A Modern and Open Real-Time Digital Simulator of All-Electric Ships with a Multi-Platform Co-Simulation Approach

Jean-Nicolas Paquin, Wei Li, Jean Bélanger, Loic Schoen, Irene Peres, Cristina Olariu, Hugo Kohmann

***Abstract*— Designing an All-Electric Ship (AES) requires testing of the interaction between hundreds of interconnected power electronic subsystems built by different manufacturers. Such integration tests require large analog test benches or the use of actual equipment during system commissioning. Fully digital simulators can also be used to perform Hardware-in-the-Loop (HIL) integration tests to evaluate the performance of some parts of these very complex systems. This approach, in use for decades in the automotive and aerospace industries, can significantly reduce the costs, duration and risks related to the use of actual equipment to conduct integration tests. However the computational power required to conduct detailed simulation of such diverse and numerous power electronic components can only be achieved through the use of distributed parallel supercomputers, optimized for hard real-time performance with jitter in the order of a few microseconds. Such supercomputers have traditionally been built using expensive custom computer boards. This paper presents the technology and performance achieved by the eMEGAsim real-time digital simulator, which is capable of meeting these challenges through the use of standard commercial INTEL quad-core computers interconnected by DOLPHIN SCI communication fabric. The precision achieved in the simulation of a detailed power electronic model implemented with SIMULINK and SimPowerSystems, and executed in parallel with RT-LAB, will also be presented using a typical basic AES configuration. Furthermore, AES design implies the collaboration between several multidisciplinary teams using different tools to simulate all electrical, mechanical and fluid dynamic subsystems. The ORCHESTRA real-time co-simulation publish-and-subscribe framework enabling the integration of multi-domain simulation tools will also be presented.**

***Index Terms*-- real-time simulation, accelerated simulation, off-line simulation, zonal electric distribution system, zeds, all-electric ships, detailed modeling, electromagnetic transients, hardware-in-the-loop, multi-core processors, co-simulation, distributed simulation, electromagnetic transient simulation, pc-cluster real-time digital simulator**

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I. Introduction

THE modular design and redundancies built into an all-electric warship's power system are critical in ensuring the ship's reliability and survivability during battle. For instance, auxiliary propulsion systems will dynamically replace the primary system in case of failure. This implies that such a power system be dynamically reconfigured. Therefore, the power management operations need to be highly efficient with minimal power quality issues, and the best operation integrity possible during transients caused by system reconfigurations or loss of modules.

The design and integration of a Zonal Electric Distribution System (ZEDS) is challenging in many ways. Such a project requires the testing of the interaction between hundreds of interconnected power electronic subsystems, built by different manufacturers. Large analog test benches or the use of actual equipment during system commissioning are therefore required at different stages of the project. Fully digital simulators can also be used to perform Hardware-in-the-Loop (HIL) integration tests to evaluate the performance of some parts of these very complex systems, thereby reducing the cost, duration and risks related to the use of actual equipment to conduct integration tests. This approach has been adopted by the automotive and aerospace industries for decades. However the computational power needed to simulate all power electronic components in detail requires the use of distributed parallel supercomputers. Furthermore, the simulation of fast switching Voltage-Source Converters (VSC) is challenging since simulating fast switching devices found in Electric Propulsion Modules (EPM) requires the use of very small time steps, in the order of a few microseconds, to solve the system's equations. In addition, these fast switching phenomena must be simulated in combination with slow electromechanical components in an electrical network, in both steady state and during transient conditions that may last several minutes.

Such supercomputers, capable of simultaneously simulating very fast and very slow transient phenomenon, have traditionally been built using expensive custom computer boards. Off-line simulation techniques, using variable time-step solvers are therefore often used to perform preliminary studies. This is due to the high acquisition and operating costs of traditional custom digital simulators. However, off-line

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variable step simulations, executed on only one processor, are very time consuming if no precision compromise is made on models (i.e. the use of average models). This eliminates the possibility of analyzing harmonic stability and fast transient operations that may occur on ZEDS-based warships during on-line reconfiguration or loss of equipment.

This paper presents the technology and performance achieved by the eMEGAsim real-time digital simulator, capable of meeting this challenge through the use of affordable standard commercial INTEL quad-core computers interconnected by DOLPHIN SCI PCI-Express communication fabric. The precision achieved in the simulation of a detailed power electronic model implemented with SIMULINK and SimPowerSystems, and executed in parallel with RT-LAB, will also be presented using a typical basic AES configuration.

The real-time simulator discussed in this paper has been used for AES research conducted at the University of Michigan, and sponsored by the U.S Office of Naval Research [1]. Its scalability, flexibility, and capability to accurately simulate fast switching drive systems and FACTS power systems integrated into very large power system models make it ideal for conducting multi-domain engineering analysis and design.

