AC 2007-1693: INTEGRATING SHIPBOARD POWER SYSTEM TOPICS INTO CURRICULUM

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Dr. Grzybowski is a Life Fellow of the IEEE. His main research interests are in the area of high voltage engineering. His current research focuses on the lightning protection of power systems, ships, aerostats and other objects. He conducted study also on aging processes in polymer insulation such as cables, insulators, and magnet wires. He has authored/co-authored three books in high voltage engineering and over 220 technical papers published in IEEE Transactions, journals and Proceedings of International and National Conferences.

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Jimena L. Bastos received the B.S. in Electronics Engineering from the National University of Engineering (Universidad Nacional de Ingenieria), Lima, Peru, in December 2000. After graduating, she worked as a junior design engineer in a major Peruvian telecommunications company. She received her M.E. and Ph.D. degrees from the University of South Carolina, Columbia, SC in August 2003 and 2005, respectively. During graduate school, she worked as a graduate research assistant in the Moletronics research group and then in the Virtual Test Bed research group. On both research groups, she worked on the modeling and simulation area. Her dissertation research focused on the application of modeling and simulation techniques in electrical drives and power electronics control applications. As a result of her graduate research work, she holds two invention disclosures for creating two software tools for computer-aided design of circuit-based models and nonlinear controllers for power engineering applications. She joined Mississippi State University as a Research Faculty in August 2006, after spending one year in a post-doctoral position at the University of South Carolina. At her current position, she is currently combining her research activities in power engineering with her teaching activities. She participated in the team of professors who taught an Electric Ship related class and she is currently offering a course that focuses on power modeling and simulation.

Integrating Shipboard Power System Topics into Curriculum

Abstract
Traditionally electric power programs have had very strong relationships with electric utilities. Lately campuses are seeing a more diverse corporate representation seeking students with power engineering background. These companies include power equipment manufacturers, consultants, chemical companies, automotive companies and more.

A new set of companies looking for power engineers are naval ship builders and other ship building support industries. The new all-electric ship program provides a platform for increased control and utilization of electric power systems to improve ship features of reconfiguration and survivability. The industry now needs more electrical power engineers to solve its future challenges.

This paper will describe efforts at our university to integrate more shipboard power system topics into the undergraduate and graduate curriculum. The shipboard power system provides some unique challenges and features. By incorporating the ship power system activities into the classroom, faculty member are able to expose students to the varied challenges between these systems and traditional utility systems. As part of the curriculum update, our activities include upgrading our graduate education classes to allow current engineers within the shipbuilding community to retool in ECE classrooms to provide the background and support of future shipbuilding design and engineering needs. By collaborating with shipbuilders within the state, curriculum improvements are helping with state economic development as well as providing a workforce with a more diverse background.

Introduction
The power engineering field has seen many changes over the last twenty years. Traditionally power programs at universities provided power engineers to regional utilities and manufacturers. At the start of deregulation, hiring slowed and some universities discontinued their power programs as senior power faculty retired and electrical engineering expanded into new areas of communications, computer engineering, signal processing and microelectronics.

However recent trends are showing an increase in the demand for power engineering graduates. Many power engineering publications and conferences are discussing the maturing of the utility engineering staff and how new engineers will be needed to replace these retiring engineers. Additionally the blackout of 2003 highlighted the shortcomings of our electric utility system.

During this same time, universities have seen a shift in the companies that hire power engineers. Large chemical companies, automotive manufacturing facilities and other large manufacturing plants that have substantial power demand and need staff to help maintain industrial power plants and facilities, are now recruiting power engineering students. In the last two years, some universities are also seeing a push from the shipbuilding community for more engineers with training and background in power and controls.

