Validation Tests of The Hypersim Digital Real Time Simulator with a Large AC-DC Network

D. Paré[1], G. Turmel[1], J.-C. Soumagne[1], V. Q. Do[1], S. Casoria[1], M. Bissonnette[1],
B. Marcoux[2], D. McNabb[3]

(1) Institut de Recherche d'Hydro-Québec (IREQ), 1800 blvd. Lionel Boulet, Varennes (Québec), Canada, J3X 1S1 (pare.daniel@ireq.ca, (2) TransEnergie Technologies, 740 rue Notre Dame Ouest, bur. 800, Montréal H5B 1N7 (marcoux.benoit@hydro.qc.ca), (3) TransEnergie, 2 Complexe Desjardins, 10e étage, Montréal H5B 1N7 (mcnabb.danielle@hydro.qc.ca)

Abstract **- Hydro-Quebec (HQ) had used for many years a very large hybrid simulator for studying various aspects of its power system network. New developments on its network requires to expand and maintain the simulation facilities, and with the development success of Hypersim digital simulator, it was decided to use this technology to gradually replace the hybrid simulator.**

This paper presents the development and validation of this large scale digital simulator for AC and DC power system performance studies. Validation tests are performed with a relatively large AC-DC interconnected network including generators (turbine, AVR), dynamic loads and a full bipole HVDC transmission system. The network is simulated on both Hypersim real-time simulator and on the hybrid simulator, it is connected with the real external HVDC controls. Comparison of simulation results obtained with Hypersim and with the hybrid simulator are presented. The benefits of precision valve model as well as the effect of the simulation time step will also been discussed.

Keywords - Power System real time simulation, HVDC control testing, Hypersim

I. INTRODUCTION

Hydro-Quebec (HQ) has extensively used its real-time simulation facilities for testing protection systems, new controllers and various FACTS systems and for optimization of existing controls. These facilities include a fully automated large-scale hybrid simulator [1] using principally analog models to represent the transmission network and digital models for loads, machines and controls. Fully digital real-time simulator of medium scale was also in use for many years for testing protection systems and controllers.

In order to be able to sustain the need for future development and new equipment installation, a larger size digital simulator [2] was added to these facilities for simulation of complex power system networks. HQ has undertaken to use this digital simulator for network studies and made many comparisons with the hybrid simulator as well as with the electromagnetic transients program (EMTP).

To make sure that the digital simulator is also reliable tool to study large network, tests have been carried out on the Hydro-Quebec AC-DC interconnected network simulated on both Hypersim and the hybrid simulator. This paper will present the result comparison obtained with these two different technologies.

II. DIGITAL SIMULATOR DESCRIPTION

Software

Hypersim software is based on a graphical user interface to edit the power system, enter component parameters and control the simulation. Many tools are also available to display simulation waveforms, automate tests sequence and store results in a database [2].

Hypersim has been developed with portability in mind, it can therefore be used on various platforms: it supports actually the SGI parallel computer and the PC-Cluster [3].

The simulator is also very open to other applications: it can take the generated code of a Simulink model and filters are available to input EMTP files.

Simulation of a large network requires new functionalities which has been added: automatic load flow to initialize model parameters, taking snapshot to restart the simulation from same conditions.

Hypersim can also simulate networks in non real-time mode but still take the benefit of available parallel CPUs. for much faster simulation than the performance of a single CPU, even for larger power systems.

Hardware

The hardware architecture of the Hypersim digital simulator is based on a commercially available parallel computer from SGI, which can be scaled from 2 to 512 processors.

The configuration used during the validation tests is the SGI Origin 3800 with 32 high performance MIPS processors at 500 MHz (Fig. 1). The processor number will soon be increased to enable the simulation of larger power system network.

For interconnection with external equipment under test, the computer provides standard PCI I/O slots accessible from any processors, and also scalable according to the study requirements. Actually, Hypersim is equiped with D/A and A/D for analog signals connection. The digital I/Os have the capability of time delay measurements between time step. This means that external event which occur between time step are used by Hypersim with the correct timing to reflect the exact time of state change.
The advantages of using a generic computer for real time

Fig. 1 SGI Origin 3800 with 32 high performance processors at 500 MHz.

simulation instead of a dedicated hardware are multiple: it can be used for other software applications and it can be easily upgraded with faster processor and therefore keep the simulator at the forefront of the technology.