II. Distributed Real-Time Simulation

Real-time simulation is broadly used in power system simulation. The use of powerful computers with analog and digital IO cards brings mathematical models to real world through the connection of Hardware-in-the-Loop (HIL).

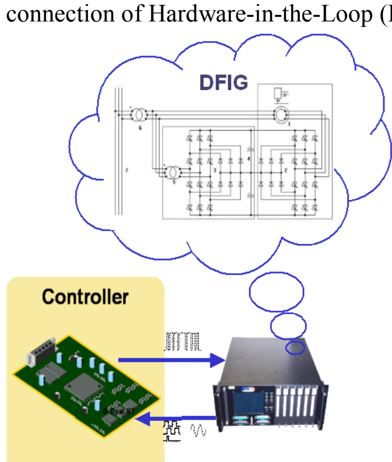

Fig. 1. Schematic example of controller testing on a DFIG detailed model using HIL.

During the power system analysis and design process, hardware design engineers may want to test the effectiveness of controllers and their effect on complex power system models. The schematic example in Fig. 1 illustrates how HIL testing can be used to perform preliminary analysis and testing of a power system controller. Compared to the use of rapid control prototyping techniques, where the mathematical model of a controller is tested on a physical test bench connected in the loop, this HIL technique is a better option for large power system applications, in both practical and economic terms. A large number of normal operation and fault conditions can be easily reproduced using a plant model. Reproducing such conditions on a physical plant is a classical approach. However, it can be both costly and time consuming. By using the HIL technique, a significantly larger number of tests can be conduced while still dramatically shortening the overall design process. In addition, when designing and testing large power system controllers, employing model-based design techniques will prove most cost-effective since the model-based design approach can enable the representation of the dynamic behavior of a large network in an un-destructive manner. The use of detailed models is required in HIL testing to get as near as possible to real world physics.

A. Real-Time Simulation of Detailed Models

Use of the real-time simulator presented allows not only faster prototyping but also faster production of results for long term simulation in network planning and analysis. Depending on model complexity, it may be possible to exploit the idle calculation time between steps for online accelerated simulation when HIL is not required.

System planning engineers use detailed models for their flexibility and resemblance to reality. The modeling of particular average models can be time consuming when adaptation is needed for different studies, for example, adapting an average model for the study of power quality aspects to a model for control interactions and stability studies. Moreover, advanced mathematical modeling experience may be needed for the creation of particular models. Detailed models permit the simultaneous study of different aspects such as protection coordination, power quality, stability analysis, control interaction studies, and control prototyping.

Since detailed models take into account the real world behavior of devices, they are easily adaptable for use on different simulation benchmarks. This flexibility means that detailed models can be used for the development of novel control and protection schemes for small to large-scale power systems. Moreover, on a distributed simulation platform, model-based prototyping can be extended to HIL testing of network controllers. The use of detailed modeling on a distributed real-time platform aggregates the efforts of the simulation specialist that builds mathematical models with that of the system planning engineer, and the hardware developer who needs to test controllers. The flexibility of a distributed real-time simulator is after all its most important asset. Once the model is built, it is available to a number of specialists in many different fields.

B. eMEGAsim

eMEGAsim is a distributed, parallel computing real-time simulator designed for electromagnetic transients in power systems. As an integrated software and hardware system based on Intel processors, it can combine FPGA-based models to obtain simulation time steps in the order of nanoseconds. In addition, with a large number of FPGA-based inputs and outputs (I/O) cards, eMEGAsim enables high-speed, direct connection with external equipment for hard real-time simulation.

At its core, eMEGAsim has the RT-LAB software [2] and commercial-off-the-shelf (COTS) components including dual Intel® Core™2 Quad processors and Xilinx Virtex™ FPGA. eMEGAsim is scalable from 8 to 64 processor cores and can simulate increasingly large systems with real-time performance. As illustrated in Fig. 2, as the number of used cores doubles, the time-step decreases by more than a factor of two. These computation efficiencies (greater than 100%) are due to direct utilization of the efficient cache subsystem of the Intel® Core™2 Quad processor chips.

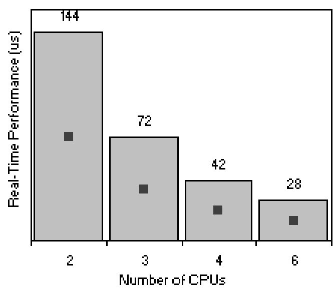

Fig. 2. Real-time performance (time-step in µs) according to the number of processor cores used for the distribution of the model (the detailed wind farm connected to a single feeder). Example with a single target computer equipped with dual Intel® Core™2 Quad processors.