The shipbuilding community is seeing a paradigm shift. In the past, other groups did ship designs and shipbuilders were contracted to build the specified design and work with manufacturers and system integrators to develop a final product. With the advancements in ship systems, today's shipbuilders are now taking a more active part in the research, development and design of the ships at a much earlier stage. In addition to those who build the ships, they also need engineers to help with the research and development of the systems on the ship. With the need for capabilities for fight-through and reconfiguration, many of the systems are moving to more electrical based systems including power and controls applications. Additionally the Office of Naval Research has been a major source of research funding for power engineering faculty within the last 10 years. Research projects related to the all electric ship are underway in individual projects, such as the ONR Young Investigator Program, as well as large consortia, such as the Electric Ship Research and Development Consortium including Florida State University, Massachusetts Institute of Technology, Mississippi State University, Purdue University, U.S. Naval Academy, University of South Carolina and University of Texas-Austin.

The increased demand in industry and needs for engineering talent in naval related research provide an opportunity for universities to look at integrating naval shipboard power system applications into the curriculum. Like many topics, naval power system topics lend themselves well to graduate courses. However, our university is working to integrate naval power systems into undergraduate classes as well exposing power engineering students to the many facets of the field.

Shipboard Power Systems

Shipboard integrated power system provides application case studies for several power curriculum areas. Figure 1 shows a single-line diagram for a typical shipboard power system employing electric propulsion. The system architecture shown is typical of a shipboard distribution system for heavy cargo ships or icebreakers utilizing cycloconverter electric drives. Figure 1 highlights some of the areas of opportunity related to integrating ship systems into power engineering classes. The next section will discuss how particular topics related to shipboard power systems are integrated into the curriculum.

Integration of Shipboard Power System Ideas into Class Topics

As part of the graduate curriculum, five faculty members team taught a graduate class, ECE 8990 on Shipboard Power Systems. The 8990 designation allows for a special topic class to be taught at the graduate level. This class combined many of the topics shown below. Additionally faculty members have integrated topics into their undergraduate classes as discussed.

<u>Power Quality Studies</u>

Small-scale power systems such as those found on ships provide a rich assortment of power quality related topics for course discussions and projects. The fact that the power electronic drive is a substantial percentage of the supply short circuit power means that harmonic problems are much more severe than typically seen in large power systems. Therefore, distortion of the voltage at the generator main bus will be pronounced as shown in Figure 2. The cycloconverter drive in particular provides opportunities for discussion of both characteristic harmonics and

inter-harmonics. In ECE 8990 "Shipboard Power Systems" class, an overview of these issues and solutions were covered. Additional details are covered in the dedicated power quality class.

