control of generation resources to ensure economic and secure operation of interconnected power systems at a national or regional level as part of a conventional EMS.

The Hydro GMS performs real-time monitoring and control of hydraulic resources to ensure the control of generation, voltage and water spillage in one or more large hydroelectric plants.

3.2 Dispatch-Level

The GMS supports multi-control area and multiple "pre-defined islanding" configurations and consequently can be employed for varied national and regional level control schemes to control and monitor regulating entities: control areas, power plants and generating units in order to meet the following operational objectives:

- Load-frequency control,
- Tie-line control of interconnected systems,
- Time error correction,
- Inadvertent energy exchange monitoring and control,
- Control of generation regulating entities,
- Economic operation of generating units,
- Performance monitoring,
- Production cost accounting.

GMS can support multiple independent control areas. The Operating Area Configurator application monitors the network electrical connectivity and can detect pre-defined configurations corresponding to known control areas. When an unknown configuration is detected the execution of the AGC is suspended.

The GMS system takes into account the economics of operation through its Economic Dispatch function. Typically, every 5 minutes Economic Dispatch distributes the current load among the generators so as to minimise the cost of generation. The generator MW output determined by ED is then used as a base point by AGC.

AGC aims principally at maintaining frequency and/or interchange levels at prescribed values. It calculates MW set points for controlled generators. The set points are determined as deviations from the ED calculated base points. As secondary objectives AGC tries to correct inadvertent energy interchange and time error.

During the course of the day and in spite of the control exerted by AGC, the total net energy exchange (defined as the algebraic sum of the integrals of tie-lines power flows over time) may be biased towards too much export or too much import. Utilities have agreements specifying when and at what rate those errors must be corrected and AGC includes features allowing it to bias its interchange objectives in the desired direction.

It may also happen that, over a period of several hours, the average frequency tends to be either too low or too high. The integral of the frequency has dimension of “cycles” so, the cycle being equal to 1/60th of a second at normal frequency in North America, this quantity is termed the time error of the system. Again, utilities must keep that error as close as possible to zero and AGC can, given the error and the period over which the error must be corrected, bias its frequency target in order to eliminate the time error.

In addition to its control functions, GMS includes Reserve Monitor and Production Cost Monitor functions. The Reserve Monitor keeps track of the MW and MVAR reserves, and generates alarms when reserves become too low while the Production Cost Monitor calculates the cost of generation for both power and energy.

3.2.1 Main features

- Linear and adaptive area control error filtering,
- Proportional-Integral controller,
- Setpoint control and pulse control commands,
- Equal incremental cost dispatch,
- Cost function based on heat rate data, discharge rate curves or bid-price data,
- Inter-regional transfer limits,
- Dispatch of multiple plant and fuel types,
- Retrieval and write-back of measurement (SCADA) data,
- Online database updates and parameter validation,
- Interface with Network Analysis and Security Subsystem,
- Interface with Operations, Planning and Scheduling Subsystem.

3.2.2 User-Interface

- Graphical and tabular representation of generating unit monitoring, dispatch and control data
- Graphical representation of area control error, frequency and interchange
- Graphical representation of area, plant and unit reserves
- Summary, execution and control displays for AGC, Economic Dispatch, Reserve Monitor, Production Cost Monitor

3.3 Hydro GMS

The GMS can also be employed for varied hierarchical control schemes, ranging from regional hydro generation dispatch centres to hydro plant generation control centres to provide co-ordinated voltage and frequency control and monitoring and control of reservoir flows. More specifically, the GMS applications are used to monitor and control hydraulic generation resources in order to satisfy various operational objectives:

- Load-frequency control,
- Control of generation regulating entities to maintain generation targets,

Figure 5: AGC Control Area Summary Display.

- Economic operation of generating units,
- Topology processing for plant connectivity,
- Joint Var Control of generating units within a plant to control voltage and avoid reactive power interchange between units,
- Monitoring and control of reservoir outflows,
- Performance monitoring.

In other words, the GMS hydro applications are the basic functions for real-time monitoring and control of the generating units within a hydro power plant. Automatic Generation Control (AGC), Generation Dispatch (GD), Reserve Monitor (RM), Spillway Gate Control (SGC), Network Topology Processor (NTP) and Automatic Voltage Control (AVC) are the main GMS hydro applications.