The resulting efficiency enables faster and more accurate simulation of electromagnetic transient phenomena and therefore greater understanding of the power system under study. eMEGAsim is able to deliver considerable performance advantages with maximum communication overhead and jitter as low as 1 µs. The use of the QNX® Neutrino® real-time operating system, widely used in mission-critical applications such as medical instrumentation and air traffic control, greatly optimizes the efficiency and sturdiness of the eMEGAsim simulator.

III. The Real-Time Co-Simulation Approach

Successful Real-Time simulation of complex systems requires the integration of heterogeneous models. This feature is offered with the eMEGAsim real-time digital simulator through the use of the Orchestra real-time co-simulation management software. Written in different programming languages, generated with various simulation tools or even generated using the same simulation tool but different model files, the modular configuration of ZEDS is best analyzed using the co-simulation approach since every component may be developed by different teams, or even by different consulting firms. As illustrated in Fig. 3, by facilitating integration and interoperability between disparate co-simulation components, Orchestra enables the engineer to conduct Real-Time co-simulation of virtual AES earlier in the design process.

Opal-RT Orchestra software is a communications framework facilitating real-time data exchange between eMEGAsim Simulink-based models and external software or hardware components. Based on the Publish/Subscribe concept for data exchange, inspired by High Level Architecture (HLA) for simulation [3] and Distributed Data Structures (DDS), Orchestra is specifically implemented for real-time simulation. All data exchanges are described under an Extensible Markup Language (XML) file, in which multiple domains with multiple configurations can be defined.

Orchestra includes built-in Simulink blocks for data exchange management under Simulink models. Also, a real-time, low latency Application Programming Interface (API)

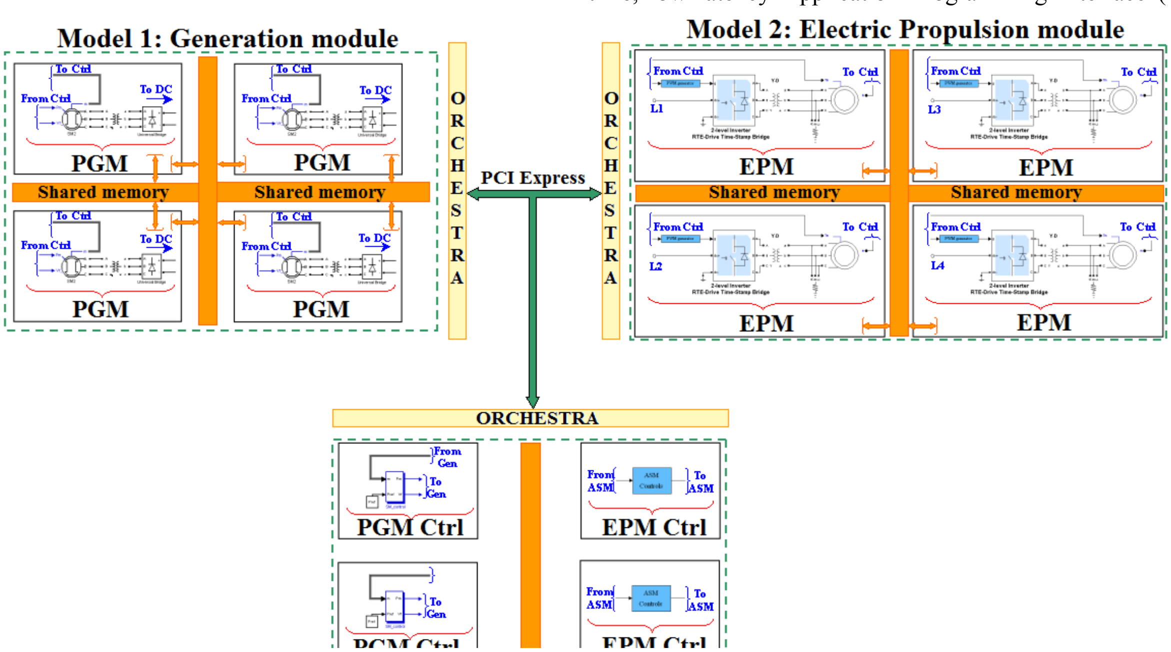

Fig. 3 Comprehensive diagram of the Co-Simulation Approach for AES simulation

increases the flexibility of the real-time digital simulator, enabling any C-compatible external tool or language to be linked to the main model via the co-simulation framework.