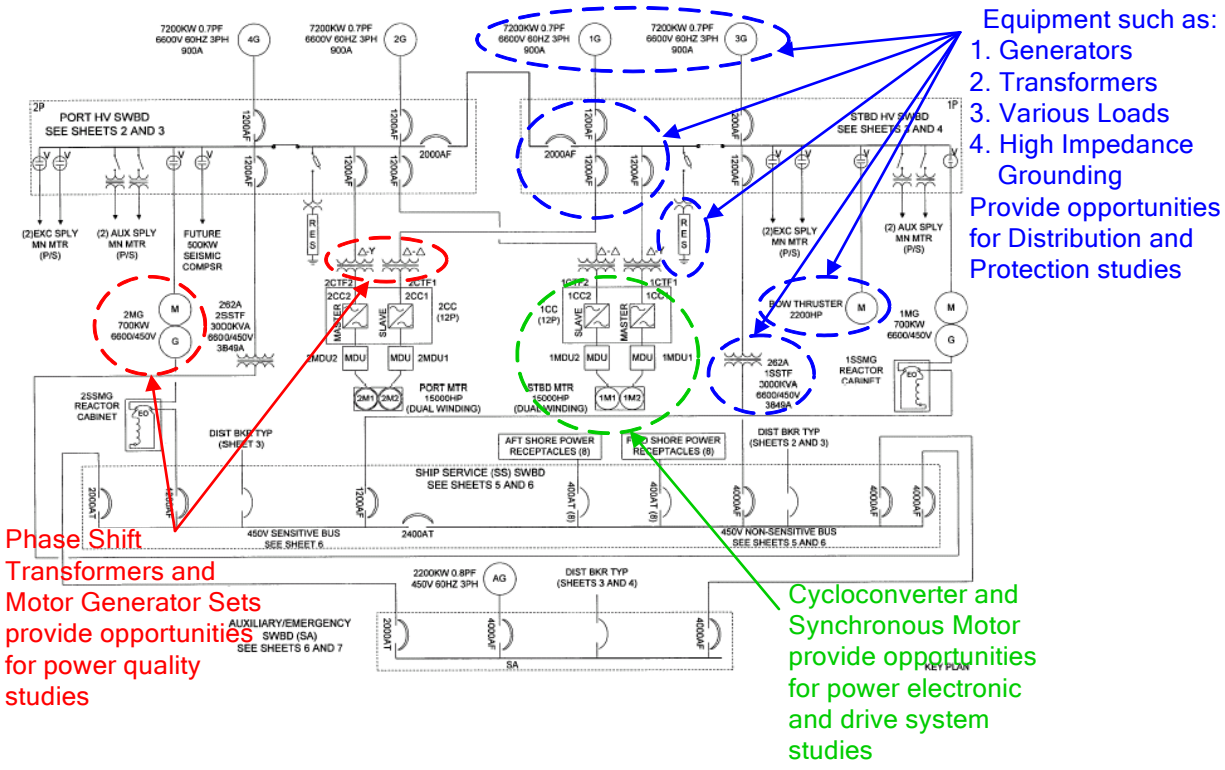


Figure 1. Small-scale shipboard power systems provide a wealth of case-studies and examples for most power system curriculum courses.

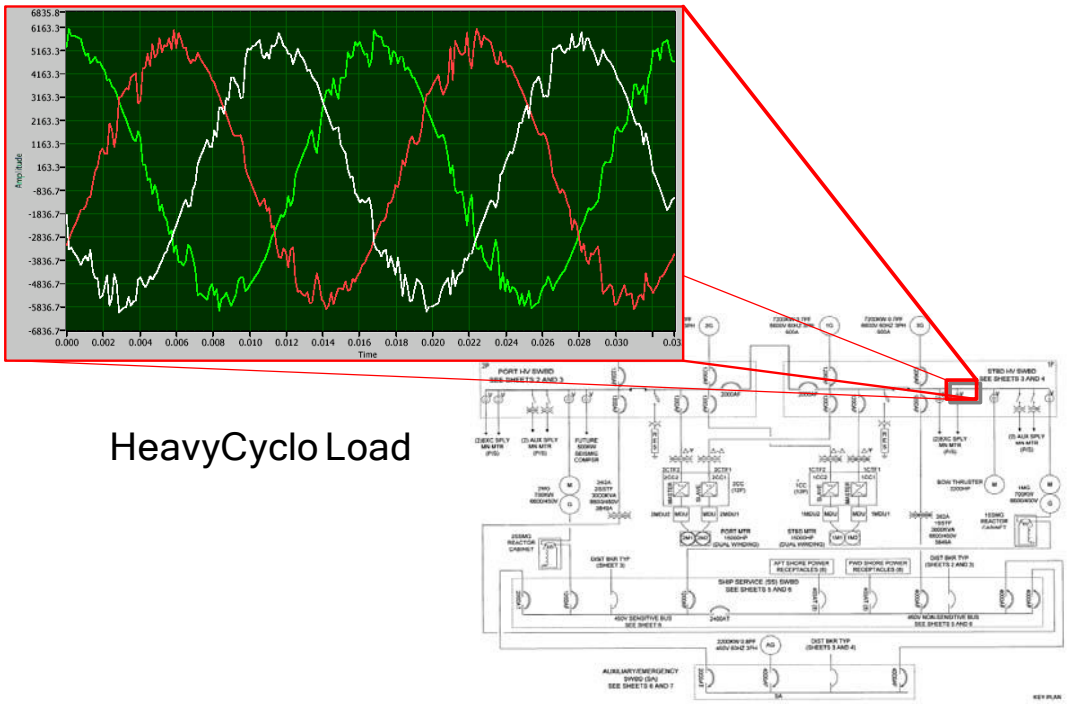


Figure 2. Severely distorted supply voltage due to large non-linear loads.

