OPAL-RT TECHNOLOGIES

Success Story

University of Michigan Researchers use Opal-RT Simulators for Analysis & Optimization of All-Electric Ship Integrated Power Systems

1. Context

In the twenty years since the end of the Cold War, affordability has become a high priority for marine engineers involved in the design of future naval ships and ship systems. US Navy efforts have focused on developing naval propulsion, electrical, and machinery control systems that significantly reduce acquisition and lifecycle costs of naval warships while still meeting all of the Navy's performance requirements.

An important part of these efforts has been the development of the Integrated Power System (IPS) for All-Electric Ship applications. IPS consists of an architecture, family of modules, and design process which enable the development of affordable propulsion and electrical systems that can be configured for a broad range of naval applications including surface combatants, aircraft carriers, amphibious ships, auxiliary ships, sea lift ships and high value commercial ships.

IPS offers a number of benefits, most notably reduced costs of ownership, increased architectural flexibility in comparison to mechanical drive ships, quieter operation, and increased survivability in battle conditions.

IPS enables a ship's auxiliary electrical loads, such as pumps and lighting, to be powered from the same electrical source as the propulsion system, eliminating the need for separate power generation capabilities for these loads. In commercial applications, this is known as the "power station" concept.

2. The Challenge

The power network associated with an All Electric Ship (AES) typically has electric propulsion, sophisticated electric weaponry systems and other ship services. A Zonal Electrical Distribution System (ZEDS), a key component of the IPS architecture, enhances the reliability and survivability of the ship's power distribution network. Unlike a conventional radial electrical distribution system which distributes power to loads through load centers, ZEDS employs two main buses (starboard bus and port bus) to provide redundant power flow paths for vital loads. With the introduction of Power Electronic Building Blocks (PEBB), ZEDS can seamlessly and dynamically reconfigure power flow paths in response to different load priorities for different real time battle scenarios.

While the integration of power generation systems offers many benefits, the introduction into the mix of new technologies such as advanced power electronic systems, intelligent control systems and state-of-the-art energy storage technologies increases the need for real-time power management and power system reconfiguration, especially in the event of equipment failure or when a ship sustains damage during battle. The main objective of real-time power management is to ensure continuous power supply for electric loads, thereby augmenting the reliability and survivability of the shipboard Power System, and consequently enhancing the mission effectiveness of the warship.

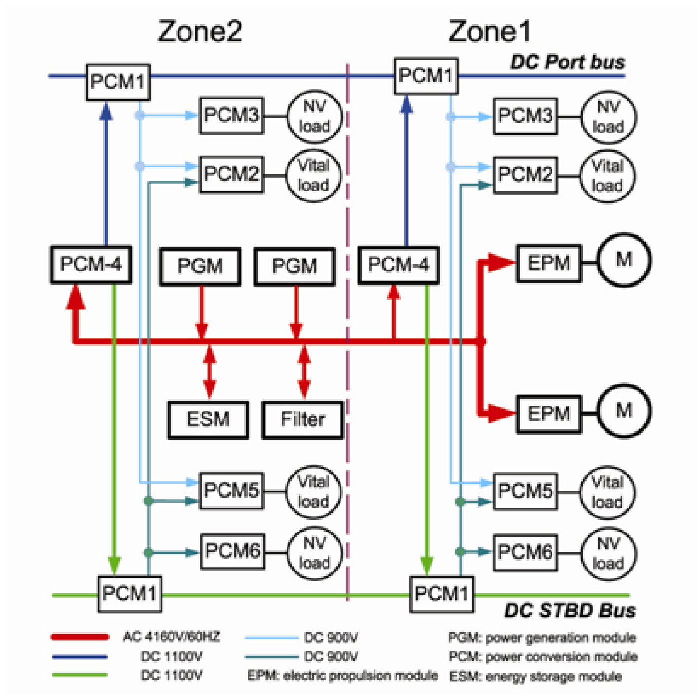

Fig.1 One-line Diagram of a Shipboard Integrated Power System

3. The Solution

To meet this need, a team of researchers lead by Dr. Jing Sun at the University of Michigan's Department of Naval Architecture and Marine Engineering has developed, with financial support from the US Office of Naval Research (ONR), a PC-based Real-Time Simulation facility for conducting All Electric Ship IPS analysis and optimization.

Since obtaining her Ph. D in Electrical Engineering Systems from University of Southern California in 1989, Dr. Sun has been involved in a number of research projects related to control system development and optimization of automotive and marine propulsion systems with a particular focus on system modeling, identification, control algorithm development and integration, control system rapid prototyping and experimental validation.