External components communicate with a local framework using shared-memory or reflective memory for computer targets using the same Operating Systems (OS). The Orchestra framework is distributed over multi target computers via FireWire, Dolphin SCI PCI-Express or Infiniband links. The use of such a powerful framework facilitates the use of I/Os for tools that are not made for Hardware-in-the-Loop and IO-based applications by interfacing them with the built-in eMEGAsim-Simulink I/O management blocks. For instance, control signals provided by a C-coded controller algorithm is easily output from the real-time simulator with easy point and click Simulink block assignments. Moreover, published and subscribed signals can be dynamically enabled/disabled without stopping the real-time simulation. For instance, an I/O connection can be replaced on-line by a fully-digital simulated model of the external hardware.

IV. Fast Scalable Real-Time Digital Simulator

Opal-RT simulators have proven to be scalable and have been used for a number of multi-processor and PC-cluster based simulations of power systems [4]. Through the use of Infiniband communications technology constant performance was achieved over a very large bandwidth. However, simulation of recent state-of-the-art power system technologies now requires the lowest latency possible from low communication bandwidth to a fairly large bandwidth in order to achieve smaller time-step for accurate precision in the simulation of fast power electronic devices. The recent availability of Dolphin SCI PCI-Express communications technology and the Dolphin Developers Kit 0 for the eMEGAsim platform has shown outstanding results for low to medium size bandwidth communication. Comparative results between three different communication technologies are shown on Fig. 3.

Fig. 4 illustrates an achievable latency comparison between Infiniband PCI-Express, Dolphin SCI PCI-Express, and OHCI PCI-x communication technologies. From 1 to nearly 400 communicated signals, the Dolphin technology achieves the lowest latency, with an ultra-low latency between 5 to 10 µs, from approximately 1 to 128 communicated signals. It is also observed that the Infiniband PCI-Express technology has a minimum latency of only 19 µs. However, one can observe that for bandwidth larger than 400 communicated signals, the InfiniBand PCI-Express technology achieves the lowest latency. As for the very low-cost OHCI PCI-x communication link, it is usually recommended for use on clustered real-time simulators that do not require ultra-low latency. It is usually satisfactory for meeting the latency requirements for real-time simulation of mechanical subsystems and controllers with model time-steps larger than 200 µs. The Dolphin SCI PCI-Express, the Infiniband PCI-Express and the OHCI PCI-X technologies are therefore very complementary in terms of price, performance and bandwidth. However, for the simulation of power systems integrated with VSC-based drives for propulsion, power management systems and slow rotating electrical generators and conversion systems, the combination of the Dolphin and OHCI technologies would be recommended.

Dolphin's interconnect adapter provides a transparent, reliable high bandwidth and very low latency connection between systems equipped with PCI Express slots using the IEEE SCI standard.

The Dolphin adapter is designed to meet the requirements for high availability clustering and remote I/O applications. The programmed, remote memory access (RMA) feature enables ultra-low latency messaging and low overhead and transparent I/O transfers. PCI Express transactions are converted into corresponding SCI transactions allowing physically separate PCI Express systems to appear as one. This feature allows applications to send data between system memories without the use of operating system services, greatly reducing latency and overhead. A full remote memory write made up of a request/response pair typically takes 1.4 µs. Pipelined 4 byte write posts account for only 0.21 µs each.

V. Simulation Environments for Power Systems

A. SPS/Simulink

Simulink is the industry leading, graphical interfaced, modeling and simulation tool, used in many engineering fields.

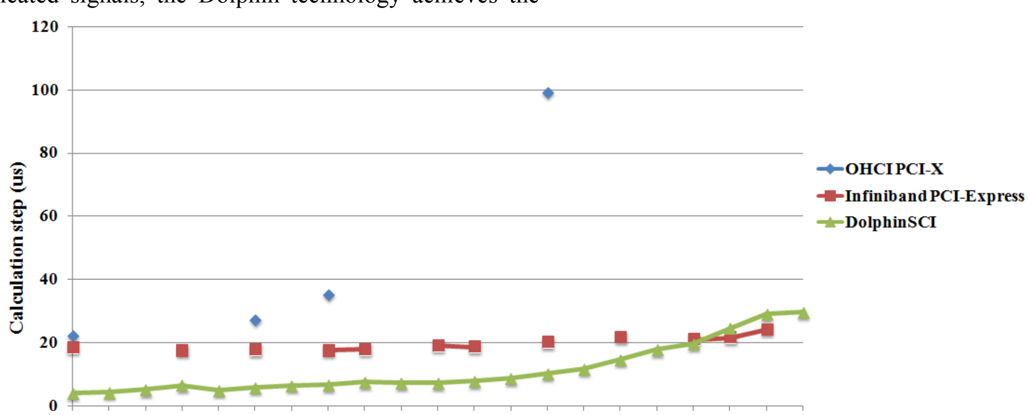

Fig. 4. Achievable latency comparison between Infiniband PCI-Express, Dolphin SCI PCI-Express, and OHCI PCI-x communication technologies.