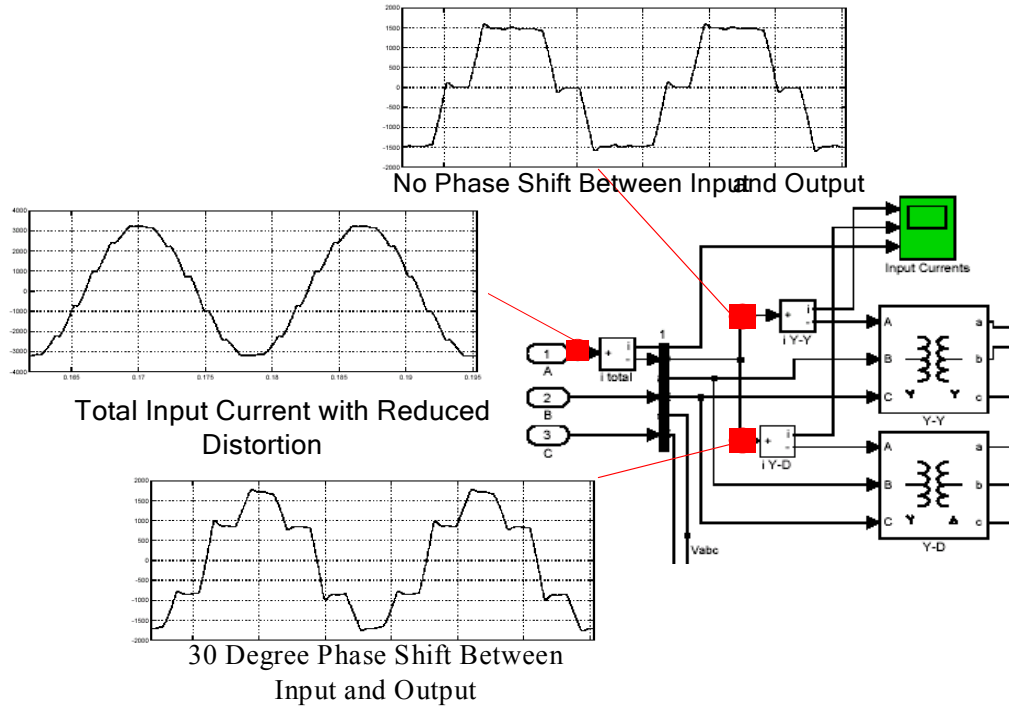


Figure 3. Phase-shift cancellation of harmonic distortion is a method used in shipboard systems.

Solutions to harmonic problems such as shunt-tuned filters and phase-shift cancellation using transformer configurations are topics that are typically covered in courses on power quality. Shipboard systems provide a more challenging and interesting environment to perform trade-off

studies among the various possible harmonic mitigation methods. The system presented here utilizes a phase-shift cancellation method demonstrated in Figure 3.