The whole computer system with CPU and I/O required only 2 cabinets, which is an enormous size reduction in comparison to the hybrid simulator. Beside the size reduction, the time required to set-up a study of a new power system is also considerably reduced. Furthermore, user can switch easily from one network to another, a facility which is unthinkable on the hybrid simulator.

III. DESCRIPTION OF THE SIMULATED NETWORK

Figure 2 presents the Hydro-Québec HVAC-HVDC interconnected network simulated on Hypersim and the hybrid simulator. All the 735 kV buses are represented. Some 315 kV buses and lines are also explicitly represented, but the major part of the lower voltage transmission and distribution system, including the loads and generation, are represented by reduced dynamic equivalents. The hydroelectric generators are represented by detailed model incorporating turbine, automatic voltage

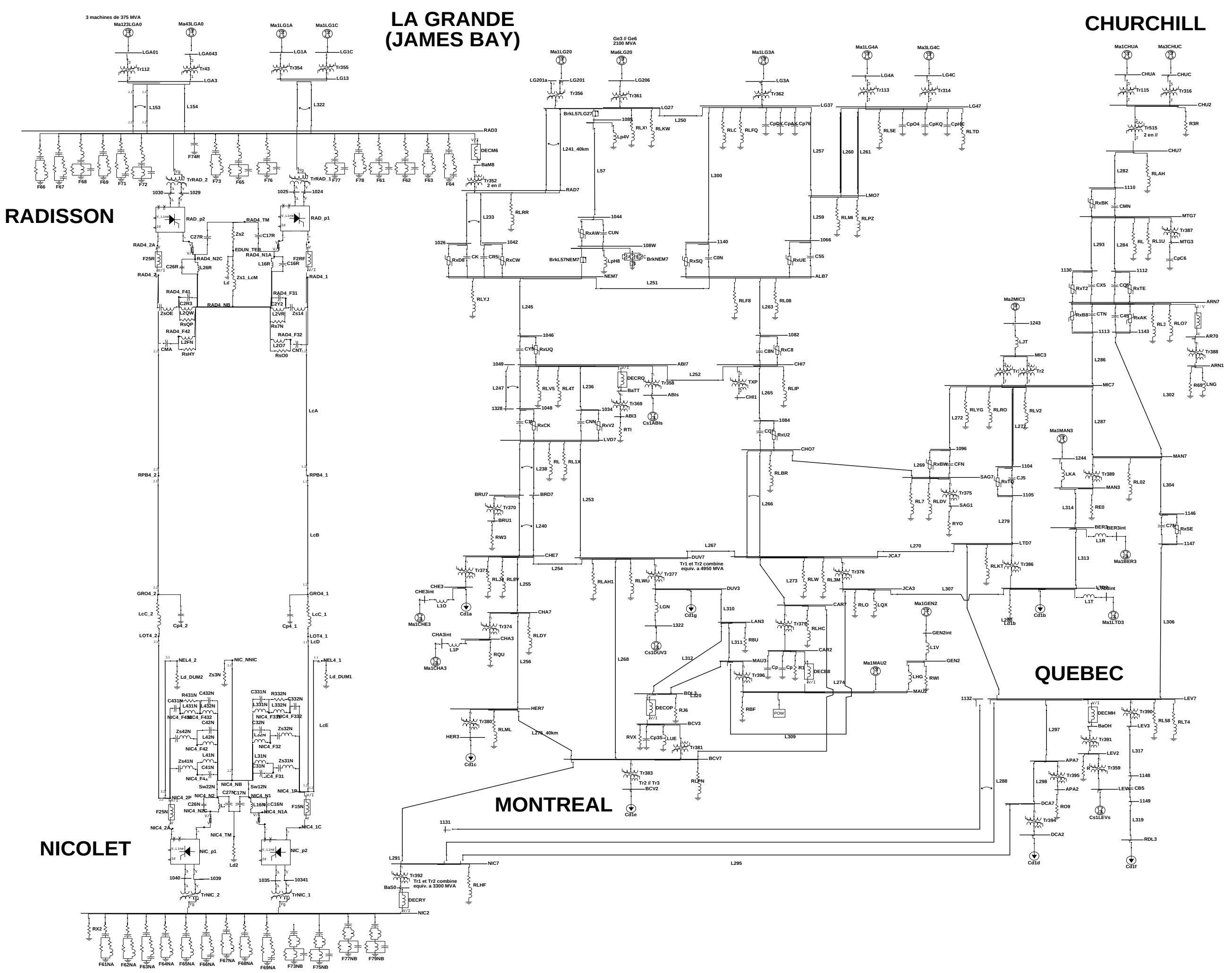


Fig. 2 Hydro-Québec's HVAC/HVDC network simulated on Hypersim and hybrid simulator.

regulator (AVR) and stabilizer.

The multiterminal HVDC link includes in detail with a bipolar model, ±450 kV transmission lines, DC smoothing reactors, 60 Hz blocking filters, DC filters, electrode lines and switches as well as the DC switch yards. The AC filters at each station are also represented in detail.

For the digital simulation with Hypersim, all elements, except the four ABB controllers, are simulated by digital models. The four poles control (Radisson converter and Nicolet inverter) are replicas of the site controls, they use the same hardware and software as the real controls on the Hydro-Quebec network. The controls were also equiped with DC line protection, AC undervoltage detection and commutation failure protection. In overall, the simulated network includes the following components:

- 122 three phase buses
- 44 single phase buses
- 19 generators (turbine, AVR, stabilizer)
- 3 synchronous compensators
- 7 dynamic loads
- 4 DC controller
- 1 bipole 12 pulses DC system
- 9 coupled lines (distributed parameters)
- 51 single lines (distributed parameters)
- 8 Marti lines (DC lines)
- 43 transformers
- 28 AC filters
- 18 surge arrestors
- 163 RLC elements (loads and shunts)

IV. CONNECTION AND VALIDATION OF HYPERSIM IN CLOSE LOOP

Close-loop connection

The close-loop connection of the simulated network in Hypersim to the ABB controller is shown in Fig. 3. Hypersim sends (via D/A converter) to the ABB controller the DC voltage (UDL), DC current (IDC), three phase-to-phase AC voltages as well as currents of the high side of the converter transformers. The ABB controllers sends (via the digital input or DI) the 12 firing pulses to Hypersim. Using the time-delay (reported by the DI module) between the firing pulse and the simulation time-step, Hypersim performs the interpolation required by the precision valve model to simulate the exact timing of the valve firing [4].

Validation

In order to validate Hypersim for large network, same tests are done on the predecessor hybrid simulator and on Hypersim. Both simulates the Hydro-Quebec's AC-DC network connected to the real ABB HVDC controllers in close-loop.

The reason for choosing the hybrid simulator as a comparison base is that this simulator has been used for years to perform serious studies for Hydro-Quebec. It has been intensively validated against load flow, stability, EMTP programs and even with some Hydro-Québec field tests[5].