SimPowerSystems (SPS) [5] developed by Hydro-Quebec Research Center (IREQ) is a Simulink toolbox that provides multiple model components, all based on electromechanical and electromagnetic equations, for the simulation of power systems and machine drives. Both tools are available in the MATLAB software for mathematical processing. By using the toolboxes included in this multifunctional software, it is possible to easily model any power system device or control. Users can also easily develop their own models.

SPS uses the state-variable analysis approach to solve power system equations. The linear differential equations can either be represented with continuous or discrete state-spaces. Although the use of fixed-step algorithms is required for real-time simulation, it is also possible to solve system equations using variable-step integration techniques within the Simulink environment. However, the SPS toolbox is designed for off-line simulation of electrical systems and is not optimized for hard-real-time and parallel simulation.

B. SPS/Simulink on eMEGAsim

Simulink has emerged as a worldwide standard for scientific computing and real-time simulation of electro-mechatronic systems used in aerospace and automotive industries through the use of the popular Real-time Workshop C-Code generator [6]. This tool has been adapted to real-time simulation of power systems by using solvers optimized for real-time simulation of electrical networks such as ARTEMiS [7] and real-time distributed software platforms such as RT-LAB, which have been used in a number of industrial sectors for more than 10 years. In addition to SPS/Simulink, ARTEMiS and RT-LAB, eMEGAsim uses RT-Events, a toolbox especially optimized for real-time simulation of power electronic drive models. The same tools have been used for several years by major hybrid vehicle and power electronic system manufacturers [8].

C. ARTEMIS Real-Time Solver

The solver used with eMEGAsim enables real-time simulation by pre-calculating system equations of state-space model parameters that are stored in memory and loaded in real-time for each circuit topology depending on switch status. It also includes a set of special discrete solvers based on well known L-stable approximations of the matrix exponential. L-stability is an extension of A-stability in which most numerical oscillations are naturally suppressed [7].

This tool comes with a library of essential decoupling elements for the distributed simulation of the system state-space equations to take advantage of modern multi-core processors and PC clusters. The decoupling is either naturally made with Bergeron traveling-wave power line models with inherent delays or artificially added by substituting transformer inductances or shunt and series capacitors with a distributed model enabling the solution of the state-space systems in parallel. The same technique is applied by all research centers and private organizations using parallel computers to simulate large power systems. Of course, such techniques add high-frequency poles and zero close to the simulator sampling frequency, which is typically 20 kHz to 100 kHz. This high-frequency error is generally accepted for the evaluation of slow dynamic transients, temporary overvoltage, harmonics and switching transients up to 2 to 5 kHz as well as for the performance evaluation of protection and power electronic controllers.

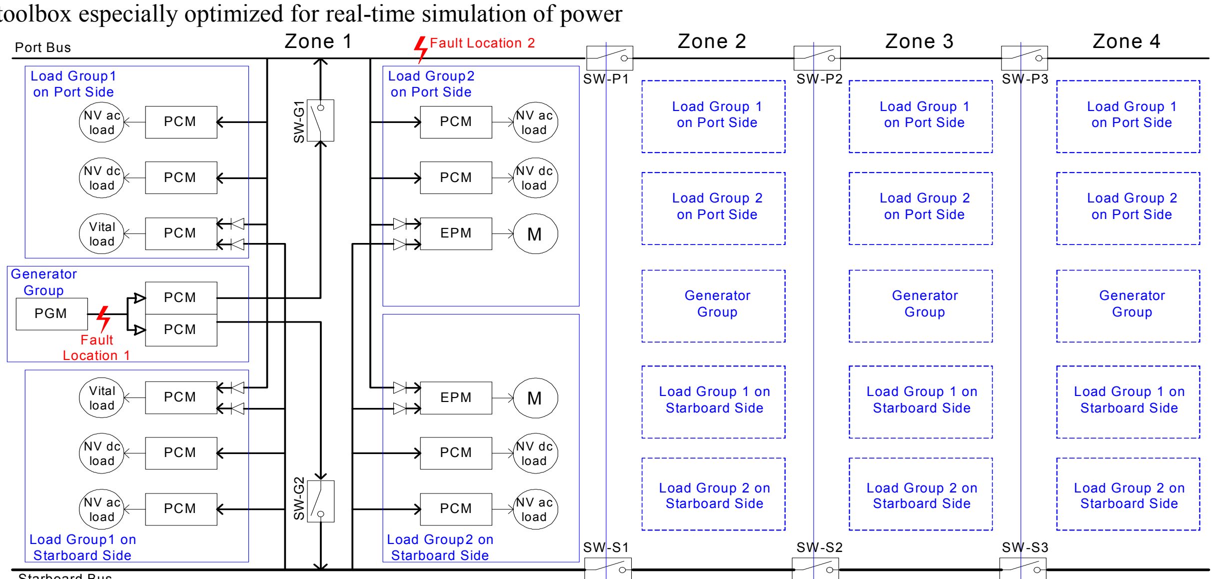

Fig. 5 Integrated Power System (IPS) with zonal architecture employs the 420V dc port bus and starboard bus to provide power flow paths from generators to loads.