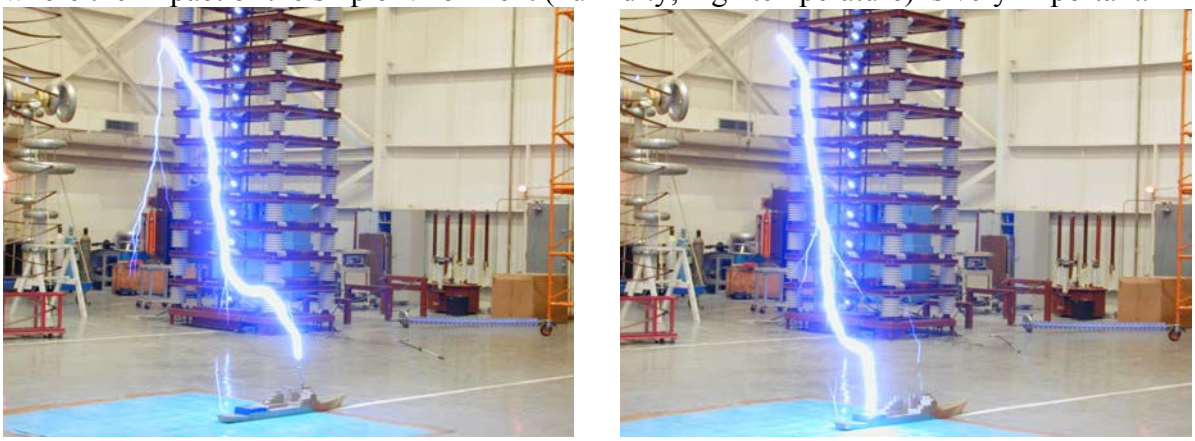
High Voltage Engineering and Lightning Protection

In the graduate course called ECE-8990 Shipboard Power Systems, the following topics were presented:

- Lightning protection of ships
- Aging of high voltage insulation in power cables and machines used on the shipboard

In the topic on lightning protection of the ship, most of the effort was given to discussing the lightning protection zone, which depends on the height of the lightning protection rod and polarity of the lightning impulse. Some laboratory study results on lightning strokes to the ship were given and discussed in Figure 4 and 5.

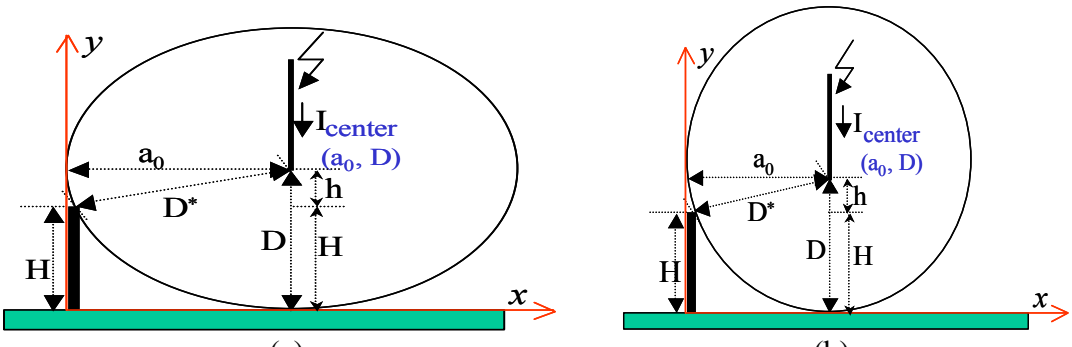
The general aging mechanism of the insulation was discussing related to the aging phenomena and electrical degradation of the high voltage insulation used in the power devices (cables and machines) installed on the ship. Special emphasis was shown towards the aging of the insulation where the impact of the ship environment (humidity, high temperature) is very important.



(a) (b)

Figure 4. Lightning strokes to ship model:

a) Lightning stroke to the lightning protection rod
b) Lightning stroke to the antenna



(a) (b)

Figure 5. The Protection Zones of Franklin Rod

a) For Negative Polarity b) For Positive Polarity

Throughout the semester, the laboratory experiments for both topics were performed in the university's High Voltage Laboratory.

The above topics related to the shipboard power systems are also discussed in the split-level courses as such:

- ECE 4990/6990 Fundamentals of High Voltage Engineering
- ECE 4663/6663 Insulation Coordination in Electrical Power Systems

In the first course (ECE-4990/6990), the aging mechanisms in high voltage insulation were broadly discussed. During the lectures a large portion of time was devoted to the analysis of the insulation degradation in the power system and shipboard cables.

