Simulation of an extra large network in EMTP: from electromagnetic to electromechanical transients

Luc Gérin-Lajoie and Jean Mahseredjian

Abstract--**This paper presents a new experiment with a graphical user interface and advanced numerical methods, for maintaining and simulating a very large network in an EMTP (Electromagnetic Transients Program) type program. It is a feasibility study for extra large networks when performing various types of simulations within the same environment and using the same data set. The demonstration network is the Hydro-Québec network from 735 kV to 49 kV voltage levels. Standard transient stability software is used for the corroboration of the network's dynamic behavior. The related challenges and solutions are presented.**

Keywords: **EMTP-RV, PSS/E, large networks, transient stability**

I. Introduction

The power system engineer is faced to solve problems of various complexity levels. The classical approach with computer analysis tools is to establish a compromise between precision, computational speed and available data. The ultimate goal is to achieve the most precise simulation with all required modeling data and within minimal computer timings. There is also an issue of unique data set maintenance and flawless transition between simulation types, such as load-flow, transient stability (electromechanical transients) and EMTP (Electromagnetic Transients Program).

The frequency range of modeling in EMTP-type programs has been constantly increasing with increasing computer speed, improved models and numerical performance. At Hydro-Québec (TransÉnergie) the level of modeling in EMTP studies is continuously escalating. The inclusion of machine voltage regulation controls allows studying 60 Hz overvoltages in conjunction with automatic system separation controls [1]. It is also required for various studies, such as, motor startup, network islanding, single-pole reclosing analysis, statistical studies, harmonic analysis for industrial installations and research activities related to power swing detectors.

The creation and maintenance of a large utility network in a single Graphical User Interface (GUI) environment with load-flow, stability and EMTP data has many advantages. It provides a unique and validated data set, allows data extraction and aggregation for various applications and allows performing different types of analysis from different locations.

This paper presents the feasibility, challenges, methods and computing times for the creation, simulation and validation of an extra large network in an EMTP type application (EMTP-RV version). To the author's best knowledge, it is the first time that such a large network is created and solved in an EMTP-type environment with computational engine and graphical user interface. EMTP simulations are multiphase and can contain data for the widest frequency ranges from electromagnetic transients to multiphase load-flow. This means that EMTP data is at the highest level and can be extracted and used in other types of applications, such as PSS/E (stability) and real-time simulators. Moreover, it is foreseeable to include supplementary information if the GUI devices are not limited and allow extra data fields. Such data fields can be used for various translation and data relaxation rules.

II. Network data input

The software used in this paper is EMTP-RV [2] and its graphical user interface EMTPWorks [3]. This choice is related to previous work conducted by the authors and also the availability of required capabilities for assembling and simulating extra large networks. The validation (verification) software for stability and short-circuit studies are PSS/E [4] and ASPEN [5]. The databases for these two applications were available at Hydro-Québec.

A. Building the network, GUI considerations

At the first level there are several GUI considerations since the data input and maintenance constitutes the first and most time-consuming step. The approach in this paper avoids using ASCII file type inputs and maximizes GUI usage and visualization. Four important schematic design methods must be applied in the GUI: hierarchy, layering, data scripting and device attributes.

Although EMTP networks are multiphase, it is needed to draw using the single-line diagram approach and separately

Luc Gérin-Lajoie is with Hydro-Québec, TransÉnergie, Montréal, Canada
Jean Mahseredjian is with École Polytechnique de Montréal, Campus Université de Montréal, 2900, Édouard-Montpetit, Montréal (Québec), Canada, H3T 1J4 (corresponding author, 514-340-4711 (4870); e-mail: jeanm@polymtl.ca).

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connect to phases or draw arbitrary circuits only when required. The user should enter the network data and connectivity only. The design should not be forced to account for particular issues related to the underlying computational limitations. Limitations, such as artificial network separations or dummy separations between devices for numerical reasons must not be strained since they will seriously handicap the creation of large networks and data maintenance. This was achieved using the computational engine of [2].

B. Hierarchy

Hierarchical design means designing with subnetworks. This concept is illustrated in Fig. 1. The top design level contains subnetworks numbered from 0 to 5. Subnetworks 0 and 5 are at the second hierarchical level and subnetworks 1 to 4 are contained at the third level from top down. This is also related to object oriented development with hiding and encapsulation. At the highest level the number of circuit details must be minimized and details must be moved into subnetworks. In the diagram of Fig. 2 the Static Var Compensator (SVC) is a top level device made of several subnetwork levels for modeling its internal circuits and controls, but it appears as a small symbol with a mask for setting internal parameters. Its contents become accessible in separate windows. The same approach is used for the contents of Eastmainlasarcelle shown in Fig. 2.

An example of multimachine power plant representation is given in Fig. 3. The shown AVR blocks contain several encapsulated subcircuits.