VI. Real-Time Simulation of an AES using the eMEGAsim Platform

A. Model Description

The Integrated Power System (IPS) with the zonal architecture employs the 420V dc port bus and starboard bus to provide power flow paths from generators to loads. For vital loads, the two buses act as backups for each other. The IPS is divided into several zones. Each zone is comprised of the two main dc buses, power generation module (PGM), power conversion module (PCM), and one or more of the models of electric propulsion modules (EPM), vital/non-vital loads, and energy storage model (ESM).

The IPS in this research has 4 zones. Each zone has one PGM, four vital loads, and eight non-vital ac or dc loads. Each PGM includes 4 generation units, each of which is a diesel-generator and diode-rectifier connected to a common 500V dc-bus. The 500V dc bus feeds the 420V dc port and starboard buses through a PCM. The two main 420V dc buses convey power to all ac and dc loads through PCMs. A vital load is connected to both the port and starboard buses; while a non-vital load is connected to either of them. An EPM, as a vital load, has a dc/ac converter, an isolation transformer, an induction machine, and the controller. A non-vital ac load includes a dc/ac converter, a filter, an isolation transformer, an ac load, and ac inverter voltage regulator. A non-vital dc load includes a dc/dc converter, a dc load, and the dc power regulator. The carrier frequency of the PCMs is 2 kHz.

B. Ship ZEDS On-Line Reconfiguration Scenarios

The IPS can flexibly re-configure its power flow paths by controlling the dc switches connecting PGMs to the port and starboard buses, and those linking the buses of adjacent zones. Two scenarios, loss of a PGM and loss of the port bus, are studied in this paper and simulation results are given in Fig. 5 and 6..

A ground fault on the PGM dc bus in Zone 1 (Fault location 1 in Fig. 7) is applied at 0.1s and cleared at 0.35s to emulate a temporary PGM loss. During the fault, PGM switches SW-G1 and SW-G2 are tripped to isolate the fault from the rest of the system. In Fig. 5, the PGM dc bus voltage drops to zero. However the port and starboard bus voltages and the load voltages remain in normal operation ranges. The PGMs of other zones pick up the generation loss and provide power to loads in Zone 1.

In scenario two, the port bus in Zone 1 (Fault location 2 in Figure 8) has a ground fault from 0.1s to 0.4s. To protect the PGM and port bus in other zones, the corresponding switches, SW-G1 and SW-P1, are tripped. The voltage of the port bus in Zone 1 drops to zero; and those non-vital loads tapped to it lose power and fail. However due to their redundant power supply, the vital loads in Zone 1 are not affected by the dc bus failure. Other zones also keep working properly. The loss is limited to non-vital loads of Zone 1 only.

C. Simulator Performance Monitoring

The model is decoupled to multiple subsystems, and simulated on 12 CPUs of two targets (6 CPUs in each target). The distribution of the model among the CPUs is illustrated in Fig. 6. CPUs located within the same target exchange simulation signals through shared memory; while communication between targets is handled by a Dolphin SCI PCI Express link. In this case, the voltages and currents of the port and starboard bus (4 signals) at the point of common coupling of Zones 2 and 3, and 5 synchronizing signals, are exchanged between the two targets via the PCI Express link. The minimum time step of the model is 33 microseconds.

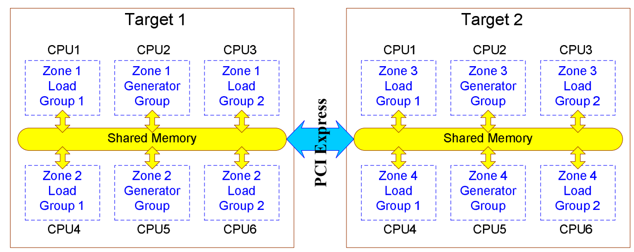

Figure 6. Decoupled model simulated on multiple targets and CPUs

By using the PCI Express link, the engineer can easily increase model scale and complexity, from a one-target-multi-CPU model to a multi-target model, without adding significant signal exchanging time between targets. To quantify the performance of the PCI Express link in this study, a scaled-down model of two zones is studied as a reference. The reference model has the same contents as the original four-zone model in target 1, and is simulated in 6 CPUs of one target. The minimum time step of the reference model is 32 microseconds. Comparison of the real time performance of the two models shows that the communication of simulation signals (9 in number) between targets via the PCI Express only adds 1 microsecond to the minimum simulation time step.