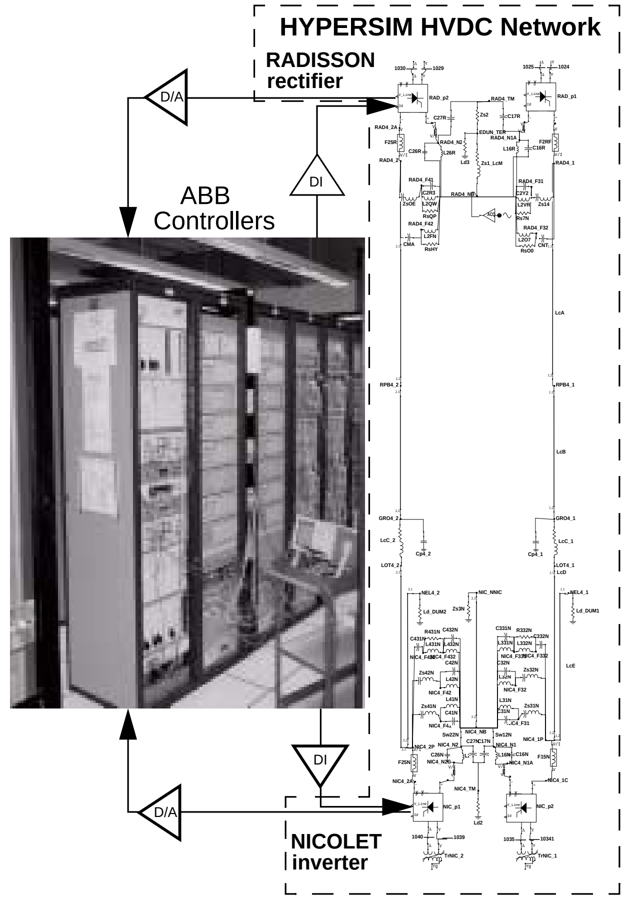
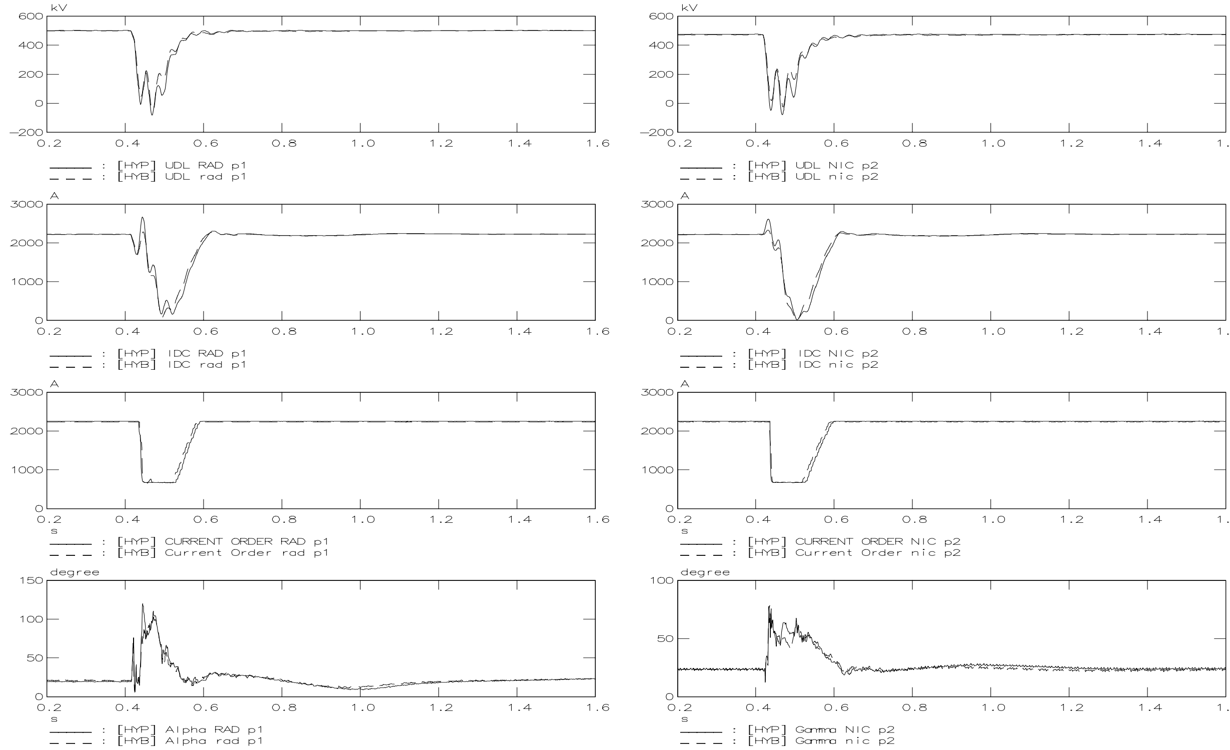


Fig. 3 Close-loop connection diagram between Hypersim and the ABB HVDC controller.

