Y9.HIL.2: Small Signal Stability Improvement and Demonstration of SST (DAB) Enabled FREEDM DC System

Project Leader: Hui "Helen" Li

Faculty: Alex Huang, Mischa Steurer

Students: Qing Ye

1. Project Goals

This project is to maintain and enhance a stable FREEDM DC system. This project together with previous research provides a systematic method of system modeling, stability analysis and improvement, stability-oriented design guidance, and HIL test bed validation. In addition, the advanced power converters and newly developed control strategies in FREEDM system can be applied with the developed technology to evaluate and demonstrate their effects on system stability.

2. Role in Support of Strategic Plan

This project has contributed to strategic plan in the following three aspects. In the fundamental science layer, we proposed the impedance modeling method for the Dual-active-bridge (DC/DC) converter with various control schemes; in the enabling technology layer, we addressed the potential small signal instability of multiple power electronics devices; in the system demonstration layer, the FREEDM LVDC system stability will be demonstrated using HIL testbed.

3. Fundamental Research, Technological Barriers and Methodologies

1) To characterize DAB converter terminal behavior as a dc grid source converter and to investigate its effect on system stability by comparing to other source converters such as PFC rectifiers and two-stage ac/dc converters. The technological barrier is to derive an accurate terminal behavior of the DAB converter. We proposed an impedance modeling method of DAB converter considering various control strategies.
2) To develop stability analysis models and methods with consideration of constant power load (CPL) and power management strategy, propose resonance mitigation techniques to improve the FREEDM system stability robustness. The technological barrier is to develop an effective and efficient stability analysis method and design a feasible resonance mitigation technique to enhance system stability. We proposed a concise and effective impedance-based stability criterion to analyze the FREEDM LVDC system stability. We are also going to develop a virtual impedance control technique to improve the system stability robustness.
3) To design a HIL test bed to demonstrate the enhanced stability of SST (DAB) converter enabled dc grid. The technological barrier here is to design a HIL test bed with online impedance measurement functionality. We are going to develop an online impedance measurement algorithm to be implemented in the HIL test bed.

4. Achievements

1) Impedance modeling of DAB converters with various control schemes

Based on the control schemes demonstrated in Fig. 1, the output impedances of DAB converters are derived accordingly. The comparison of analytical and off-line measured impedance of DAB converters are depicted in Fig. 2. The blue lines are the analytical value from mathematical derivation, and the red rectangles are the measured value through circuit perturbation. Analytical results and measured results are consistent with each other, which validate the accuracy of derived impedances.

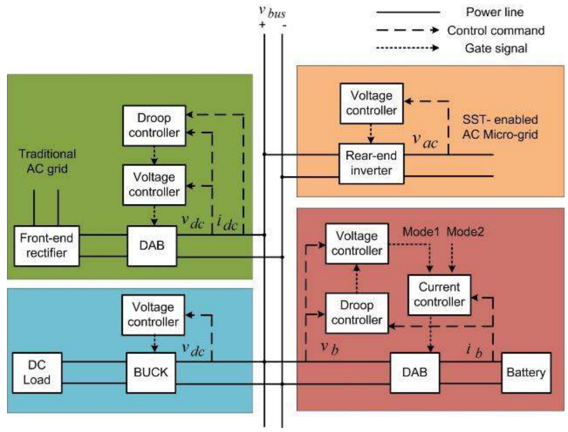
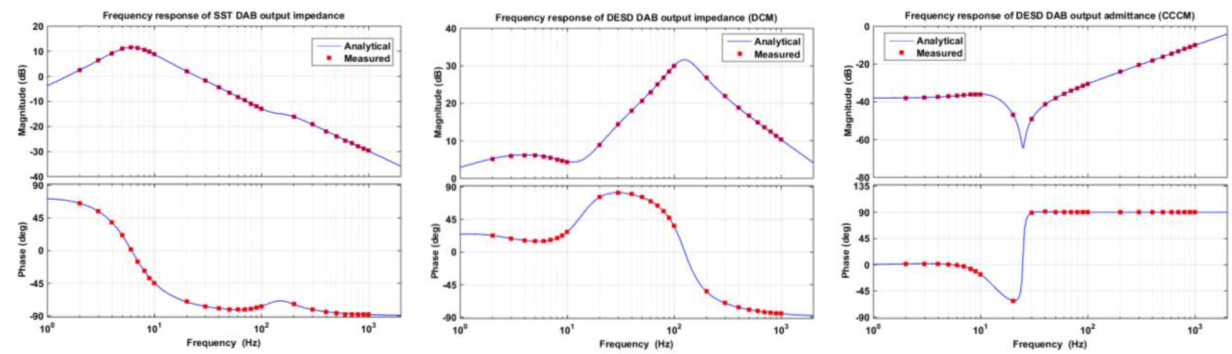


Fig.1. Control schemes of a DAB converter enabled DC microgrid.



(a) (b) (c)

Fig. 2. Comparison of analytical and measured impedances of (a) the source DAB converter (b) the DESD DAB converter in droop control (c) the DESD DAB converter in constant current control.

2) An impedance-based stability criterion for SST (DAB) enabled DC microgrid

The impedance-based model of the concerned DC microgrid is depicted in Fig. 3. The DESD unit is modeled as a current source in paralleled with its output admittance under constant current control, while a voltage source in series with its output impedance under droop control. With derived impedance models, the system stability analysis when DESD operates in two control modes are performed and shown in Fig. 4. When the DESD operates in constant current control, the system is stable since the critical point (-1, j0) is not encircled as shown in Fig. 4(a). However, when the DESD operates in droop control, system is unstable because the dominant zeros are very close to imaginary axis and system does not have sufficient damping capability, as shown in Fig. 4(b). The off-line simulation results in Fig. 5 validate the theoretical analysis.