Based on Opal-RT's eMEGAsim Real-Time Power Grid Simulator, the simulation facility developed by Dr. Sun and her team is designed to address the multi-disciplinary issues associated with All Electric Ships, such as optimal power management and dynamic system reconfiguration. In parallel with development of the simulation facility, a modularized IPS model has been developed and integrated into the simulator.

"Building a simulator facility for electrical systems has always been a challenge, given the costs involved, the required simulation accuracy and the need for flexibility in the simulator architecture" said Dr. Jing Sun. "We elected to go with an Opal-RT simulator due to the low maintenance costs, high simulation performance and high degree of flexibility that result from Opal-RT's use of commercial-off-the-shelf PC technology."

Fig.2 University of Michigan Real-Time Simulation Facility

eMEGAsim is an easily scalable, PC-based Real-Time Simulator that is fully integrated with MATLAB/Simulink from The MathWorks, enabling the use of a wide variety of software toolsets including Control System Design and Analysis toolboxes, Code Generation toolboxes, and Physical Modeling toolboxes. OPAL-RT has continued to further enhance the eMEGAsim simulation platform for AES applications. In addition to incorporating the latest i7 multi-core CPU technology from INTEL, OPAL-RT simulators now come equipped with Dolphin DX PCI-Express communications technology, which has shown outstanding results for low to medium size bandwidth communication.

Opal-RT also provided specialized software tools such as ARTEMIS and RT-Events that support multi-rate fixed-time-step real-time simulation of power systems with dramatically improved computation speed and accuracy. The eMEGAsim simulator used at the University of Michigan is equipped with 8 INTEL CPUs allocated in 4 physically separate targets. CPUs housed in individual targets communicate via shared memory while individual targets communicate with each other through a 10Gb/s Infiniband communications link. The simulation facility also includes three host PCs which can communicate with each target via a 1Gb/s Ethernet switch.

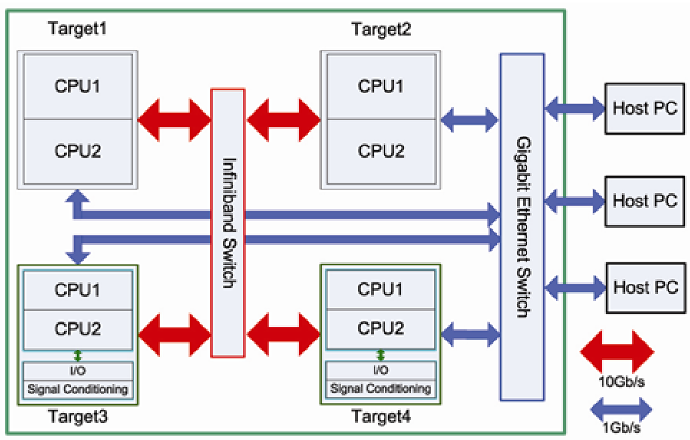

Fig.3 eMEGAsim Real-Time Simulator Configuration

The targets interact with external hardware through 32bit PCI Bus I/O interfaces. Through the use of RT-Events, Opal-RT's specialized real-time interpolation algorithm toolbox, precision of I/O can be better than 1μs. The I/O interface provides a platform for data acquisition and signal conditioning modules that enable the implementation of high frequency analog/digital I/O, event capture and event generation. All of the targets and CPUs are synchronized either by software or by hardware. Therefore, all CPUs can synchronously interact with analog and digital I/O. This feature makes it possible for the system to implement physical components for Hardware-in-the-Loop simulation or to perform fast control prototyping experiments. In addition, the synchronized targets can run Real-Time Simulation at different time steps, providing the flexibility to distribute complex models across multiple targets or CPUs within the simulation platform. The eMEGAsim Real-Time Simulator can also interact with other standalone OPAL-RT targets via an Ethernet link. Standalone targets can be used as experiment data acquisition devices or as any simulated AES subsystem.

Since an IPS is a large scale power system containing a large number of high frequency power switches and other components that demand great resources from a simulator, it is not practical to simulate using traditional offline simulation tools. Real-time simulation not only provides greater simulation speed, but also provides Hardware-in-the-Loop testing and rapid prototyping capabilities that are unmatched by offline simulation tools.

Development of complex power system models can be a daunting task. As a result, the IPS model created by the University of Michigan research team was first developed, tested and simulated as individual modules as follows:

1. A Power Generation module which includes power plants consisting of gas turbines and fuel cells, representing a hybrid power configuration with complementary power sources designed for fuel efficiency. The gas turbine model includes the compressor, turbine, combustor characteristics and rotational dynamics, while the fuel cell system captures the dynamics associated with the fuel cell and reformer in terms of temperature, pressure and reactant flows.
2. A Propulsion Module which is comprised of:

   A. An Electric Propulsion Module which represents a three-phase AC/DC/AC variable speed transmission system with a low speed, high torque Permanent Magnet Synchronous Motor (PMSM) driving the AES propeller.