First, tests are done on hybrid simulator and saved in the data base. The steady-state operating conditions prior to any test are validated by comparing AC voltages (magnitude and phase angles), DC voltages, currents, valve firing angles and tap changer positions measured on the analog Hybrid simulator against results obtained from Hydro-Québec's AC/DC load flow program RP600. The frequency response of individual models and of the simulated network viewed from the converter buses are verified by comparing measured simulator impedances and phase angles with results obtained from the EMTP frequency domain analysis. The dynamic response of the machines is validated by comparing results from the simulator for balanced three-phase faults with those obtained from Hydro-Québec's stability program ST600.

Secondly, the network simulated with the Hypersim digital simulator was connected to the ABB controller and the same tests were repeated. As one example of result from both simulators, a 6 cycles (100 ms) three-phase-to-ground line fault at Némiskau 735 kV followed by the opening of line L57 to eliminate the fault were done. Fig. 4 shows the superimposition of waveforms measured on the Hydro-Quebec network simulated using the Hypersin digital simulator and the hybrid simulator. The left side of this figure shows the rectifier's signals including the DC voltage (UDL), the DC current (IDC), the current order and the alpha angle. The right side presents the same signals for the

Test: a 6 cycles (100 ms) three-phase-to-ground line fault at Némiskau 735 kV followed by the opening of line.



Rectifier side

Inverter side

Fig. 4 Superimposition of some waveforms obtained with the Hypersim and the hybrid simulator for the DC part of the network.

inverter, except the last signal is gamma angle.

Similar results obtained from both type of simulations confirm the reliability and stability of the Hypersim digital simulator. Other waveforms are shown in Fig. 5: the phase-to-ground voltage at Némiskau 735 kV bus (Ua_NEM7), Radisson 315 kV bus (Ua_RAD3), Duvernay 735 kV bus (Ua_DUV7), fault currents at Némiskau, active power, reactive power and frequency of the hydroelectric generator at LA GRANDE 2 (LG2), and active power of the dynamic load of RDL3. Many other tests were performed with different fault locations and they give comparable results.

V. BENEFITS OF PRECISION VALVE MODEL AND EFFECT OF SIMULATION TIME-STEPS

The digital simulation of HVDC network requires an accurate simulation of valve firing instance. The calculation is performed only at the time-step moment but the firing pulses send by the real controller can arrive at any time. Hypersim hardware has the ability to catch the firing pulses at the exact time and measure the delay between the firing pulse and the next time step. This information is sent to Hypersim as a parameter needed by the precision valve algorithm [4]. Without precision valve model, jitter effect will be created by the asynchronism between the system frequency and the firing frequency. This will generate non characteristic harmonics which can even be amplified by action of controllers. The precision valve allows furthermore to use larger time step without significant lost of simulation performance.

Fig. 6 shows the superimposition of DC voltage obtained with the hybrid simulator and with Hypersim operated at 56 and 80 µs. It shows also the benefits of the precision valve model in Hypersim. For 56 and 80 µs and with precision valve model, Hypersim behaves like the hybrid simulator. For the case of 56 µs of time-step and without precision valve model, a considerable jitter effect can be seen.

VI. CONCLUSIONS

The paper has summarized the description of the fully digital simulator Hypersim. In terms of software, this simulator has been developed to be portable on various platforms, in real-time or non real-time mode. On the hardware side, it can run on simple workstation in non real-time mode or on the SGI parallel machine and PC cluster for both real-time and non real-time mode.

An application case of relatively large network simulated on both the hybrid simulator and on Hypersim has been carried out. The purpose is to make sure that Hypersim can simulate large and complex networks in real-time while preserving a small time-step and satisfactory results. Comparisons of results between the hybrid simulator and Hypersim have demonstrated very good matching. The precision valve model has also well behaved inside the simulation of a complex AC-DC interconnected network

Test: a 6 cycles (100 ms) three-phase-to-ground line fault at Némiskau 735 kV followed by the opening of line.