The AGC application controls MW output of online regulating generators with the objective of maintaining the system frequency and desired generation levels within specified bounds.

The RM application calculates the available real and reactive power reserves within a plant. Different reserves are calculated as a function of different unit limits and plant conditions.

The GD application computes base points and participation factors for qualified units in the power plant to achieve a selected operating objective. The computed base points and participation factors are used by AGC to allocate generation control errors among qualified units.

The NTP application monitors the connectivity of the main busbars in the plant switchyard and the connectivity of the electrical devices connected to the main busbars.

The SGC application controls opening of the plant spillway gates in order to achieve a specified total plant release or gate position. The user can manually enter the required release or a scheduled value can be used.

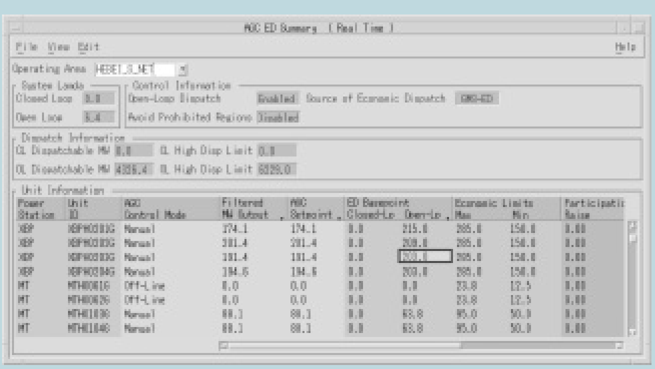

Figure 6: AGC Generating Unit Tabular Display.

The AVC application regulates the voltage on a selected plant busbar by controlling generating units' reactive power generation.

During normal operation, these objectives are carried out by the applications executing automatically at pre-defined intervals. But they may also be launched in response to pre-defined events or on dispatcher demand when manual intervention is required.

3.3.1 Main features

- Linear and adaptive control error filtering
- Proportional-Integral Controllers
- Setpoint control and pulse control commands
- Minimization of the water discharge level using the equal incremental cost dispatch
- Balanced load factor dispatch according to MW capacities
- Generating unit Mvar dispatch
- Open-loop and closed-loop control of spillway gates
- Retrieval and write-back of measurement (SCADA) data
- Online database updates and parameter validation
- Interface with Operations, Planning and Scheduling Subsystem

3.3.2 User-Interface

- Graphical and tabular representation of generating unit monitoring, dispatch and control data,
- Graphical representation of control error (MW, Mvar, kV and spillway flow), frequency and plant generation (MW and Mvar), voltages and spillway flows,
- Graphical representation of plant connectivity and equipment using dynamic bus colouring,
- Graphical representation of reservoir elevation, release and gate positions,
- Summary, execution and control displays for Automatic Generation Control, Generation Dispatch, Reserve Monitor, Automatic Voltage Control and Spill-way Gate Control.

4.0 Future Challenges

4.1 Generation control in a market environment

Since the generation applications were originally developed for vertically integrated utilities, the advent of de-regulated energy markets is providing significant challenges. In terms of generation control, the evolution of power system operation into a market structure requires that the provision of secondary frequency control and reactive power support by generating units become marketable ancillary services.

The evolution to a market-based AGC and the handling of ancillary services are among the most significant changes for generation functions.

4.1.1 Market-based AGC

- AGC modifications to accept external generating unit basepoints and external ACE signals from the Independent System Operator (ISO),
- Modified load following for the market environment,
- Replacement of conventional, “cost of operation” economic dispatch by a market-based dispatch, based on price,
- Checking the mismatch between the actual power and contract power: Balancing Energy and Ex-Post pricing function,
- Support dynamic scheduling: transfer of AGC regulation components between control areas by dynamic interchange scheduling,
- Monitoring of unit regulation performance.

