AC 2007-1700: SHIP-TO-SHORE COLLABORATIONS: INTEGRATING RESEARCH OF SHIPBOARD POWER SYSTEMS INTO TODAY'S POWER ENGINEERING RESEARCH ACTIVITIES

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Ship-to-Shore Collaborations: Integrating Research of Shipboard Power Systems into Today's Power Engineering Research Activities

Abstract:
Electric power programs within Electrical and Computer Engineering departments at universities have traditionally relied on interactions with electric utilities and manufacturers as its customer base for both students and research activities. With deregulation and changes within the electric utility business, research funds and projects with these organizations has been limited.

In the last five to ten years, the Office of Naval Research has provided millions of research dollars to universities to study many power system, power electronic and high voltage engineering challenges related to shipboard power systems. This research supports the future all-electric ship program that provides a platform for increased control and utilization of electric power systems to improve ship features of reconfiguration and survivability.

While shipboard power systems and utility systems have different constraints, there are areas of overlap where research activities can benefit both platforms. This paper discusses the opportunities for combining shipboard power system and electric utility power system research activities for the benefit of both systems. It discusses the major differences and similarities in technical challenges and how collaborative research involving both types of systems is improving the state-of-the-art in electric power research. Several examples of cross-over research will be discussed.

Introduction

The applications for power engineering are growing as technology advances. This impacts both curriculum and research activities at universities. While NSF and EPRI continue to fund some basic research related to power systems, other non-traditional groups are providing additional research opportunities to look at power engineering from a new angle or approach. The Department of Homeland Security has provided funds to look at the aging power infrastructure and evaluate vulnerability and security issues. The Department of Defense, particularly the Office of Naval Research is providing funds to many power engineering faculty to investigate future shipboard systems based on the concept of the all-electric ship. With the increase in available electric power on the ship because of possible electric drives, ship systems now have an opportunity to explore new ways to operate, maintain and protect the ship. The electrical engineering side of power engineering plays a key role.

This paper provides an overview of some of the research activities related to electric ship research that overlap with activities related to utility systems. The goal is to demonstrate the dual use or cross-over opportunities and see how cross fertilization between the research efforts might help both areas. A paper related to integrating shipboard power systems into the curriculum discusses more of the curricular issues [1]. Additional results from this research are available from references [2-39].

Research Activities Related to Shipboard Power Systems

Power System Applications Related to Shipboard Systems
In the area of power systems, research at our university can be grouped as shown in Figure 1

Reconfiguration is needed for both ship and utility power systems. The electric utilities are set up such that there are a fairly small number of possible likely combinations. However with the electric shipboard power system and the possibility of ship damage, the ship power system must be more flexible. Research activities are under way to investigate how the different configurations of the power system might impact its ability to recover from damage.

Our research activities have focused on two different aspects of reconfiguration. One technique is to use a centralized method of optimization that looks at the entire shipboard system and provides an optimal solution minimizing the number of outaged loads after a fault. This work uses LINGO software to do the optimization [2]. The other approach is a distributed approach that uses multi-agent systems to do a fast reconfiguration of the system without depending on global information on the system[3].

These two approaches attack the same problem from different angles. One of the unique situations for these shipboard applications is the integration of distributed generation within the reconfiguration strategy. By looking at placing distributed generation strategically around the ship, researchers are investigating how the DGs can provide power to different parts of the ship when some loads are cut off from the main supply.

Researchers are looking into intentional islanding. While this technique is critical for shipboard systems it also provides an alternative restoration route for electric utilities. For instance intentional islanding after damage is a key survivability feature for ship systems. While most electric utilities avoid islanding, one cooperative in Mississippi used islanding during the recovery of Hurricane Katrina that allowed for faster restoration. By better understanding the restoration of a power system considering distributed generation and islanding on a ship, MSU researchers hope to build a knowledge base for land-based electric utilities.

A second part of reconfiguration is the adjustment of control systems that monitor and protect the power system. For utility systems, protection schemes can often be divided into groups that cover most of the options. However with a very reconfigurable shipboard power system, the protection systems must also be adaptive and be able to reconfigure as needed. Research efforts are also underway to look at unique ways of DC protection that allow for fault removal and continued power to most loads.

The final area relates to modeling and simulation. With the new opportunities for control and adaptability for shipboard power systems, there is a need to model and simulate parts of the system. EPRI has developed the Common Information Model (CIM) used to create an open architecture, object oriented model for power system equipment. By determining the unique pieces of equipment within the shipboard power system and modeling this equipment using CIM, researchers can look at using off-the-shelf simulation packages for analysis of the shipboard systems. CIM models have been made for pulsed weapons and an active filter [4].