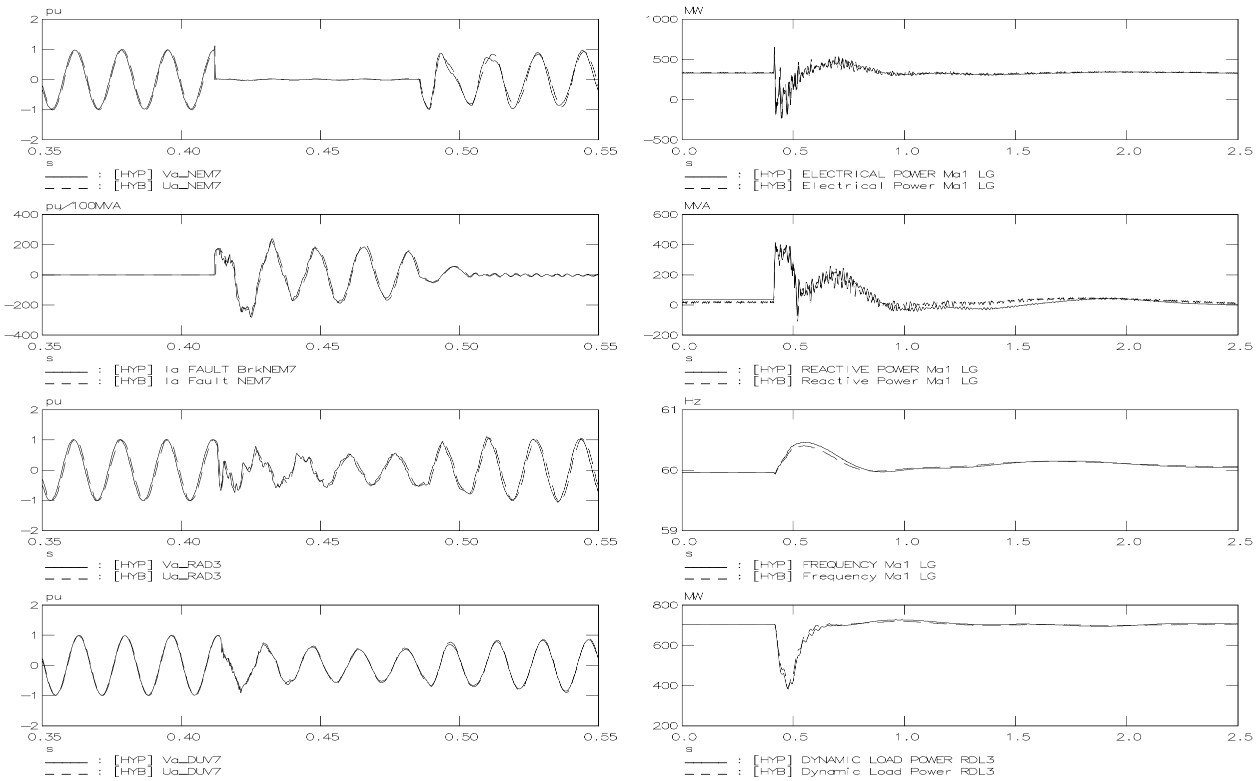


Fig. 5 Superimposition of waveforms obtained with Hypersim and the hybrid simulator for the AC part of the network.