Some subnetwork types may be used many times and a mechanism must be available for updating all subcircuit contents by modifying the internal details of only one instance. This object-oriented mechanism is called unique type definition. If two subcircuits are of the same type, then any (data or circuit) change in one of the subcircuits is automatically reflected in all other subcircuit instances. Thus a single change in one type definition is automatically propagated to all instances of the same type. In Fig. 1 the subnetwork 2 is used at two different locations, but maintains the same type definition. A unique definition can be maintained for contents, but mask data can vary by using named values in subnetwork devices data fields. Subnetwork data and contents are programmable.

Primitive devices can also become subnetworks. This provides the capability to maintain a device symbol, but modify its model through the modification of its contents.

The notion of subnetworks is not new as such and exists in other applications, but the type definition notions are unique to EMTPWorks [3].

C. Layers

Since the ultimate goal is to develop a reference network for various study types, it has been found that GUI layers provide the solution to the maintenance of multiple levels of study. Devices are given a layer attribute that allows them to be excluded and included through a single layer selection command. Layers provide a convenient approach for precision and study type selections. If the objective is to perform faster transient stability computations then nonlinear devices such as surge arresters or magnetization branches can be excluded. Precision can be increased by including the series-capacitor protective arresters. Layers are available at all hierarchical levels. In Fig. 3 the load-flow (LF) devices are active only in the load-flow solution layer, but transmit data to the adjacent synchronous machines for the corresponding steady-state solution before the time-domain initialization.

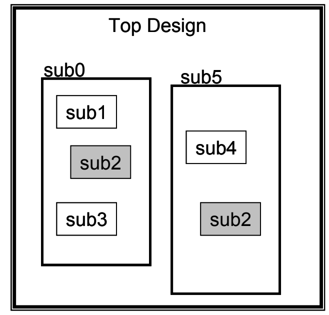

Fig. 1 The hierarchical circuit construct with unique type definition

D. Scripting and attributes

Using only the GUI mouse based functions for entering and maintaining data is not viable for building and maintaining large networks. Entering data and making data changes in many devices, validating data, searching for devices and sending requests to select operational topological conditions and layers, can be achieved efficiently through scripting. In EMTPWorks the scripting language is JavaScript with EMTPWorks extensions. These extensions allow grabbing the main circuit (design) object and accessing all devices and device attributes.

Each device is an object with attributes for data and methods. Data attributes contain electrical data, device symbol drawing data and position data. In addition to a set of pre-defined attributes, it is possible to define new attributes.

Scripting is used to access and modify data attributes. Scripts are used, for example, to enter or correct data for hundred transmission lines without manually touching the lines on the GUI. Device methods provided with specific tags for identifying triggered scripts can be used to automatically trigger data refresh scripts due to changes in database files or due to attribute changes affecting other device properties. Scripting has been found essential for creating and maintaining large networks. Script methods are also used also to navigate through the network and locating devices.

III. The Networks

Two different networks have been developed in this paper. The first extra large network (in the context of EMTP-type studies) represents the complete (100%) Hydro-Québec power grid. The second smaller network is a reduced version of the first network. It does not represent medium and low voltage transmission lines and regroups some loads into large centers.

A. *Complete first network*

The first network, named hereinafter L-Network (very large), constitutes a reference for obtaining network equivalents for various study purposes. It is also the previously discussed unified environment for maintaining and extracting data for various applications. The first layer of data is related to the load-flow solution constraints. The applied computational engine uses an automatic transition from a multiphase load-flow solution to steady-state and time-domain solutions. Each load-flow device is paired with a steady-state equivalent model as shown in Fig. 3. Each load-flow device provides all phasors required for the initialization of the corresponding steady-state model. The equivalent steady-state circuit model of each device is used to initialize the time-domain version at $t = 0$.

The complete Hydro-Québec network is organized using a multilevel hierarchical design structured on 6 pages in the GUI. There are a total of 30000 physical devices and 28000 signals. The list of physical devices includes 19000 control devices and coupled 3, 6 or 9-phase devices are counted once. The signal count adds 8000 power nodes to 20000 control system signals.

The top level listing (subnetwork contents are not counted) of main devices is:

- 1100 transmission lines representing the existing 1560 lines and derivations
- 296 three-phase transformers representing the existing 1500 three-phase units connected in Ynyn, DD, Dyn, Ynd, Ynynd, Yndd and ZigZag grounding banks
- 532 load models representing a total of 36000 MW. All medium and high voltage shunt capacitors and inductors were modeled separately. Some loads were modeled with the transformer and shunt capacitor at the lower voltage level.
- 7 SVC (Static Var Compensator) models of 300 Mvars and 600 Mvars. The SVCs have been combined on some buses by creating 600 Mvar models.
- 32 series capacitor MOVs and 303 nonlinear inductances used for high voltage power transformer saturation representation.
- 99 synchronous machines (SM) with associated controls representing more than 49 power stations and four synchronous compensators. All synchronous machine devices are matched to corresponding load-flow type devices for specifying the PV constraints used for initializing machine phasors at load-flow solution convergence. All machines are given a single-mass model except one nuclear power plant generator modeled using 10 masses.