Characteristics of Shipboard Power Systems (SPS), such as presence of pulse load, tight couplings of AC/DC, more power electronics, ungrounded unbalanced system and short cables, makes the stability of SPS a challenging problems. MSU 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 fast index based approach for voltage stability.

Different types of stability including rotor angle, voltage and frequency have been one the most important conventional problem in utility. Voltage stability of Shipboard Power System was found to be more important similar to utility. Increased use of power electronics in utilities makes the problem similar to an electric ship in this respect. Research activities done in this direction for SPS will surely benefit utility problems as utilities are moving towards a tight coupled, heavy loaded grid with deregulation.

Modeling and simulation of Shipboard Power Systems (SPS) and Hardware In the Loop (HIL) are one of the major research activities at MSU. MSU researchers are using several commercial power system tools and also developing tools for SPS modeling and analysis. A Hardware In the Loop simulation refers to a system in which parts of a pure simulation have been replaced with actual physical components. HIL provides dynamic response to equipment under test, validation for a model as well as helps to better understand the functionality and influence introduced by new hardware. Research activities at MSU include development of four different platforms for hardware in the loop (HIL) in VTB real-time, RTDS, MATLAB real time and National Instruments. National Instrument (NI) is tool for designing test, measurement and control system and highly used for data acquisition. Figure 2 shows setup for Schweitzer Engineering.

Laboratory (SEL) relay model validation using NI PXI controller [5]. Virtual Test Bed (VTB) is multidisciplinary, customizable, physics based tool and provide ease in modeling [6]. Figure 3 shows setup for HIL using VTB real-time and dSpace controller.

Real Time Digital Simulator (RTDS) performs fully digital electromagnetic transient power system simulation in real time. Newer naval ships require significantly larger amounts of energy and power compared to commercial ships due to loads such as pulsed weapon and high-tech, high-power military loads. An electric ship power system is different for the utility power system, so existing utility technologies cannot be directly extended to the electric ship. But, research activities related to SPS can be extended to a utility system with some modification. Relay model validation is definitely one of the examples, which will help research activities related to utility. HIL will provide another opportunity for having controller in loop for optimization problems such as optimal power flow.

In addition to the work described above, researchers are also looking at distributed simulation that can allow simulation or hardware to be remotely located and joined via models and tools through the Internet or other network. This work can be important in developing wide area monitoring or utilizing resources that are geographically separated [7].

