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14. ABSTRACT
Shipboard MVDC power systems need to support pulsed loads, which have destabilizing effects on the MVDC power transmission bus voltage. Despite the reference shipboard MVDC architecture having energy storage to buffer the large power swings of pulsed loads, a large constant power still needs to be delivered to maintain the energy storage state of charge. This recharging constant power itself introduces small signal instability to the MVDC bus voltage. This thesis investigates the advantages of adding a dynamically tuneable virtual capacitor and resistor in parallel to the pulsed load for maintaining small signal stability. The stabilizer is implemented in a negative load configuration in the existing reference architecture hardware, where the stabilizer negatively impacts the power quality of the downstream load. To address this, a dual use is added to existing hardware by having the energy storage also cancel out the newly introduced noise. A controller was designed to control a MVDC power converter module for providing these stability services. In addition, the controller manages its internal energy storage and stabilizes its internal DC bus that powers its downstream pulsed load.

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Shipboard electric systems, control systems, pulsed power

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Title: Pulsed Energy Management Architectures

Accomplishments:

<u>What were the major goals and objectives of the project?</u>
The first major goal of this project is to achieve an acceptable level of understanding for shipboard MVDC technology.

The next major goal is to make contributions towards the controls aspect of integrating an electromagnetic railgun (EMRG) system with a shipboard MVDC system. One contribution in progress is an EMRG charging pulse negotiation protocol between the shipboard MVDC and EMRG systems.

<u>What was accomplished towards achieving these goals?</u>
Extensive background research was done with shipboard MVDC published literature. Such literature covered various aspects of shipboard MVDC controls including: multi-agent systems (MAS), MAS-based power system controls, fault detection and recovery, power generation and distribution, energy storage management, power stability controls, scalable power electronics controls, power electronics building blocks (PEBB), load shedding, and pulsed load management. A survey paper (titled "Survey of Shipboard MVDC Control Architectures Supporting Electromagnetic Launcher Capabilities") was written for publishing. This paper was also presented at the 19^{th} Electromagnetic Launch Technology Symposium. This paper covers only some of the researched literature.

A shipboard MVDC-EMRG negotiation system was designed. A power pulse can be characterized into a 10-dimensional space as according to "MVDC Shipboard Power System Considerations for Electromagnetic Railgun" by N. Doerry and J. Amy, Jr. With these 10 dimensions, any pulse can be characterized for negotiation. This was verified as correct with some assumptions.

For this negotiation system, there are two precondition assumptions. The first precondition is that all generators are online in a battle mode. The second precondition is that thermal limitations are not a problem. These assumptions can be removed as a more sophisticated negotiation system is developed. For now, we are focusing on achieving a baseline functioning negotiation system to expand upon. A major negotiation assumption is that the negotiated pulse parameters apply limits upon the actual pulse applied by the EMRG charging system. This way, the negotiated pulse represents the most aggressive that the EMRG can charge, and the negotiated pulsed will always have at least the desired charge energy. This way, the actual pulse can be less aggressive than negotiated if the desired charge energy is lower than the maximum energy provided by the negotiated pulse. Other minor assumptions not listed here are recorded as well.

A scoring algorithm was developed using linear piece-wise models based upon the ΔPower, Power, Energy, and time dimensions. Each dimension can be independently scored and their scores can be combined into a MVDC score and EMRG score. These two system scores can be combined into a final score for the negotiated pulse. The scoring boundaries are the same as described in Doerry and Amy's paper. These dimensions were chosen as there are power ramp rate, power throughput, and energy limitations of the power sources. Also, the EMRG requires the desired energy within a desired time. The scoring algorithm includes score losses due to: non-critical load shedding, propulsion speed limiting, slow load restoration, and insufficient EMRG charging rate. The score functions can be further refined in the future.

