Project: Testing a Megawatt-Scale Impedance Measurement Unit at Medium Voltage Levels

Project Completion: 2017

Output: For the first time a medium voltage environment relevant to the next generation of electric shipboard power systems was used in testing a novel impedance measurement unit (IMU). A technical report [1] on testing the IMU [2] describes the test concept and outcomes.

Outcome: The Center for Power Electronics Systems at Virginia Tech (CPES, VT) developed and built a medium voltage class impedance measurement unit, targeting applications that measure the input and output impedances of power system components at kV- and MW-levels within DC- and AC-systems. Florida State University, Center for Advanced Power Systems (FSU-CAPS) used its advanced 3x5 MW laboratory facilities for system relevant experimental tests including hardware-in-the-loop simulation. The joint project allowed to design and perform experiments that fully explored the IMU's capabilities.

Project Motivation:

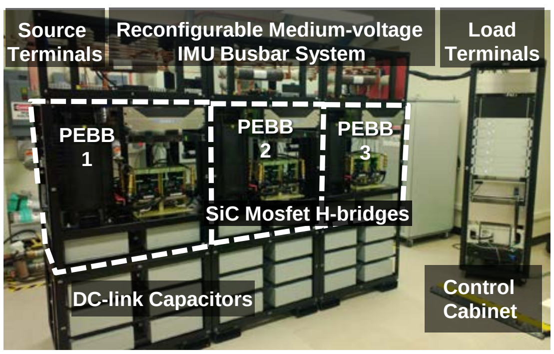

Figure* 1: *Impedance measurement unit developed at VT-CPES

The U.S. Office of Naval Research is actively pursuing science and technology for advanced electric ships that build on integrated power systems. The motivation for this project comes from the success of earlier efforts in developing impedance measurement and impedance-based controls capabilities at the low voltage levels that directly support advanced power system concepts. An extension of impedance measurement units to the medium voltage (MV), megawatt-class converter level will provide significant benefits to the U.S. Navy. Building on theory developed by ESRDC researchers [3] and earlier practical application experience at the low voltage levels [4], a novel medium voltage impedance measurement unit was tested within this project. The primary objective was to evaluate the suitability of such a novel instrument, see Figure 1, for use in frequency domain characterization of megawatt scale equipment. The impedance characteristics of components will provide the information necessary for system integration studies. This project was the first test and use of an IMU at these voltage and power levels. The technical objectives included demonstration of the IMU design concept and impedance measurement capabilities within AC- and DC-systems.

An approach to testing the IMU at the medium voltage level was developed in coordination between the two centers and performed in FSU-CAPS' laboratory facilities (see Figure 2), which includes the capability to use controller and power hardware-in-the-loop (CHIL and PHIL) simulation. As the IMU's power stage design is based on the Power Electronic Building Block (PEBB) concept, the individual stages were evaluated before operating the unit as an impedance measurement device. Tests feasible at CAPS included the operation at 3.3 kV/60 Hz, 4.16 kV/60 Hz, and 4 kV DC-systems. Guided by modelling and simulation efforts, commissioning and test plans were developed. Work prior to testing addressed issues of experiment selection and design. One critical aspect was the protection of experiments due to the uniqueness of the proposed tests. System-based tests were conducted with the help of a digital real-time simulator (DRTS) to facilitate CHIL simulations and control of the surrounding power system components in PHIL.

The project concluded with the following outcomes. Test procedures and protection logic and actions could be implemented with the help of representative rest-of-system models within the DRTS platform, supporting verification and validation of experiment design and execution. The medium voltage, megawatt-level facilities at CAPS provided several means of subjecting the device under test to realistic surrounding system conditions, and both AC- and DC-configurations were evaluated. Impedance characteristics were successfully determined by the IMU at the medium voltage level. The most challenging problems experienced during testing are related to the SiC-modules and common mode issues. These issues were to some extend expected due to the high switching frequency and partly mitigated by the initial design itself. Additional measures were taken while testing was progressing from low to medium voltage levels. The IMU was successfully operated at AC-voltage levels of up to 2.8 kV in both shunt and series mode. The conclusions drawn from the experience gained includes the need for improved switching characteristics of SiC-modules and reduced common mode sensitivity. The first aspect can be addressed with new designs of the integrated SiC- and firing pulse circuits. The second aspect will require establishing new design guidelines for both the IMU-device and system level.

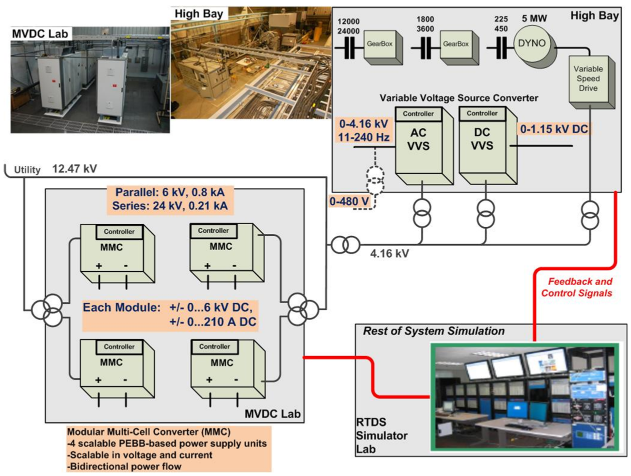

Figure 2: Medium voltage megawatt-level test facility at FSU-CAPS

Project Extent: This project involved multiple researchers from FSU-CAPS and VT-CPES and is documented in a technical report [1] and the following publications [2, 5, 6, 7].