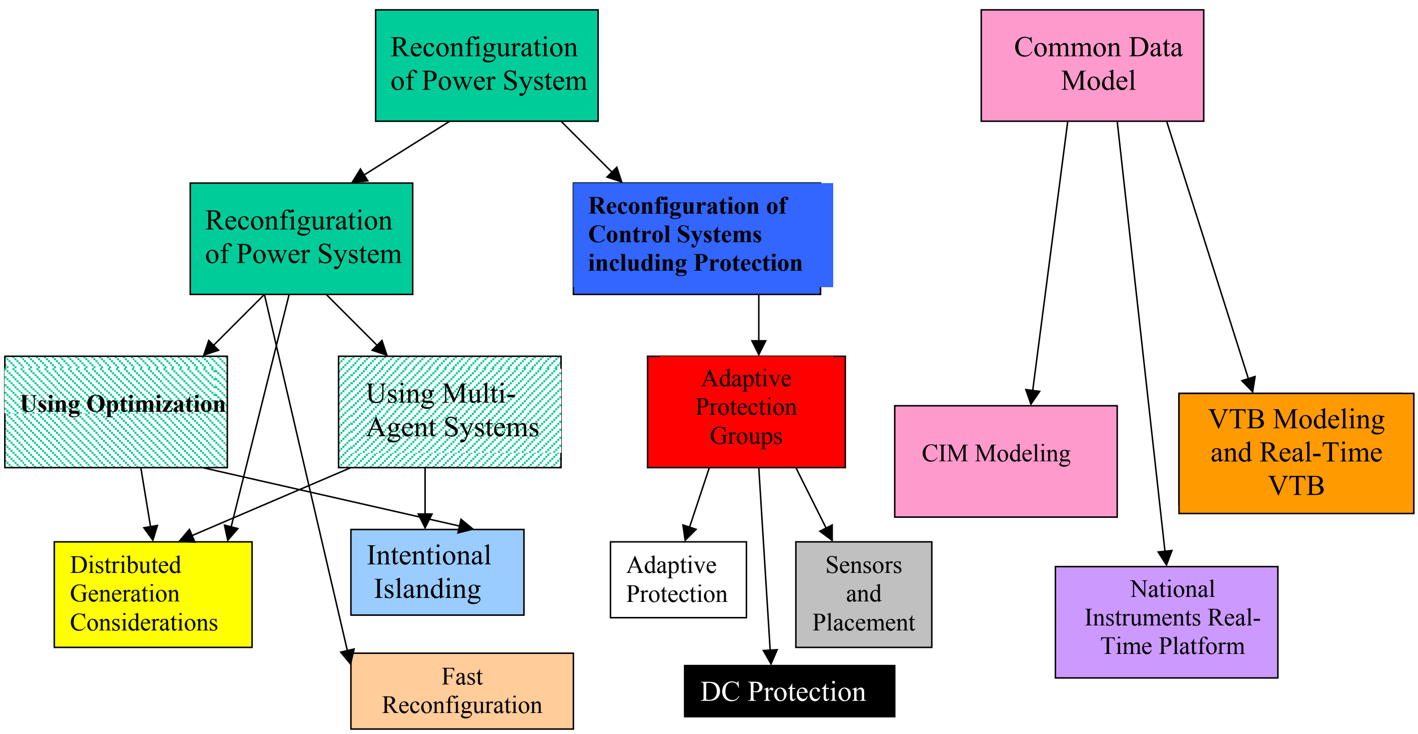


Figure 1: High Level Representation of Shipboard Research Related to Power Systems