Table 1. Comparison of model execution on 1-target and 2-targets.

Model	Number of Targets	Number of CPUs	Model scale	Minimum simulation time step	Number of signals communicating between targets
Reference model	1	6	2 Zones	32μs	N.A.
Full scale model	2	12(=6*2)	4 Zones	33μs	9

VII. Conclusions

All-Electric Ships have particular modular topologies and efficient power management systems which allow for complex power system reconfiguration. Multiple system reconfigurations, particularly when ship damage occurs during battle, in turn increases the complexity of the study of AES power quality, the optimization of power management and system operation integrity during transients. Through the use of the eMEGAsim real-time simulator, complex studies of very large power systems' electromagnetic transients can be handled with accuracy and precision. The eMEGAsim

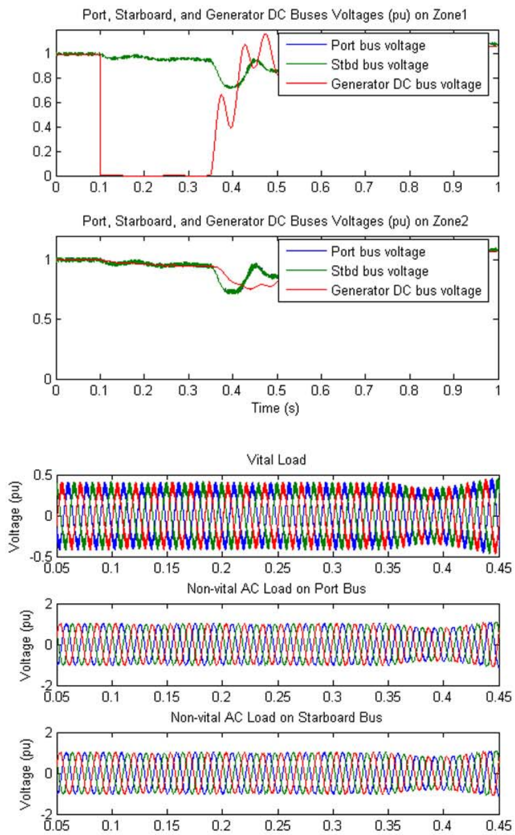

Figure 7. System responses to loss-of-PGM scenario

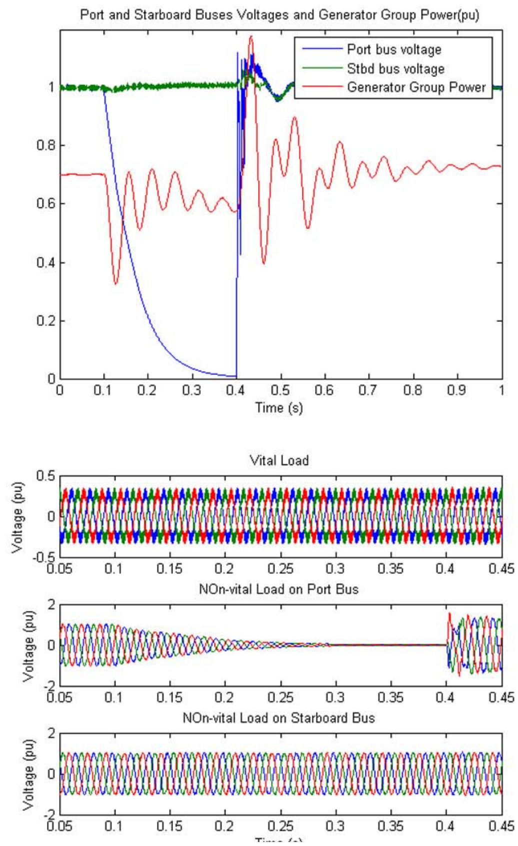

Figure 8. System responses to loss-of port-bus scenario

platform achieves this through the use of COTS PC-based technologies, FPGA-based IO, and multiple libraries designed for use in the MATLAB/Simulink modeling environment, developed by The MathWorks.

eMEGAsim users can also take advantage of Orchestra, a co-simulation framework that allows for the simulation of multiple parts of a large model, each possibly developed by multi-disciplinary teams or by different working groups, on disparate development platforms if needed.

Through the use of a very fast PCI-Express communication link, with very low latency at a fairly large bandwidth, simulator PC clusters can be interconnected to achieve the real-time simulation of increasingly large ZEDS. This is required for the simulation of state-of-the-art power systems integrating fast VSC-based drives and power converters.

VSC-based converters are best simulated using the Time-Stamping technology offered with RT-Events, Time-Stamp Bridges and Time-Stamping IOs from Opal-RT.