The transmission lines are modeled using the constant parameter model (CP) which includes propagation. The more advanced frequency-dependent model layer can be selected for specific higher frequency content studies. The list of synchronous machines is augmented with 20 more machines related to distributed generation. In the context of dynamic stability studies it is not recommended to use even a single fixed voltage source with internal impedance since such a source generates fictitious reactive power during voltage swings and erroneously accentuates voltage excursions.

A complete equivalent of the above large network is available in PSS/E data. The PSS/E network is used for validation purposes in the presentation below.

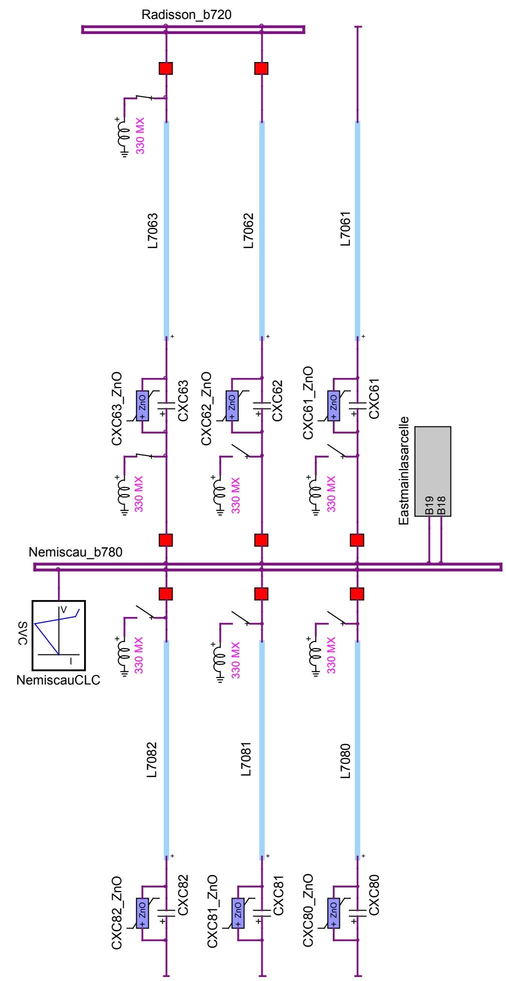

Fig. 2 A snapshot from the 735 kV series-compensated network representation

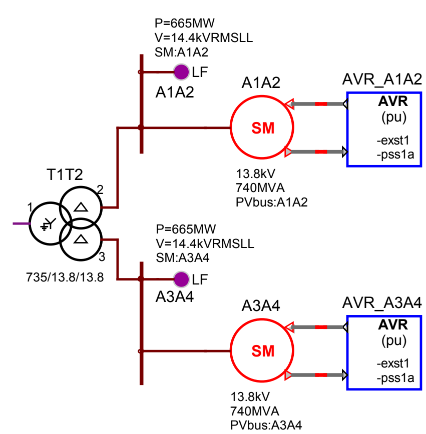

Fig. 3 Multimachine power plant representation

B. *Reduced network*

The reduced second network, named hereinafter R-Network, was constructed as an alternative to the first network for achieving reduced computer timings in simulations. Most of the UHV studies can be conducted using this reduced network version. It represents the entire 735 kV and 315 kV systems and includes almost all lines at the 230 kV level. Transmission lines are combined when necessary and equivalent load devices are used for lower voltage derivations for preserving the power-flow conditions. A particular effort is made to model shunt capacitors at the 120, 230 and 315 kV levels in order to obtain the most faithful frequency response compared to the complete network model. It has been found that this approach provides good results with minimal effort when the study zone is electrically sufficiently far from the location of the equivalent.

The reduced network has a total of 24000 physical devices and around 24000 signals. There are 4000 power devices and 2500 power nodes. The listing of top level devices is:

- 170 lines, with 75 lines at the 735 kV level, 53 at 315 kV, 23 at 230 kV and 19 at 120 kV
- 90 three-phase transformers
- 27 load models, 7 at 315 kV, 6 at 230 kV, 4 at 161 kV, 6 at 120 kV and 4 at 13.8 kV for a total of 33800 MW
- 7 SVC models
- 39 synchronous machines with AVRs for representing 31 power stations and 3 synchronous compensators for a total of 35600 MW of generation.