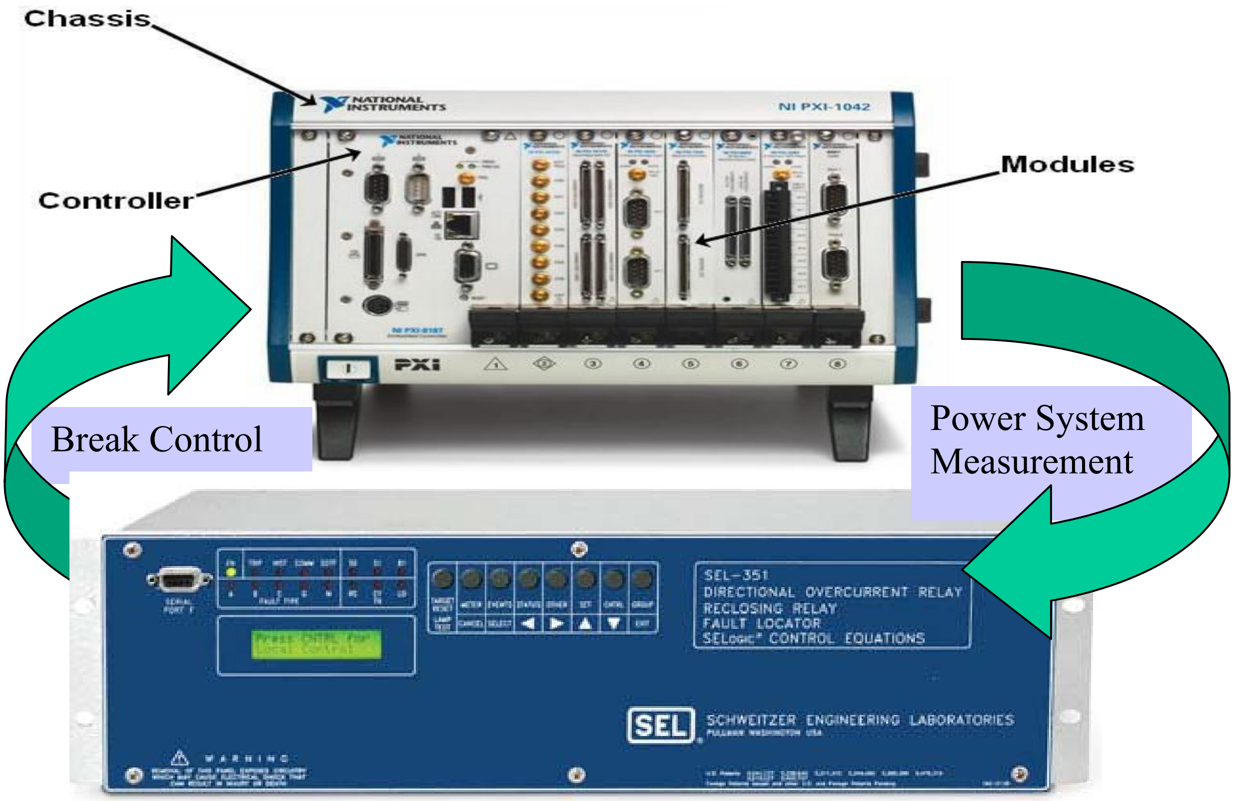


Figure 2: Real time HIL test using NI

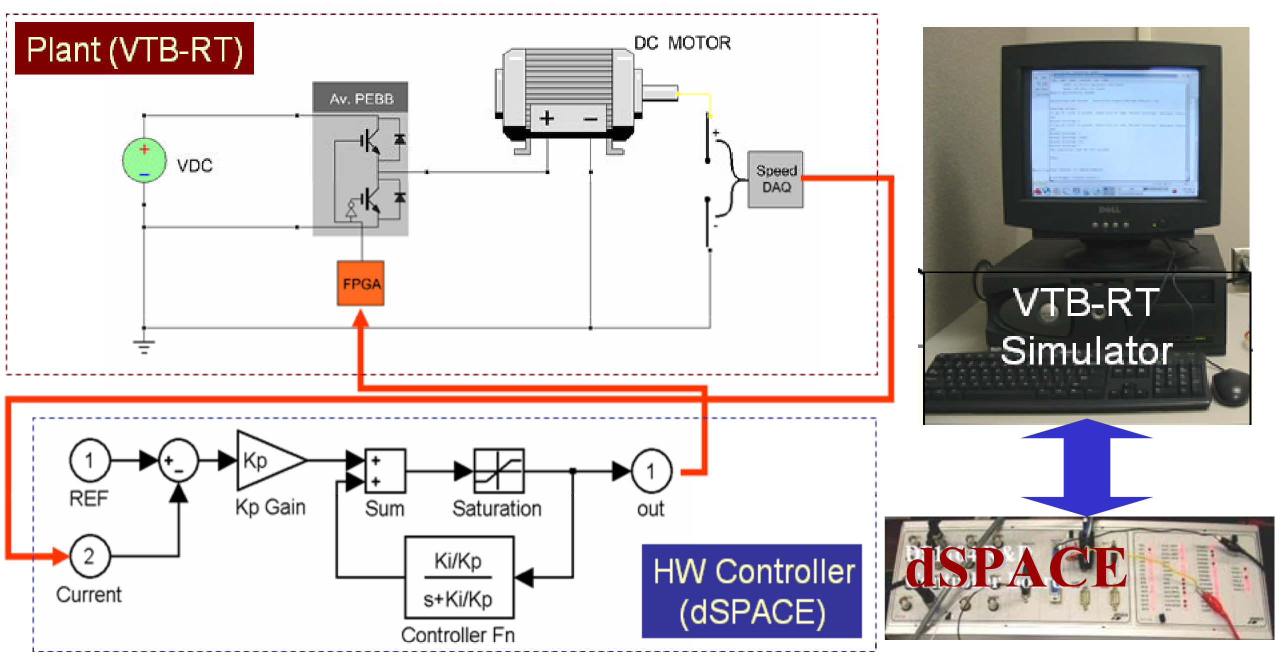


Figure 3: Real time HIL test using VTB

Impact of Power Electronic Research for Shipboard Systems

Present trends indicate shipboard energy management systems will contain increasing numbers of power electronic devices. The long term goal of future naval shipboard power systems is an Advanced Power System (APS) that is able to manage energy flow with sufficient flexibility to allow for future mission requirements such as better survivability, and support of pulsed and other demanding loads. In order to make this goal feasible, system designers require an open and hierarchical power electronics system architecture with standardized modules and control interfaces in order to explore the design space effectively. There has been progress in this area due to continued research and development of the power electronics building blocks (PEBB) concept.

There are many different control architectures for power electronics systems. Presently, power electronic systems employ custom control architectures and thus their interfaces are also specific to the type and manufacturer. Each one is made unique and has a fixed and limited application due to custom control architectures that are tailored to the specific application. This limits system designers' choices when considering the power electronics systems that make up a power electronics based system such as the APS. It is not only a problem for shipboard systems, but also creates problems for upgrading the existing power electronics systems that are part of utility power grids such as the interface between HVDC and AC parts of a system.

In order to address the issue of custom control systems and interfaces for each converter design, recent work [8, 9, 10] has presented the concept of the open system architecture (OSA). The OSA is a model to construct specific power converter functions with modular PEBBs that are not application dependent. Thus, it aims to provide a standard approach to building applications from a set of common basic functions. Further refinement of the OSA concept has resulted in the universal control architecture (UCA) in an attempt to standardize the control interfaces. The UCA has defined levels corresponding to system level functions, application or mid-level functions, and low-level control functions. This concept is illustrated in Figure 4.

A standardized control structure along with PEBB hardware also provides opportunities for encapsulating appropriate sections of the systems for delivery within a power course. As long as the interfaces and basic functions of the other components are known then it is not necessary to provide details about those systems are not directly the subject of a particular course. When a power electronics system is presented as an interconnected system of many components without any standard way of dividing up the sections then presentation of any section can become unnecessarily confused by the surrounding elements. For example, a power electronics course would focus on those elements at the lower levels while a course on power quality would focus on the application level or even system level. It would introduce extra material to attempt a discussion of the converter level of control in a power quality course, thus, confusing the true subject matter. This often occurs since without standardized partitioning of the control levels the various control sub-components are intertwined.