B. A Ship Dynamic Model that determines the load torque to the electric propulsion motor, and which calculates ship speed and propeller speed according to hydrodynamics.

3. A ZEDS Module which consists of multiple power conversion modules and electric loads. Since a DC zonal architecture has many advantages over an AC zonal architecture for AES applications, the research team elected to adopt a DC zonal architecture.

4. The Results

After preliminary testing, the modules were integrated and distributed across the eMEGAsim simulator's CPUs. The Gas Turbine, Fuel Cell and Electric Propulsion Modules were each assigned to one CPU on the simulator, while the ZEDS was separated into two subsystems and distributed across two CPUs. The simulator's remaining CPUs manage both simulator overhead, and are available for the development of future subsystems that may be integrated into the IPS model.

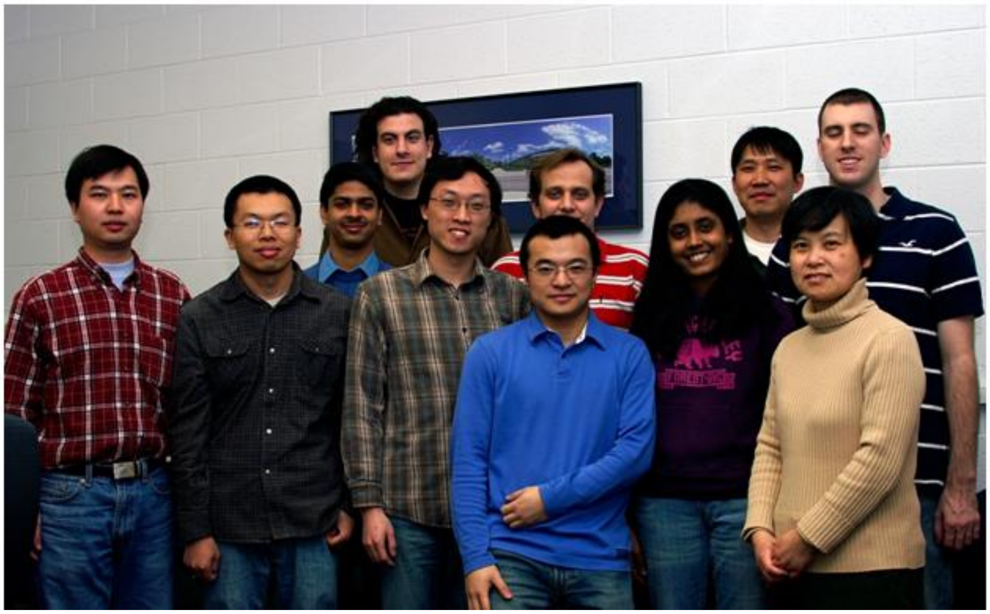

Fig.4 University of Michigan All-Electric Ship Research team, lead by Dr. Jing Sun (front right)

Preliminary simulation results published in a technical paper presented by the University of Michigan team at the IEEE Electric Ship Technologies Symposium have verified that the Opal-RT simulator is capable of performing simulations for a variety of scenarios including failure emulation, power flow path reconfiguration and energy management. The simulator incorporating different I/O hardware can support other system development activities such as hardware-in-the-loop simulation and fast control prototyping making it an effective platform for AES system research. The University of Michigan simulator facility has become an important tool for supporting research on hybrid power systems and AES applications. The facility has been used in several ongoing projects, including an ONR-supported project on dynamic reconfiguration control for IPS in AES energy management. In addition, the system has also been integrated with programmable power supplies, programmable electrical loads, energy storage banks, and power electronics to form a hybrid power system test-bed, using the Opal-RT simulators as the core components.

Opal-RT has continued to work closely with the University of Michigan and other universities in the US and Canada, providing the necessary tools to address the multi-disciplinary issues associated with AES power system development, power management and dynamic system reconfiguration.

References:

1. Yanhui Xie, Gayathri Seenumani, and Jing Sun, “Real-time Simulation and Optimization of Multi-scale Shipboard Power Systems,” Proceedings of International Simulation Multiconference, Edinburgh, June, 2008.

2. Yanhui Xie, Gayathri Seenumani, Jing Sun, Yifei Liu, and Zhen Li,“A PC-Cluster Based Real-Time Simulator for All-Electric Ship Integrated Power Systems Analysis and Optimization,” Proceedings of IEEE Electric Ship Technologies Symposium, Arlington, VA, May, 2007.