In the second course (ECE-4663/6663), the lightning protection of transmission and distribution electrical systems and insulation coordination topics were presented. The lightning protection of other objects such as buildings, ships, and storage of explosive materials were also discussed.

Modeling and Simulation

As part of the ECE 8990 "Shipboard Power System" course, students were exposed to different power system commercial tools to give better perspective. More than twenty power system tools were compared briefly for power system modeling, simulations and analysis based on mathematical models used for solver, domain environments and simulations modes. Several shipboard power system (SPS) architecture including zonal, integrated power system and DC zonal from literature were used in examples to provide a bigger picture. Hardware in the loop (HIL) tests using four different platforms in VTB real-time, RTDS, MATLAB real time and National Instruments were also discussed. HIL provides dynamic response to equipment under test and validation for a model. HIL helps to better understanding of functionality and influence introduced by new hardware. Modeling of power system devices and HIL are major research activities at our university, and integrating these things in curriculum really helped students to get started with research early. Figure 6 shows the students using the RTDS system.

Figure 6: Students work on the RTDS on shipboard applications

Special Modeling and Simulation classes have been taught related to shipboard power systems. In the spring of 2005, a class on small-scale power system- modeling and simulation was taught. Much of the focus was on the modeling and simulation tool VTB (Virtual Test Bed) developed at the University of South Carolina. A similar class, Modeling and Simulation, will be taught in the spring of 2007 with the focus on modeling and HIL applications.

Power System Analysis

The ship provides a wealth of opportunities related to power system analysis. The first set of issues is the discussion on AC versus DC distribution. The ship has requirements for a variety of frequencies and voltage levels. Some equipment like radars requires 400 Hz signals. Research on the different distribution systems and their specifications was discussed.

Another key issue for shipboard power systems is reconfiguration and survivability. In our graduate shipboard power systems class, ECE 8990, the instructor discussed approaches using centralized and decentralized reconfiguration. Optimization and multi-agent techniques were also explored. For the SPS the penetration of distributed generation was reviewed as well as discussion of intentional islanding where the shipboard systems could be separated into multiple power systems. Adaptive protection techniques are key for shipboard power systems. The ungrounded or high impedance ground provides some unique problems and graduate students can explore these issues with various simulation tools.

Stability

Stability of electric ship was another area, which was covered in ECE 8990 "Shipboard Power Systems" course. Different types of stability problems including rotor angle, voltage and frequency stability were discussed for electric ship. Characteristics of SPS, such as presence of pulse load, tight couplings of AC/DC, more power electronics, ungrounded unbalanced system and short cables, which makes the stability of SPS different from utility were clearly stated. SPS stability based on size of disturbances and time span was also discussed. Voltage stability of SPS was found to be more important and different possible approaches to solve voltage stability problem were discussed in detail. Researchers are taking a continuation power flow based approach to solve the steady state voltage stability problem and also to create benchmarks to compare with index based approach for voltage stability.

Other than graduate "Shipboard Power Systems" class, differences between utility system and SPS were discussed in conventional courses such as "Power System Operation and Control" to provide better understanding to students. Power system security and physical vulnerability of electric ships were a few of the topics covered in this class , which directly relates to shipboard power systems.

Summary

This paper provides highlights of how shipboard power systems can be included in the power engineering curriculum. Faculty members are integrating research activities for the Office of Naval Research into the curriculum to allow students to be exposed to shipboard concepts. The hope is to help employers within the state as well as increase interest in power engineering careers.

The fields of power and high voltage engineering are seeing a renewal. The old school philosophy was that many of the power systems problems were already solved and that students within these fields went to work for the local electric utilities. However, today's power engineering is exciting and has many new opportunities for graduate to explore different technical areas.

Our faculty believe that exposing students to many of the different aspects of a field provides a stronger foundation for handling changes of the future. Power engineering classes should find additional opportunities to expose students to these specialized power system applications, particularly in general power engineering courses so all electrical engineers are understand the variety of opportunities in the field.