4.1.2 Market-based Reserve Monitor

- Support schedules for regulation and reserves (transient or primary, regulating, spinning, operating) and reactive support i.e. ancillary services,
- Monitoring and checking the reserves contracts,

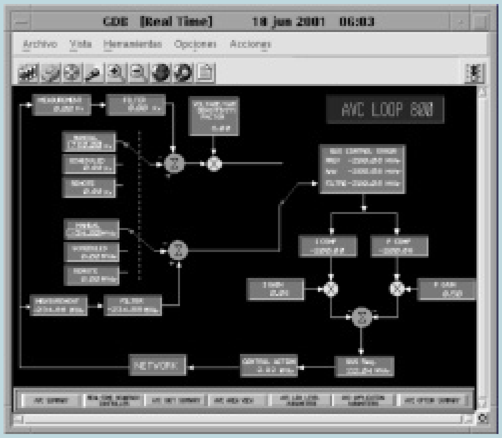

Figure 7: Automatic Voltage Control Summary Display.

4.2 IT Infrastructure

The evolution of existing EMS functions to meet market requirements and the provision of interfaces to the many, emerging market functions and information systems is continuing to provide important technical challenges for EMS vendors such as SNC-Lavalin ECS.

In the evolving deregulated environment, the various players, generation companies, transmission companies, distribution companies, power exchanges, scheduling coordinators, ancillary service providers and the independent system operator require increasingly reliable, expandable and above all open information systems that can safely manage and securely exchange both trading and settlements data, scheduling data and power system operational data.

4.3 Secondary Voltage Control

Some utilities already use a hierarchical real-time voltage control and reactive power control system with the addition of secondary voltage regulation to the automatic voltage regulation of generators.

The choice of performing the voltage control by the adoption of multi-level hierarchical structures seems to be (especially in Europe) more and more attractive for the reactive power production of regions within a larger power systems.

This application should be further developed to provide a generalised hierarchical real-time voltage control. Such a control system poses significant technical challenges but would have an important role to play in real-time closed-loop voltage control.

5.0 Further Reading

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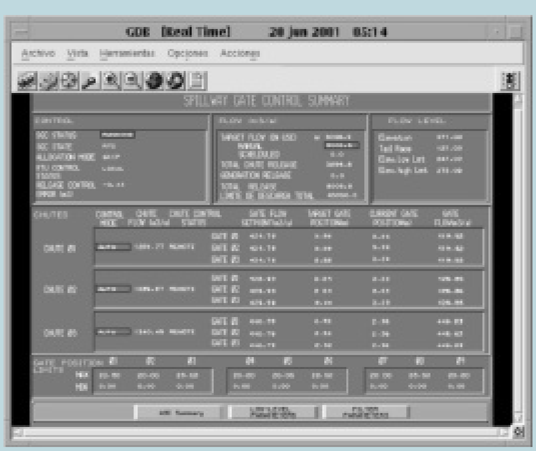

Figure 8: Spill-way Gate Control Summary Display.

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In June 2000, SNC-Lavalin Inc. acquired 100 percent ownership of the Energy Control Systems Division of CAE Electronics Ltd., and a new company - SNC-Lavalin Energy Control Systems Inc. was established. SNC-Lavalin Energy Control Systems Inc. develops and delivers energy control systems (ECS) to a wide range of power utilities. The ECS product line includes a Supervisory Control and Data Acquisition (SCADA) System as well as an Energy Management System (EMS) for generation and transmission network monitoring and control and a Distribution Management System (DMS) for substation and distribution network monitoring and control. This "GEN-3" product line is based on an open, distributed architecture and is in operation in various utility control centres throughout the world.

About the authors

Patrick Toner holds B.Eng. and Ph.D. degrees in electrical engineering from the Queen's University of Belfast, N. Ireland. He is a group leader in the SNC-Lavalin ECS division. He is an associate member of the IEE, member of the IEEE and member of the Ordre des ingénieurs du Québec.

Jean Pierre Turgeon holds B.Sc. and M.Sc. degrees in mathematics from the Université de Montréal. He is a group leader in the SNC-Lavalin ECS division and member of the IEEE.

Alain Verreault holds B.Sc. and M.Sc. degrees in computer science from the Université de Montréal. He is a software designer in the SNC-Lavalin ECS division.