VIII. References

[1] Y. Xie, G. Seenumani, J. Sun, Y. Liu, Z. Li, "A PC-Cluster Based Real-Time Simulator for All-Electric Ship Integrated Power Systems Analysis and Optimization" in *Proc. 2007 Electric Ship Technologies Symposium (ESTS'07)*, pp. 396-401.

[2] L.-F. Pak, M. O. Faruque, X. Nie, V. Dinavahi, "A Versatile Cluster-Based Real-Time Digital Simulator for Power Engineering Research," *IEEE Trans. Power Systems*, vol. 21, no. 2, pp. 455-465, May. 2006.

[3] J.S., Dahman, "High-Level Architecture for Simulation" in *First International Workshop on Distributed Interactive Simulation and Real Time Applications Electric Ship Technologies Symposium (1997)*, pp. 9-14.

[4] C. Dufour, S. Abourida, J. Bélanger, "InfiniBand-Based Real-Time Simulation of HVDC, STATCOM and SVC Devices with Custom-Off-The-Shelf PCs and FPGAs," in *Proc. 2006 IEEE International Symposium on Industrial Electronics*, pp. 2025-2029.
H. Kohmann, "Dolphin Developers Kit software", http://www.dolphinics.com/products/embedded-sisci-developers-kit.html

[5] L.-A. Dessaint, K. Al-Haddad, H. Le-Huy, G. Sybille, P. Brunelle, "A Power System Simulation Tool Based on Simulink," *IEEE Trans. On Industrial Electronics*, vol. 46, pp. 1252-1254, Dec. 1999.

[6] H. Jones, "Return on Investment in Simulink for Electronic System Design", White Paper [Online]. Available: http://www.mathworks.com/mason/tag/proxy.html?dataid=5872&fileid=24121

[7] C. Dufour, J. Bélanger, "Discrete Time Compensation of Switching Events for Accurate Real-Time Simulation of Power Systems", in *Proc. 2001 IEEE Industrial Electronics Society Conference*, pp. 1533-1538.

[8] M. Harakawa, H. Yamasaki, T. Nagano, S. Abourida, C. Dufour, J. Belanger, "Real-Time Simulation of a Complete PMSM Drive at 10 µs Time Step", Presented at the International Power Electronics Conference, 2005 (IPEC 2005), Niigata, Japan, 2005

IX. Biographies

Jean-Nicolas Paquin is a Power Systems Simulation Specialist at Opal-RT Technologies since 2007, and team leader of the Modeling and Simulation R&D team (EMS). He received his M.Eng. degree in 2006 from École de Technologie Supérieure (ÉTS) in Montreal, Canada. His professional interests include the simulation and study of HVDC control and protection systems. He is also working on the development of power system models using the real-time distributed simulation platform RT-LAB, SimPowerSystems, ARTEMIS and EMTP-RV.

Wei Li (S'06) received his B. Eng degree from Zhejiang University, China in 1996, and M. Eng degree from National University of Singapore, Singapore in 2003. He is currently pursuing his Ph.D in McGill University, Montreal, Canada. His current research interests include power electronics, wind energy, and distributed generation. He is also working with Opal-RT Technologies within the Modeling and Simulation R&D team (EMS).

Jean Bélanger is the president, CEO and founder of Opal-RT Technologies, Inc. He is a specialist in real-time simulations, with more than 25 years of experience in the field, including many years as part of the simulation division of Hydro-Quebec where he helped developed the world's first 735 kV power transmission systems. He received his M.Sc. from Laval University, Quebec. Since 2001, Mr. Bélanger is a fellow of the Canadian Academy of Engineering.

Loïc Schoen is the Director of Research & Development at Opal-RT Technologies. In 1998, he received his Engineer diploma from the FIUPSO, Orsay, France. He is a specialist in real-time software programming and a co-author of the RT-LAB software. He is also director of the Research and Development department at Opal-RT Technologies Inc.

Irène Pérès received a Ph.D in Plasma Physics from Paul Sabatier University (Toulouse, France) in 1990 and participated in several research programs in the field of numerical simulation of electrical gas discharges. She then specialized in software development for I/O acquisition cards and joined Opal-RT Technologies Inc. in 2001 where she is presently Software Development Manager.

Cristina Olariu is a Software Specialist at Opal-RT Technologies. She received her Engineer degree in Electrical Engineering from Technical University of Iasi, Romania. Her interests include device driver development and communication protocols

Hugo Kohmann is the VP of Software Development and Solutions at Dolphin Interconnect Solutions. He has more than 15 years of industry experience in making high speed, low latency interconnect hardware and software solutions. He received his M. Sc. from the University of Oslo, Norway.