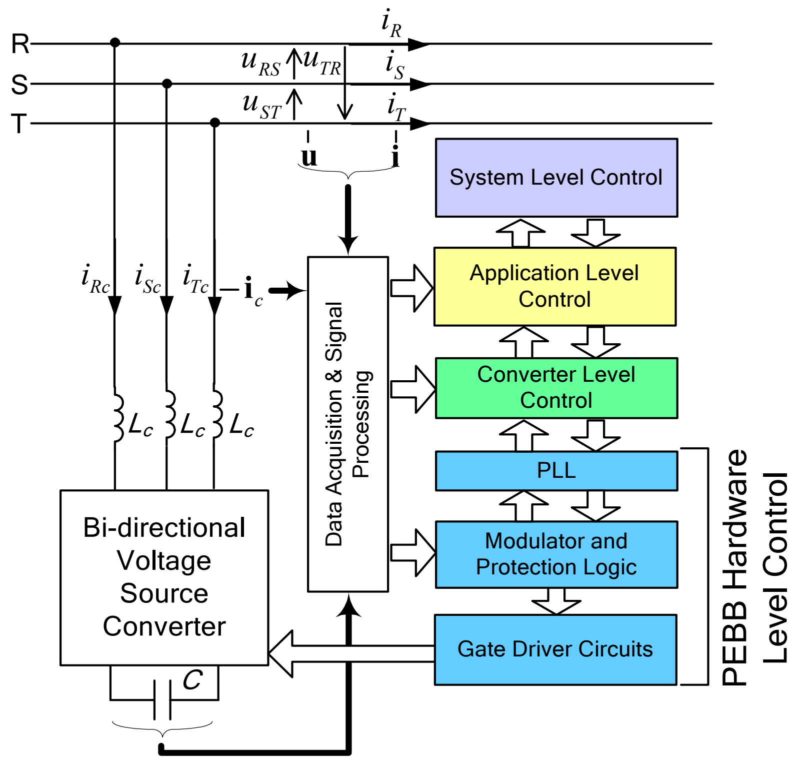


Figure 4: Illustration of a UCA type control structure for PEBB converters.

Areas of Research in High Voltage and Insulation Coordination

The MSU High Voltage Laboratory is conducting two research projects for ESRDC:
- Accelerated Electrical Degradation of Ship Motor Winding Insulation Energized by Distorted Voltage Waveforms
- Electrical Degradation of High Voltage Power Ship Cables Energized by Switching Impulses

Until now, the degradation of electrical insulation in power high voltage devices such as machine and cable insulation has mostly been evaluated for aging of the insulation caused by 60 Hz alternating voltage because the high voltage insulation was stressed by the power frequency voltage, Figure 5.

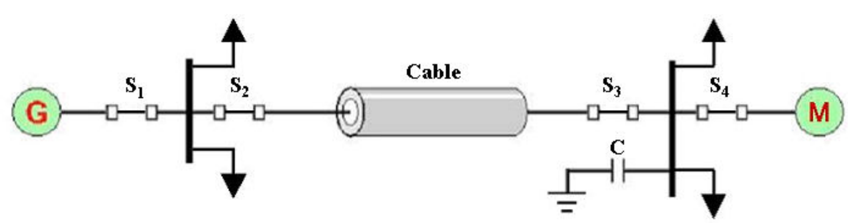


Figure 5: Distribution power system with cables and machines

Accelerated Electrical Degradation of Ship Motor Winding Insulation Energized by Distorted Voltage Waveforms

The common use of AC/DC converters in power systems and especially on shipboard generates harmonics, which are disturbing the voltage waveform, Figure 6. The electrical insulation at the disturbed voltage waveform has a lower electrical strength less than 60 Hz. This reduction in the electrical strength depends very much on the frequency of the voltage.

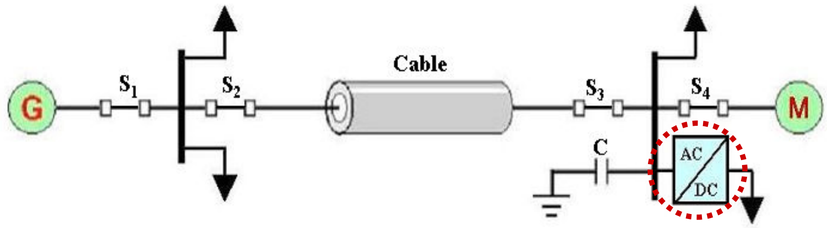


Figure 6: Distribution power system with machine and AC/DC converter

The objective of the project is to gain new insights into the characterization of the electrical properties of ship motor winding insulation while stressed by a distorted voltage waveform affected by harmonics with respect to 60 Hz. Almost all previous studies outline only partially the conditions experienced by these motors during the 60 Hz cycles of in-service stresses.