IV. Validation: R-Network vs L-Network

Three 735 kV substations electrically far away from each other and three 315 kV substations are shown in Fig. 4 for validating the network responses in frequency domain. It is apparent that the similarity of responses indicates acceptable behavior considering the elimination of low and medium voltage networks. The worst case is occurring at Substation 6 which is the electrically closest to the location of the lower voltage equivalent.

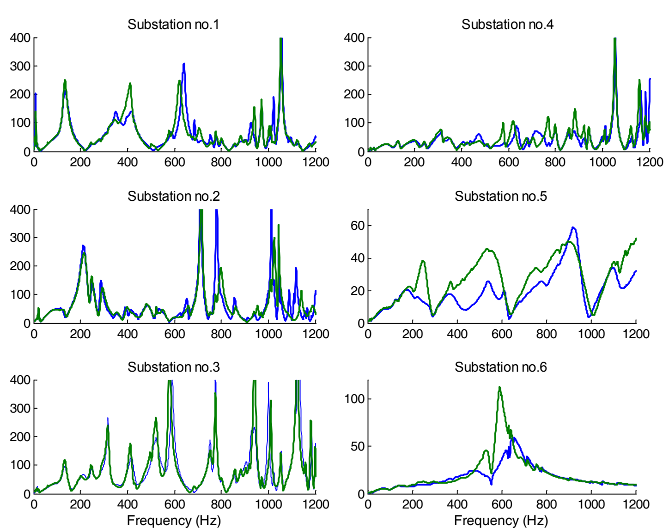

Fig. 4 Frequency response (positive sequence impedance) plots for the complete (blue) and reduced (green) networks. Left column plots show three 735 kV substations and right column plots show three 315 kV substations.

V. Synchronous Machine AVRs and Initialization

A. AVR models

In both networks the AVR models are exactly the same as those defined in the IEEE-412.5 standard. Seven models are required for the Hydro-Québec network, 6 of IEEE type and one of PSS/E type. The exciters are: EXST1, IEEET5, IEEEX1 and EXPIC1 (PSS/E model). The stabilizer models are: PSS1A, PSS2A and PSS4B. These devices are again organized in hierarchical blocks with the top level block providing a mask for modifying underlying parameters.

Since the complete network data is initially available in a PSS/E file, the effort of translation into the graphical user interface can become significant unless some specific mechanisms are provided. The solution to this problem was found by writing translation scripts capable of taking dynamic data from PSS/E and sending directly into a text style mask of the corresponding AVR device on EMTP side.

B. Initialization

Network initialization is a key factor for solving large networks in time-domain. With the size of the studied networks and the large number of synchronous machines and control functions, the network must be started as close as possible to its operating steady-state conditions. It is otherwise practically impossible to solve the network due to the dramatic increase in computer time required for the decay of the natural response and major difficulties in establishing initial conditions for machine phasors and related controls.

The load-flow solution can be obtained from a separate package (such as PSS/E) and transposed into the EMTP simulation. There are however several important difficulties in such a procedure due to data management issues and discrepancies between steady-state models. PSS/E is a positive sequence package, while EMTP is multiphase and solves in phase-domain without using per-unit circuits. The discrepancies will create extraneous transients and delay the initialization process. The data management issues also represent significant difficulties since changes on EMTP side must be reflected back into PSS/E to restart the load-flow solution.

The only way to solve this problem is to apply a multiphase load-flow solution within the same solver and preceding the time-domain computations. Such a method is available in [2]. It employs a three-step process. The first step is the load-flow solution. In this solution layer, as shown in the power plant view of Fig. 3, each synchronous machine is given a PV constraint. The loads become PQ constraints at nominal voltage. All device types, including ideal switches, must participate in the load-flow solution and arbitrary network conditions, balanced or unbalanced. All EMTP models (including specific nonlinear or frequency dependent devices) are automatically given their load-flow equivalent.

After the load-flow solution, the second step is the steady-state solution. In this layer, all devices are given their steady-state equivalent model. The following automatic steps are applied for the synchronous machines:

- The load-flow solution provides all synchronous machines with the terminal voltage phasors.
- The steady-state solution of the machine uses its internal steady-state model to initialize all mechanical and electrical variables from the terminal voltage phasors. Unbalanced conditions are also considered by injecting equivalent negative sequence voltages into the network.
- The steady-state solution field voltage Efss signal becomes available as a bundled observable signal and used for automatically initializing the machine control diagram.

The last step is illustrated in Fig. 5, where Efd_ic is actually Efss, Vm_rms is found from the steady-state v_d and v_q voltages at $t = 0$. The initial stabilizer output signal Vaux is normally zero. The hold function is used to fix the reference voltage Vref for the following time-point solutions. A similar approach is used to initialize the governor/turbine model where the initial conditions are established from the computation of the steady-state mechanical power or torque and steady-state speed.