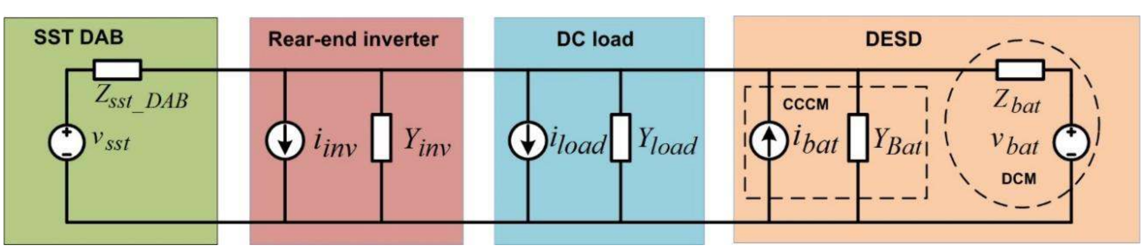
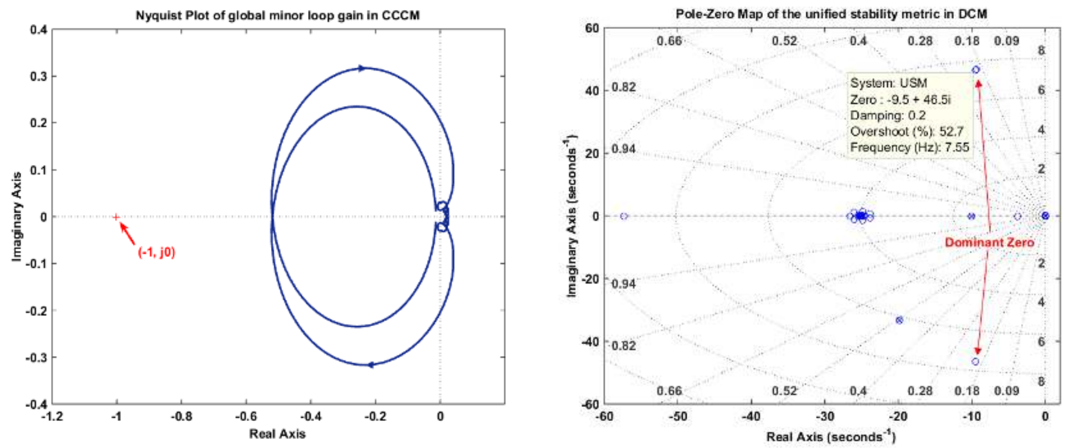
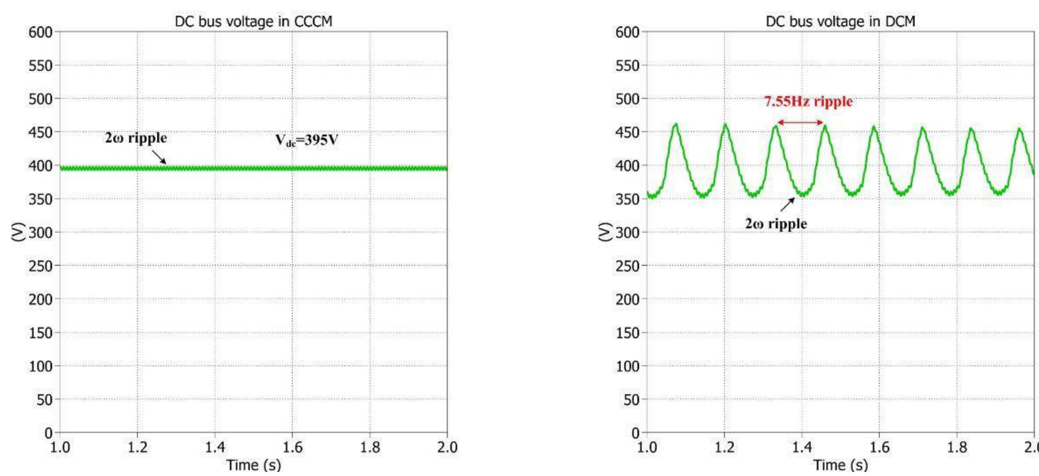


Fig. 3. Impedance-based model of the SST (DAB) enabled DC microgrid.



(a) (b)

Fig. 4. System stability analysis when DESD DAB converter in (a) constant current control, and (b) droop control.



(a) (b)

Fig. 5. DC bus voltage when DESD DAB converter in (a) constant current control, and (b) droop control.

Following tasks are to develop instability mitigation solution for system stability enhancement, and to design a HIL test bed to demonstrate the SST (DAB) enabled DC microgrid.

5. Other Relevant Work Being Conducted Within and Outside of the ERC

Stability improvement of the electrical ship MVDC system sponsored by ONR/ESRDC program

6. Milestones and Deliverables

Q1 (09/30/2016) - Impedance modeling technique for the characterization of DAB converters' terminal behavior with various control schemes (complete)
Q2 (12/31/2016) – An impedance-based stability criterion to analyze the FREEDM LVDC system stability (complete)
Q3 (3/31/2017) – An Instability mitigation solution to enhance the FREEDM LVDC system stability (in process)
Q4 (6/30/2017) – A HIL demonstration of the FREEDM LVDC system stability (in process)

7. Plans for Next Five Years

We are looking to extend this work from DC grids to a hybrid ac/dc grid.

8. References

[1] Q. Ye, R. Mo and H. Li, "Impedance modeling and verification of a dual active bridge (DAB) DC/DC converter enabled DC microgrid in FREEDM system," *2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia)*, Hefei, 2016, pp. 2875-2879.