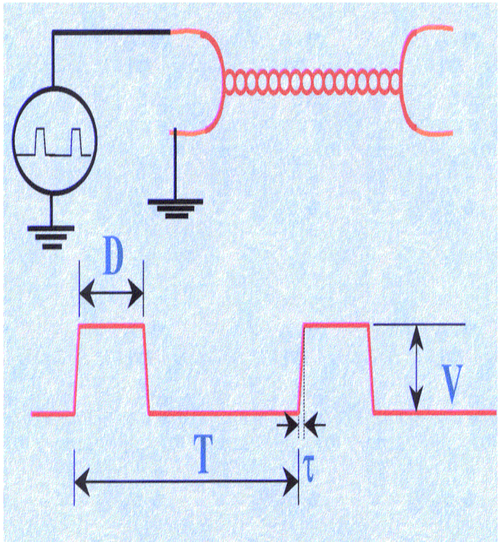
The ship motor winding insulation is aged at:

- square waveform voltage
- different temperatures
- applied voltages of 100, 500, and 1000 hours

The evaluation of dielectric strength degradation of samples is plotted versus the aging time caused by the distorted voltage waveforms. Three measurements are conducted:

- breakdown strength of the winding insulation at 60 Hz after aging
- initial partial discharge voltage magnitude, characteristics
- Weibull plot relevant to the life time characteristics of the insulation

Figure 7 presents the sample connection and the applied voltage square waveform. To obtain test results in a reasonable timeframe, the frequency of the applied pulse voltage was 40 kHz. All the results are statistically evaluated using the Weibull probability function, Figure 8. The changes in partial discharge after aging during 100 and 1000 hours are shown in Figure 9.



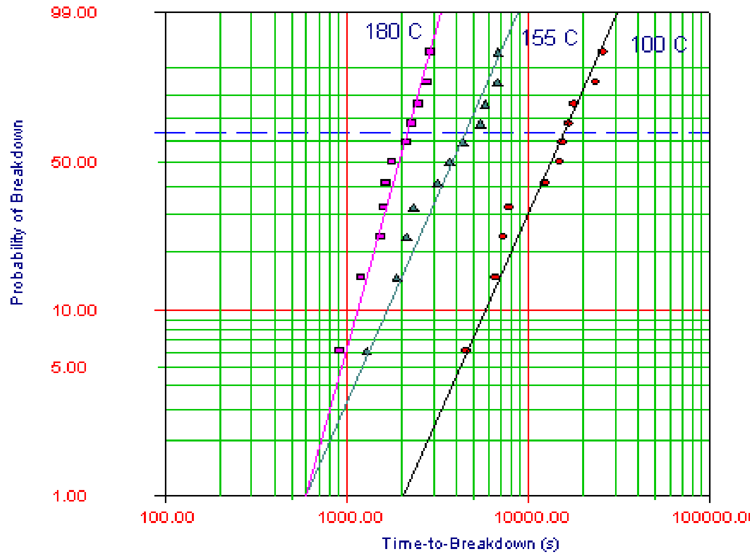
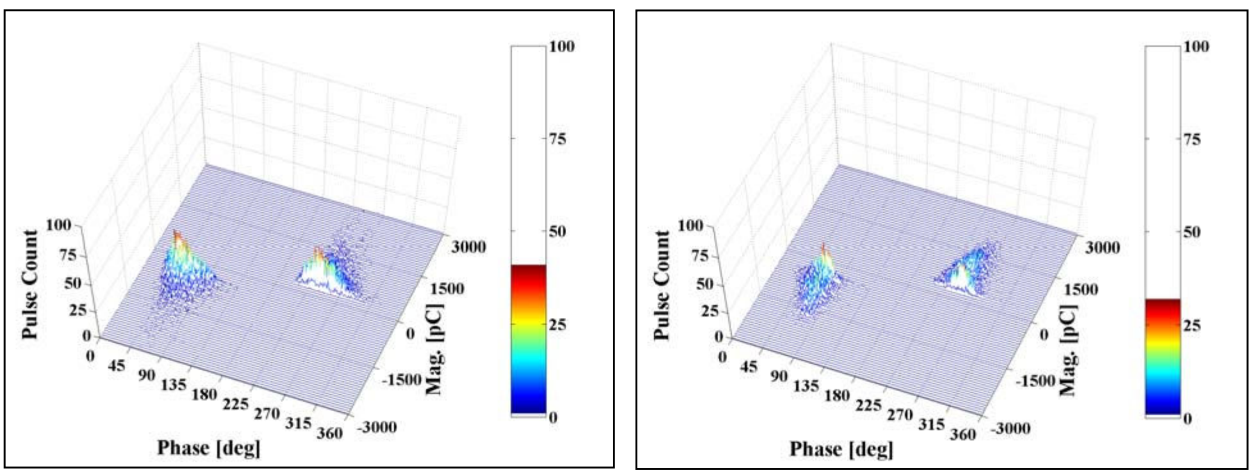