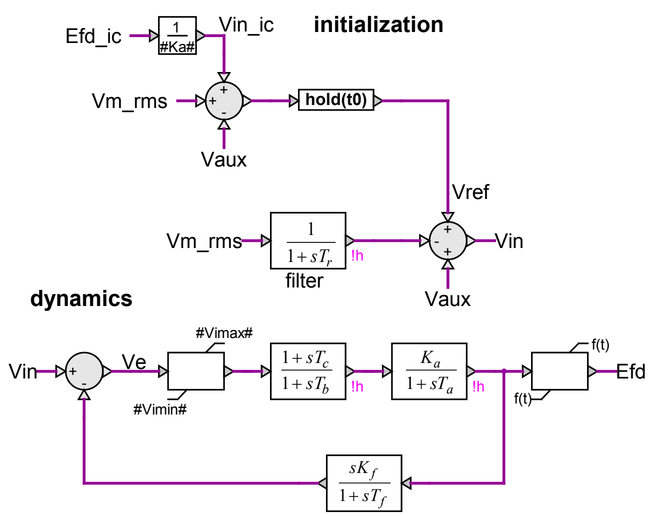

Fig. 5 Initialization and dynamic blocks in an EXST1 exciter

The steady-state solution automatically initializes all state variables, including propagation history buffers on transmission line models, and starts the time-domain simulation.

Fig. 6 presents the time-domain simulation of the L-Network with 99 synchronous machines and their AVRs. The SVCs are disconnected for this simulation. It demonstrates that the system stays at its equilibrium operating state dictated by the load-flow solution. The power-flow solutions computed by PSS/E are verifying the ones calculated in EMTP for both the L-Network and R-Network versions. Some periodic measuring devices have a normal settling delay of one period and that is why the measurements shown in Fig. 6 have an initialization delay and appear pulsed.

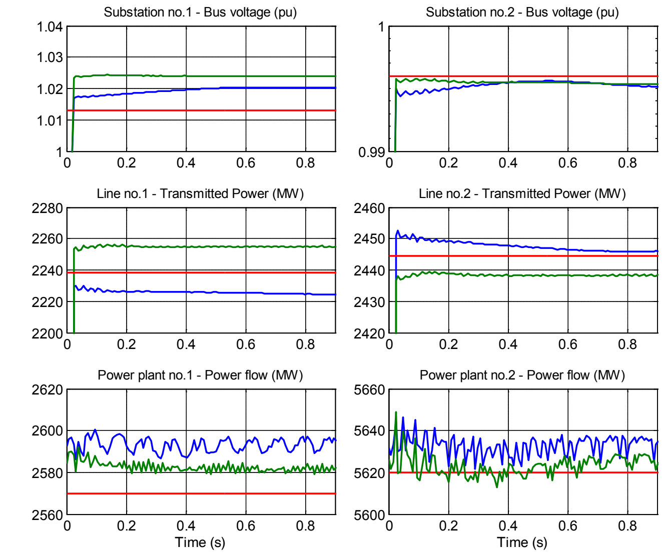

Fig. 6 Network initialization test without SVCs, L-Network (blue), R-Network (green) and PSS/E (red)

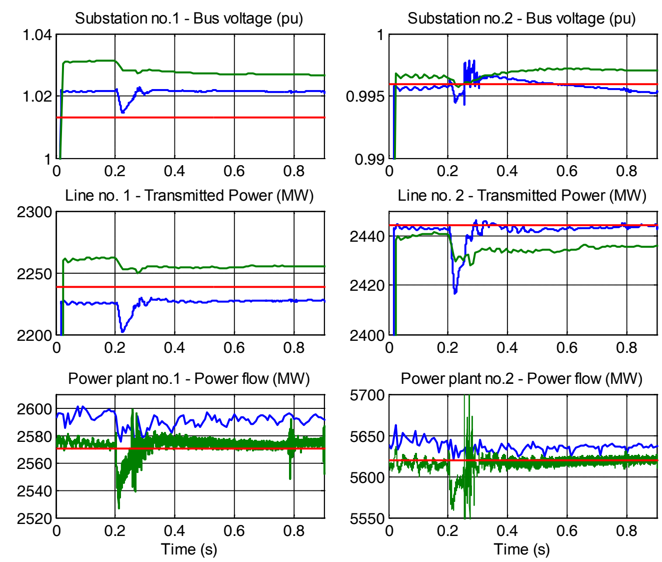

Fig. 7 Network initialization test with SVCs, L-Network (blue), R-Network (green) and PSS/E (red)

C. Initialization with SVCs

Although the load-flow solution [2] is capable to account for switches, it was not feasible to automatically initialize power electronics-based components such as SVCs, due to changeable switching patterns and related complexities in controls. The main difficulty is that although the SVC is initially floating, its control system must be started and reach the firing scheme for close to zero reactive power exchange. A solution to this problem was found by isolating each SVC during the initial 200 ms in parallel with an ideal voltage source fixing the expected load-flow phasor on the SVC bus. Then the ideal voltage source is disconnected and the SVC is connected to its bus.