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References:

[1] Michael Steurer, Karl Schoder, James Langston, Isaac Leonard, John Hauer, Ferenc Bogdan, and Michael Coleman. Testing the megawatt-scale impedance measurement unit at medium voltage levels. Technical report, Electric Ship Research and Development Consortium, December 2017.

[2] Igor Cvetkovic, Zhiyu Shen, Marko Jaksic, Christina DiMarino, Zeng Liu, Dushan Boroyevich, and Rolando Burgos. Impedance measurement unit (IMU) for 4160 V AC networks, onr report. Technical report, Center for Power Electronics Systems, Virginia Tech (CPES, VT), January 2017.

[3] S. D. Sudhoff and J. M. Crider. Advancements in generalized immittance based stability analysis of dc power electronics based distribution systems. In *2011 IEEE Electric Ship Technologies Symposium*, pages 207–212, April 2011.

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[5] F. Bogdan, J. Hauer, J. Langston, K. Schoder, M. Steurer, I. Cvetkovic, Z. Shen, M. Jaksic, C. DiMarino, F. Chen, D. Boroyevich, and R. Burgos. Test environment for a novel medium voltage impedance measurement unit. In *2015 IEEE Electric Ship Technologies Symposium (ESTS)*, pages 99–103, June 2015.

[6] I. Cvetkovic, Z. Shen, M. Jaksic, C. DiMarino, F. Chen, D. Boroyevich, and R. Burgos. Modular scalable medium-voltage impedance measurement unit using 10 kv SiC MOSFET PEBBs. In *2015 IEEE Electric Ship Technologies Symposium (ESTS)*, pages 326–331, June 2015.

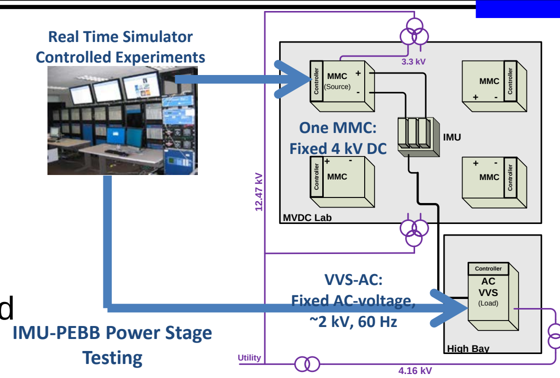
[7] K. Schoder, M. Steurer, F. Bogdan, J. Hauer, J. Langston, D. Boroyevich, R. Burgos, I. Cvetkovic, Z. Shen, and C. DiMarino. Testing of a novel medium voltage impedance measurement unit. In *2015 IEEE 3rd Workshop on Wide Bandgap Power Devices and Applications (WiPDA)*, pages 287–290, Nov 2015.

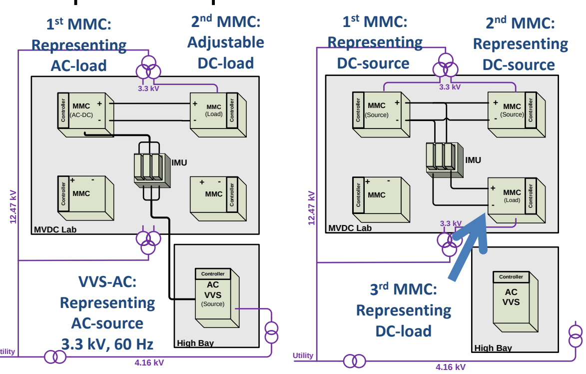
Impedance Measurement Unit

Modeling & Simulation and Hardware-in-the-Loop (HIL) Testbed

Objective

- Demonstrate capabilities at medium voltage (MV) and megawatt power level – first of its kind
- Modeling and simulation to derisk testing: Evaluate impact of selecting scenarios, controls, parameters, and protection
- Perform MV-tests and derive best practices in Power HIL procedures and experiment protection





IMU AC and DC Impedance Measurement Experimental Setups

Impacts

- Offline modeling and simulation of setups as feasible in CAPS MV-laboratory: select valuable experiments, evaluate controls, determine protection elements and actions
- Implementing Control HIL testing: low-risk demo of IMU by interfacing IMU-controller to simulated experiment
- Best practices in commissioning and test plan development
- Power HIL testing: Medium voltage demo in CAPS' MVAC and MVDC lab
- Supports system study based on experimental results
- A VT-CPES and FSU-CAPS project

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