Figure 7 Test sample connection and voltage waveform excitation

Figure 8 Weibull probability of times to failures at different temperature



(a) (b)

Figure 9: Partial discharge pattern of MW 35C AWG 14 round conductor at 750 V ac, 20°C, sampled after 100 and 1000 hrs of accelerated degradation, a) and b), respectively.

Electrical Degradation of High Voltage Power Ship Cables Energized by Switching Impulses

The power cables installed on the shipboard are frequently subjected to switching impulses because there are a large amount of capacitors installed in the system. The switching surges will be generated during the operation of switch S_3, Figure 10. The operation of switches causing switching surges on the shipboard is predicted to be high. Almost all previous studies outlined only partially the conditions experienced by these cables during the 60 Hz cycles of in-service stresses. The electrical strength of power distribution cables is also known for lightning impulses but not readily available for switching impulses.

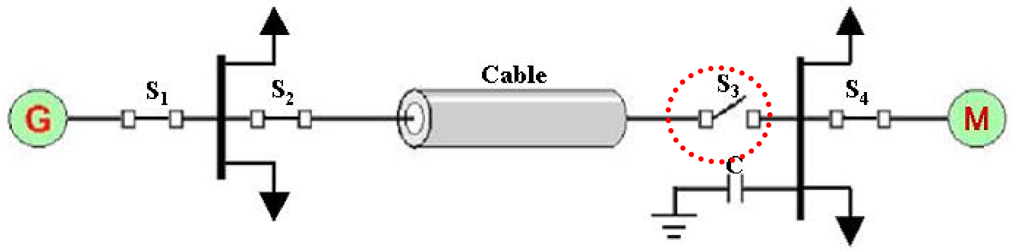


Figure 10: Power system with distribution cable and switches

This study consists of the aging of shipboard high voltage cables (XLPE and EPR) by applying switching impulses. Partial discharge measurements are taken throughout the aging process while ac breakdown voltage is measured at the end of the aging process (after a pre-determined number of impulses have been applied to a sample of cable). The test results allow shipboard power system designers to better understand the electrical aging phenomenon. This understanding will then assist in the determination of the most reliable shipboard cable, as well as an estimation of the cable's expected lifetime, although many factors other than aging by switching impulse must be considered before making such determinations.
The objective of this project is to gain new insights into the characterization of the electrical properties of these high voltage power ship cables while stressed by switching impulses.

High voltage power ship cables are aged at:

- high voltage magnitudes of switching impulses
- different temperatures
- varying numbers (100, 500, and 5000) of switching impulses

The evaluation of dielectric strength degradation of cable-samples are monitored versus the aging caused by the switching impulses applied.
The following measurement techniques are used:

- breakdown strength tests at 60 Hz
- initial partial discharge voltage, magnitude, characteristics

The partial discharges measurement results are shown in Figure 11 as a 2D plot. The marked area on the plot shows the effect of switching impulse degradation of the cable. This Partial Discharge activity close to the end of the negative half cycle of the sinus voltage wave corresponds to strong degradation of the insulating material exposed to the impulses. The captured phenomenon allowed us to observe the starting point of the degradation of the insulation material by switching impulses.