The simulation results shown in Fig. 7 confirm the validity of the proposed initialization method. All seven SVCs reach their steady-state in less than 400 ms after switching on to the network. Without the initialization trick, the steady-state is reached only after 2 seconds of simulation time, which is unacceptable considering the CPU limitations. The R-Network is more sensitive since it has lower network strength.

Another approach is to use idealized SVC models. In the idealized model the SVC is represented by using an ideal controlled inductance and capacitance. This is acceptable for dynamic stability studies in view of simulating regulation by SVCs.

VI. SHORT-CIRCUIT VALIDATION

The EMTP short-circuit current amplitudes are related to the time scale of the simulation. In the high voltage network the fault currents include subsynchronous frequencies (25 to 30 Hz) related to the series compensated lines especially when the fault is closer to the capacitor banks. The 60 Hz fault currents shown in Fig. 8 also include the asymmetrical component which is equivalent to the difference between the RMS value and the amplitude of the fundamental component. It is also noticed that the EMTP fault currents show the effect of machines in changing of reactance from X_d'' towards X_d. This is particularly more important for faults closer to a power station.

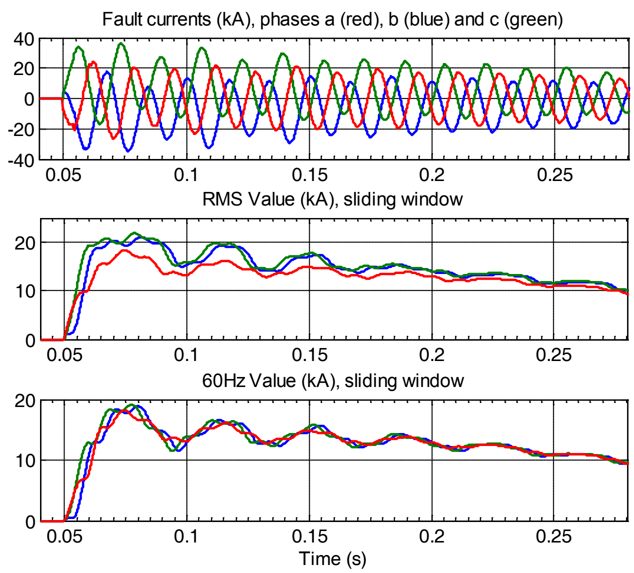

Fig. 8 Fault currents near series compensation capacitor, L-Network

For the reasons presented above, the validation of fault currents with PSS/E and ASPEN both using X_d'', must be based on the average fundamental current amplitude captured between 0.05 to 0.1 s after the fault. The tables below present the three-phase and single-phase to ground short circuit currents for both complete and reduced networks. The similarities in answers are strict.

The EMTP short-circuit current computations offer a much higher precision since EMTP allows to account for nonlinearities. In the case of series compensated lines, the capacitor protection arresters may conduct, create coupling between the sequence networks and modify the fault current due to increased impedance in time-domain [6][7].

Table 1 Comparison of 3-phase-to-ground fault currents, (kA)

Station	ASPEN	PSS/E	L-Network	R-Network
1, 735 kV	21.0	22.6	22.0	21.4
3, 735 kV	15.3	15.0	15.0	14.8
4, 735 kV	14.9	15.8	14.5	15.3
5, 230 kV	30.6	34.2	33.4	n.a.
6, 120 kV	8.6	9.7	9.1	n.a.
7, 69 kV	15.4	12.2	13.8	n.a

Table 2 Comparison of 1-phase-to-ground fault currents, (kA)

Station	ASPEN	PSS/E	L-Network	R-Network
1, 735 kV	25.1	27.3	24.5	24.3
3, 735 kV	14.0	13.5	14.1	13.6
4, 735 kV	17.3	17.8	17.0	17.8
5, 230 kV	38.7	42.7	41.1	n.a.
6, 120 kV	10.3	11.2	10.5	n.a.
7, 69 kV	19.5	16	18.2	n.a

VII. DYNAMIC STABILITY

To reproduce correctly the dynamic behavior of a large network it is necessary to model all power plants by generators and regulators. As explained earlier, ideal voltage sources are inappropriate since they generate fictitious reactive power during voltage swings. A major disturbance is chosen to qualify voltage regulation: loss of one line with 2000 MW of transmission. Once again the simulation results presented in Fig. 9 demonstrate the exceptional overall agreement of simulation results between PSS/E and EMTP. It is noticed that both electromechanical oscillation frequencies and damping are verified. This provides another important validation for the assembled network. The integration time-step used in EMTP for the shown waveforms was set to $100\,\mu s$. Almost identical results were also achieved using $200\,\mu s$.

