***Project:*** Control of Power-System-Induced Ship Hull Currents in 20 kV DC Architectures

***Project Completion:*** 2017

***Output:*** Method to develop tractable, efficient, and useful common-mode (CM) equivalent circuits of power electronic systems. Validated on several systems. Short courses provided to NSWC.

***Outcome:*** Navy has an effective means of predicting CM current in DC or AC ship power architectures. This is particularly useful in selecting grounding strategies, developing specifications for CM chokes, and evaluating the effectiveness of mitigation strategies. This has also led to a proposed mid-point ground interface for ship MVDC systems.

***Project Motivation***: Medium voltage DC power systems are being considered for future naval surface vessels. The proposed architectures will contain many power electronic circuits. Known problems with such circuits include leakage [also known as common-mode (CM)] currents through bearings or the ground plane (i.e., the ship hull) and voltage stress resulting from high-edge-rate switching. This sort of CM behavior in power systems has been associated with bearing and insulation failure. As a result, prevention and mitigation have received much attention.

To support CM analysis and design, two modeling approaches have received the most attention. The first approach is to add parasitic elements to differential mode (DM) circuits and simulate the coupled DM/CM (or mixed-mode) behavior attention. Although shown to be effective for a single converter or drive, the computational requirements are prohibitive for modeling a modern ship electrical system. A second technique is to derive CM equivalent circuits (CMECs) in which the dominant parasitic paths are parameterized and coupled to CM voltage or current sources that represent the impact of power electronic switching. This approach has a computational advantage, since the need to identify switching instants throughout a simulation

is eliminated. It is also advantageous, since techniques for linear circuit analysis are readily applied to predict CM behavior.

Although a host of CMECs have been described, prior to the ESRDC research, there had been relatively little effort to formalize their derivation. The ESRDC first formalized a CM modeling approach using a new definition for CM voltage. The formalization then led to a relatively straightforward transformation of mixed-mode power system models into their corresponding CM equivalent circuits. A straightforward connection of these CM equivalent components can be used to form the CM models of entire power systems. This enables the consideration and comparison of a broad range of mitigation approaches, including the selection of switching strategies, choke placement, grounding schemes, and so on.

The method has been demonstrated and validated by comparing the results of the proposed CM modeling approach with a detailed mixed-mode simulation of the example ship power system of Fig. 1. The CM model is shown in Fig. 2 with representative comparison between the models shown in Fig. 3. The technique has also been applied to model and analyze the CM current observed in the Purdue reduced-scale naval DC microgrid (PDCM) under alternative grounding strategies and a Navy HEV system.



Fig. 1 Representative architecture for parasitically grounded, dc-based ship power system.



Fig. 2 Representative architecture for parasitically grounded, dc-based ship power system.



Fig. 3 Current through the buck converter predicted by the detailed (Fig. 1) and CM circuit (Fig. 2).

Significant progress was made in three areas:

* *A tractable and effective means to explore impact of power system design on unintended hull currents has been derived using CMECs*
* *Methods to characterize the CMEC parameters have been developed*
* *The approach has been validated on several hardware systems*

***Project Extent***: This project involved researchers from Purdue working in collaboration with FSU, MSU and is documented in several technical papers, and a report.

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