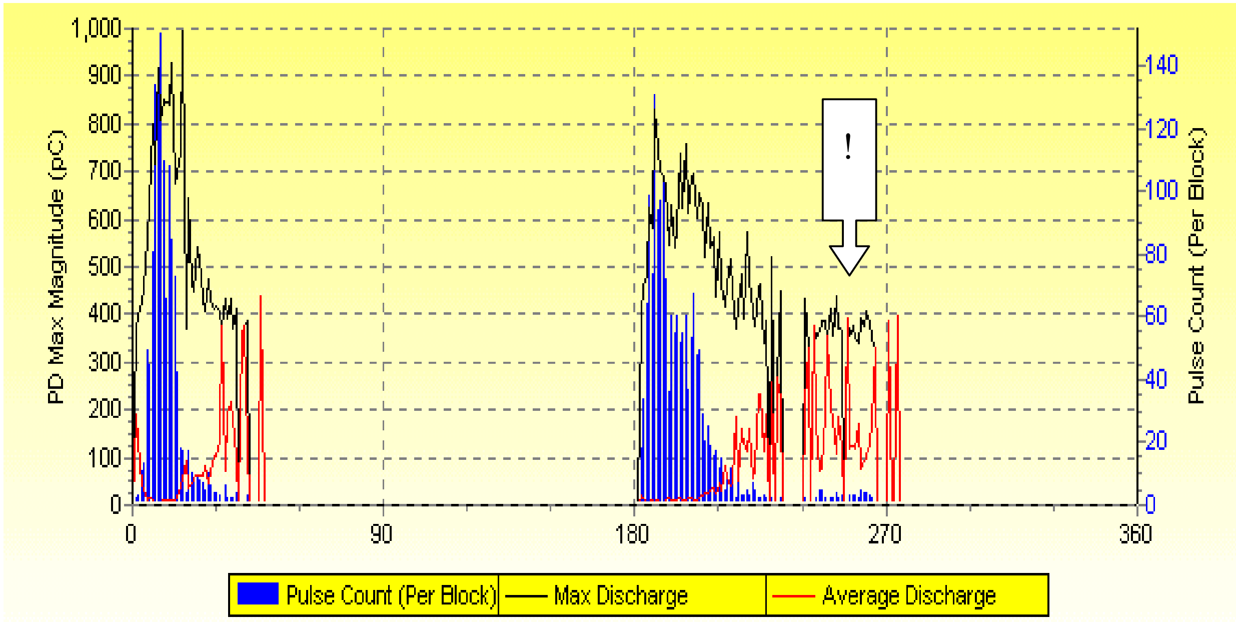
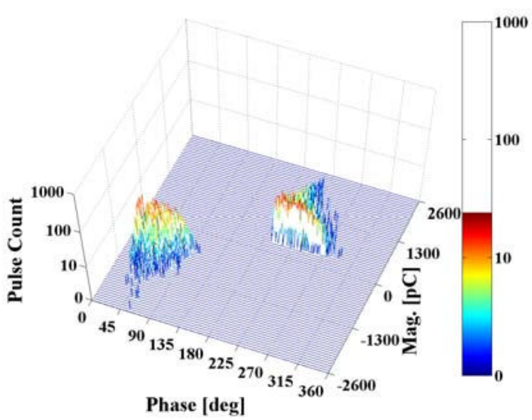
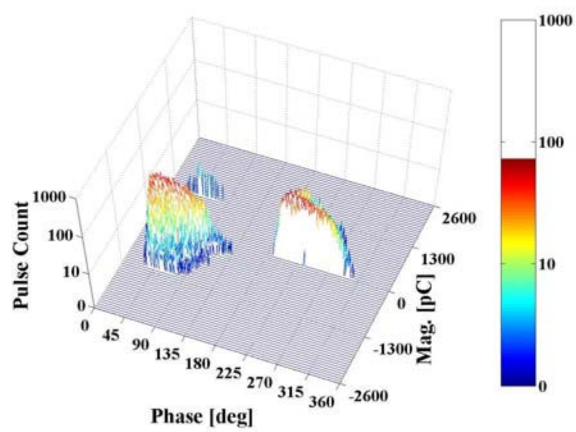


Figure 11 Measured apparent charge after 4500 switching impulses. 10 s block.

Figure 12 illustrates the partial discharges activity on a 3D plot, which gives us a better understanding of the degradation phenomena. The partial discharge exposed to the switching impulses is dependent on the voltage magnitude and number of applied impulses. The increase of partial discharges level measured at 8 kV ac voltage after 500 impulses was observed. The measurements of partial discharge at the voltage levels 1 – 4 kV did not show variation in the magnitude of partial discharge. The effect of switching impulses on the partial discharges activities was not yet measured.



(a)



(b)

Figure 12: 3D Plots of partial discharge characteristics at (a) No impulses, (b) 500 impulses

Summary

This paper has provided an overview of research activities at Mississippi State University related to electric ship systems. These activities allow crossover between traditional power system electric utility research and the new issues related to the all-electric ship. Faculty and students are using their background, equipment and algorithms for electric utilities as the starting point for the research activities. Through the current activities these concepts are being modified and extended to work with the different assumptions and issues of the shipboard power system. As these algorithms mature, the concepts will be brought back to the electric utility systems and work is being done to see how the new tools, simulations and technologies could benefit the state-of-the-art for electric utility research.

Expanding the research activities of power and high voltage engineering programs is helping to diversify the experience base of the faculty and students involved with these activities. Having a background related to several types of power systems will be beneficial to the power engineering community in the future.

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