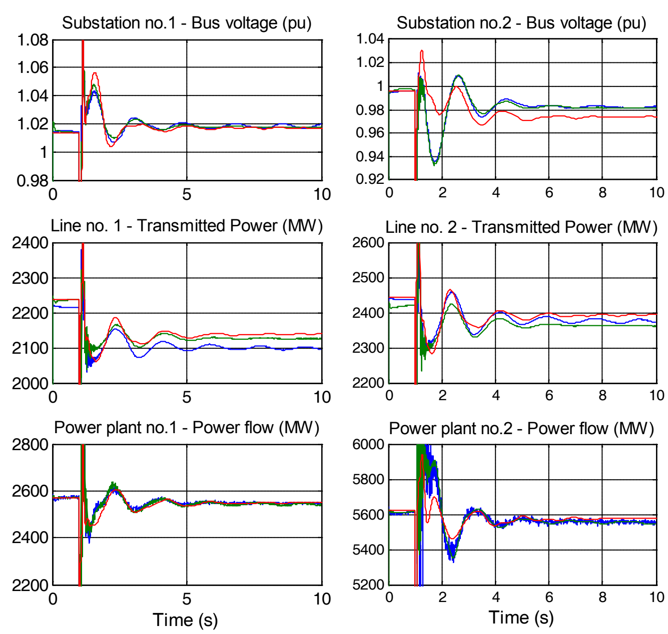

Fig. 9 Simulation of a 3-phase fault and loss of a 735 kV transmission line, L-Network (blue), R-Network (green) and PSS/E (red)

To analyze the performance of the Hydro-Québec 735 kV system protection during extreme disturbances and system separation, it is necessary to simulate various scenarios using detailed electromagnetic models including in addition to system dynamics, nonlinearities such as transformer saturation and metal-oxide varistors. Such simulations are presented in [1] using a tedious procedure through the system dynamic behavior represented by using a dynamic source model (Thévenin equivalent) with voltage and phase values obtained and replayed from a previous study using PSS/E. With the computational capabilities presented in this paper the simulations can be performed directly using a more detailed network (R-Network) and applying the complete synchronous machine model to all machines. The network solution starts directly from the load-flow and moves into the steady-state solution before the occurrence of the first event. The scenario studied here is referring to the Hydro-Québec series-compensated network bus names shown also in [1]. A similar scenario is discussed in more details in [1]. The sequence of events is the following:

1. $t = 0.1s$: occurrence of a 3-phase fault on the Chibougamau-Chamouchouan corridor;
2. between $t = 0.2s$ and $t = 0.25s$: the fault is cleared resulting into the loss of the three Chibougamau-Chamouchouan lines and Albanel- Chibougamau tie;
3. $t = 0.45s$: LG 4 power plant rejection;
4. $t = 0.53s$: remote shedding of 2500 MW of load in the Montreal area;
5. $t = 0.78s$: the protection system detects the 62 Hz threshold for switching on the sacrificial metal-oxide surge arresters at five substations for the potential network separation scenario;

The simulation results are presented in Fig. 10. In Fig. 10 c) the lines leaving the LVD7 (La Verendrye) substation towards Montreal are tripped at 1.43 s due the 1.4 pu overvoltage detection. These overvoltages are due to the fact that the James Bay synchronous machines remain connected to their transmission lines.

VIII. CPU Timings

The CPU timings for 10 s of simulation interval for the transient stability case of Fig. 9 with integration time-steps of 100 μs and 200 μs are presented in Table 3. A smaller time-step can be used for higher frequency studies. The upper limit on the time-step is due to the representation of transmission lines with actual propagation delays. The convergence of synchronous machines with network equations also imposes precision restrictions. In this paper the same machine model is used for the entire frequency range without relaxation, which represents an important computational burden. Moreover due to the presence of nonlinearities the complete system of network equations must be resolved through an iterative Newton process which may impose more than one solution at a given time-point. For both networks the mean number of iterations per time-point remains below two (during transient events). The capability for the solver to maintain a reduced number of iterations is of crucial importance since it applies a direct multiplicative factor to the total CPU time. The control system equations are solved simultaneously using the method presented in [8].