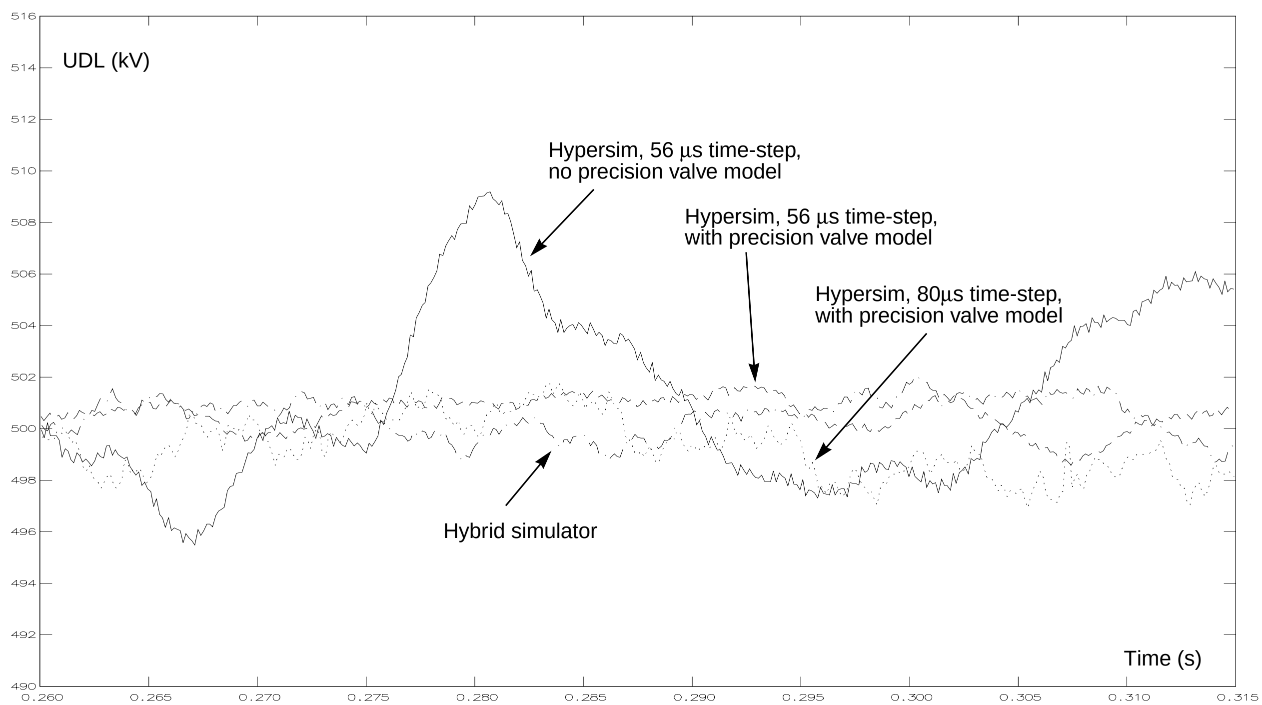


Fig. 6 Comparison of voltages measured with Hypersim (with time step of 56 and 80 µs) and Hybrid simulator. Jitter effect on Hypersim can be seen when no precision valve model is used.

REFERENCES

[1] D. McCallum, S. Casoria, A. Venne, L. Vaughan, M. Éné, D. Paré, “Simulation of the Radisson-Nicolet-Sandy Pond multiterminal interconnection,” *International Colloquium on HVDC and FACT (CIGRÉ)*, Montréal, Canada, September 18-19, 1995

[2] V.Q. Do, J.C. Soumagne, G. Sybille, G. Turmel, P. Giroux, G. Cloutier, S. Poulin, “Hypersim, An Integrated Real-Time Simulator for Power Network And Control Systems”, *Third International Conference On Digital Power System Simulators (ICDS’s99)*, Vasteras, Sweden, May 25-28, 1999

[3] C.Larose, S.Guerette, F. Guay, A. Nolet, T.Yamamoto, H. Enomoto, Y. Kono, Y. Hasegawa, H. Taoka, “A Fully Digital Real-Time Power System Simulator based on PC-Cluster” *7th International Conference on Modeling and Simulation of Electric Machines, Converters and Systems. (ELECTRIMACS 2002)*, Montréal, Canada, August 18-21, 2002

[4] V.Q. Do, D. McCallum, P. Giroux, B. De Kelper, “A Backward-Forward Interpolation Technique for a Precise Modelling of Power Electronics in HYPERSIM”, IPST’2001 International Conference on Power System Transients - June 24 - 28, 2001 - Rio de Janeiro, Brasil. pp.337-342

[5] H. Nakra, R. L. Vaughan, C. Gagnon, A. Venne, C. Thomassin, J. Gagnon“Real-Time for Power System Dynamics Studies” IEEE Transactions on Power Systems, Vol. 10, No. 2 - May 1995