A Thesis was written to investigate the advantages of adding a dynamically tuneable virtual capacitor and resistor in parallel to the pulsed load for maintaining small signal stability. The stabilizer is implemented in a negative load configuration in the existing reference architecture hardware, where the stabilizer negatively impacts the power quality of the downstream load. To address this, a dual use is added to existing hardware by having the energy storage also cancel out the newly introduced noise. A controller was designed to control a MVDC power converter module for providing these stability services. In addition, the controller manages its internal energy storage and stabilizes its internal DC bus that powers its downstream pulsed load. Future ships will have a special shipboard power grid and power converters to power future electronics. Most of these power converters will have an internal battery device that provides power when the generators do not provide enough power. Generators are very slow to change their power output. Some shipboard electronics may consume very large amounts of power at very quickly changing rates, causing instability to the power system. The batteries can accommodate the instability caused by these electronics. However, the batteries need to be quickly recharged, which is also unstable to the special power grid. The thesis modifies the recharging behavior so that it does not cause this instability. Also, it is preferable that the batteries will only draw power from the power grid in one direction and send power to the power consuming electronics. This setup is called negative load. This setup is preferable, because sending power back to the power grid will require extra hardware. Ships can only carry so much equipment due to constraints in weight or room, so additional hardware is undesirable. There already exists similar research to provide this stabilizing service, but they are not designed for a shipboard power grid supporting these quick high power electronics. This thesis also makes a controls system that manages the battery and other requirements of the power system.

<u>What opportunities for training and professional development did the project provide?</u>
A graduate student has become knowledgeable about shipboard MVDC systems. This graduate student will work at Naval Surface Warfare Center Dahlgren Division (NSWCDD) on their pulsed power controls technology for EMRG applications, so exposing him to shipboard MVDC technology will aid his future work at NSWCDD. Also, this graduate student has been newly exposed to modeling and optimizing. Finally, this graduate student will attend a professional engineering conference for a paper related to this project, exposing him to a professional conference environment. The graduate student has now graduated and produced a thesis.

<u>How were the results disseminated to the communities of interest?</u>
To disseminate the results to the communities of interest, an IEEE conference paper was written, accepted, and presented at the conference. The paper was submitted for publication on the IEEE Transactions on Plasma Science on Electromagnetic Launchers, but rejected as the reviewers felt that literature review papers were not fit for the journal. The paper was reviewed and approved for publication by ONR.

<u>What do you plan to do during the next reporting period to accomplish the goals and objectives?</u>
More features can be added. Such features include implementing a MAS-like system using independent controllers to better simulate a more realistic shipboard MVDC and EMRG system. Also, such a test system must include desired shipboard MVDC capabilities. These capabilities include: abstraction, standardized communication interfaces, scalability, and modularity.

Technology Transfer:

The thesis was submitted to the ONR for review.

Participants:

Participant 1:

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Graduate Student (research assistant)

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N/A

Nearest Person Month Worked:
10

National Academy Member:
No

Country:
United States of America

Students:

1 graduate STEM participant.

Products:

1 Conference Paper

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Survey of Shipboard MVDC Control Architectures Supporting Electromagnetic Launcher Capabilities

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Robin Yang, Willem Odendaal, David Woodward

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Shipboard MVDC Voltage Stabilization by Negative Load Energy Storage Compensated Virtual Capacitance

Robin S. Yang

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Masters of Science

in

Computer Engineering

Willem G. Odendaal, Chair

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Alan Brown

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Blacksburg, Virginia

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Robin S. Yang

(ABSTRACT)

Shipboard MVDC power systems need to support pulsed loads, which have destabilizing effects on the MVDC power transmission bus voltage. Despite the reference shipboard MVDC architecture having energy storage to buffer the large power swings of pulsed loads, a large constant power still needs to be delivered to maintain the energy storage state of charge. This recharging constant power itself introduces small signal instability to the MVDC bus voltage. This thesis investigates the advantages of adding a dynamically tuneable virtual capacitor and resistor in parallel to the pulsed load for maintaining small signal stability. The stabilizer is implemented in a negative load configuration in the existing reference architecture hardware, where the stabilizer negatively impacts the power quality of the downstream load. To address this, a dual use is added to existing hardware by having the energy storage also cancel out the newly introduced noise. A controller was designed to control a MVDC power converter module for providing these stability services. In addition, the controller manages its internal energy storage and stabilizes its internal DC bus that powers its downstream pulsed load.