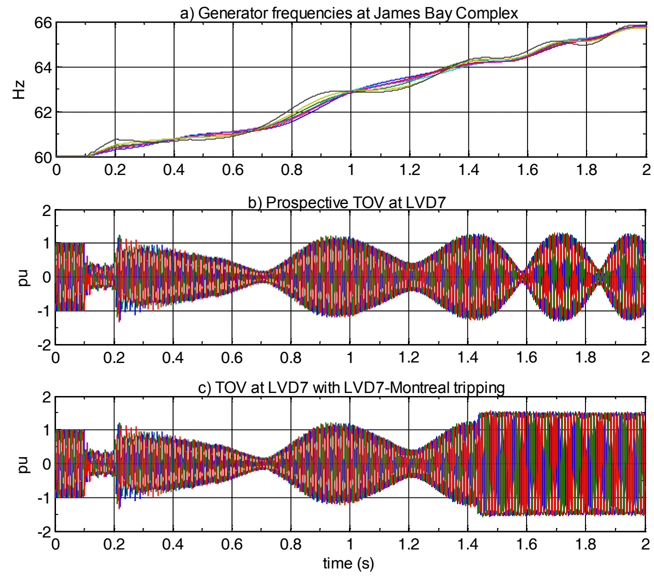

Fig. 10 James Bay system voltage oscillations due to an extreme disturbance

It must be emphasized that it is important to maintain sufficient precision (convergence tolerance) at each time-point to avoid drifts over the entire simulation interval. Experiments indicate that it is complicated to apply relaxation techniques in model equations since in most cases it impacts the overall solution precision.

The CPU timings presented in Table 3 are based on a Dual Core Laptop processor T7200 (2 GHz) with 4 GB of RAM. There are no parallel computations in the software. The 'GUI File load' time represents the time required to open the design file in the graphical user interface and show the simulated network with all its data. The 'Data generation' time is the time required to generate data from the GUI for the mathematical engine. The multiphase load-flow solution is performed independently and starts directly from the entered constraints and blank case. It uses a real matrix which at the least doubles the size of the time-domain matrix shown in Fig. 11. In the steady-state solution step the load-flow solution is obtained from previously saved data and a complex matrix is used to initialize all required state variables for the immediately following time-domain solution. Since the steady-state solver matrix is complex it has the same rank as the time-domain matrix. Sparse matrix techniques are used for all network solution steps.

In the time-domain solution of network equations the solver applies pivoting. The sparse matrix for the L-Network is shown in Fig. 11. This is an augmented non-symmetric formulation [2] which includes separate equations for sources, switches, transformers and other devices. It is noticed that significant CPU time is spent in the 'Time-domain updating' procedures. This includes data dumping for waveform scopes and is mainly dominated by history updating for transmission lines and other devices. A fast (7200 RPM) hard-disk alleviates the data storage timings for a total of 1264 scope channels in the L-Network case and 1151 channels in the R-network case.

Table 3 CPU timings (s) for a 10 s simulation interval

CPU Timers	L-Network		R-Network	
GUI File (design) load	9		4	
Data generation	10		3	
Load-flow solution	181 (6 iterations)		21 (7 iterations)	
Steady-state solution	0.48		0.12	
Time-step	100 µs	200 µs	100 µs	200 µs
Time-domain network equations	4710	2548	538	276
Time-domain control equations	846	435	715	389
Time-domain updating	409	210	75	36
Time-domain solution total	5965 99 min	3103 52 min	1328 22 min	701 12 min

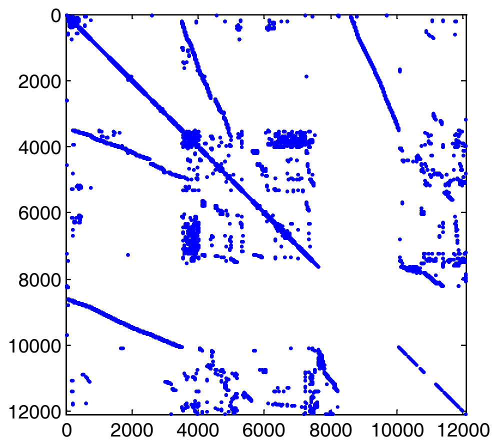

Fig. 11 Solved time-domain sparse matrix for the L-Network, 50269 non-zeros

Doubling the time-step does not necessarily divide the simulation timings by two. This is due to changes in convergence properties. The increased time-step also requires replacing some constant-parameter line models by simpler pi-section models at fundamental frequency. Significant gains in CPU timings can be achieved by replacing all transmission lines by pi-sections. Several and automatically selectable model layers can be maintained according to the type of study.

Although fully dynamic memory is applied in the initial data setup and equation building steps, the overall network matrix formulation time remains negligible.

Despite all the computational luxury described above it is established that the computer timings remain surprisingly practical even if the selected computer is not the fastest available.

IX. Conclusions

This paper presents a new experiment and new levels in simulation with EMTP type methods. It has been shown that with the selection of appropriate simulation methods in both computation and visualization fields, it is feasible to simulate extra large networks in an EMTP type program. The complete Hydro-Québec power grid has been assembled in a graphical user interface and simulated. The presented computer timings provide an important indication on the currently achievable levels with typical user computers.

Building and maintaining large networks in a unified graphical user interface is also useful for maintaining a unique network data set from which smaller networks can be extracted for performing various simulations.

X. References

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