

Y9.ET2.1: FREEDM Architecture Working Group (FAWG)

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1. Project Goals

The role of the FREEDM Architecture Working Group in Year 9 and beyond is mainly to disseminate the various FREEDM concepts, components and control methods. The goals of this project are to create and disseminate web-based simulations (WBS) that covers various aspects of FREEDM at the system level, and components level in order to promote wider system-level understanding among all students and researchers.

2. Role in Support of Strategic Plan

The output of this task is a WBS using PLECS WBS tool. For demonstrating the developed FREEDM devices to a large audience with diverse backgrounds, PLECS WBS is an excellent candidate [1]. It allows the website visitors to interact with system parameters and run simulations without installing any specialized simulation software. With its easy access, industrial members can quickly get an overview of using FREEDM devices in their applications. For students interested in FREEDM system, they can get better understanding of the project. For researchers, the WBS can be a tool for generating design ideas derived from larger system perspective and for verification of design or optimization algorithms.

3. Fundamental Research, Technological Barriers and Methodologies

Fundamental research:

For large scale system simulation of FREEDM system, cycle by cycle average (CCA) SST model is essential. In order to match the CCA SST model and digital controlled switching model, the detailed signal processing delay and PWM zero order hold effect has been studied. For modeling DESD, the battery model reflecting terminal voltage with state of charge (SOC) is studied and developed in PLECS. For modeling DRER, the PV panel model with partial shading is studied and new algorithms implemented.

Difficulties:

1. For students not in power electronics area, running power electronics system simulation needs installation of PLECS simulation software on their own computer.
2. For beginners, there is a learning curve to use the PLECS simulation software.
3. A website needs to be designed for hosting the simulations.
4. The adjustable parameters needs to be specified at the stage of webpage design.
5. DESD and DRER does not have common reference model.

Methodologies

1. PLECS web based simulation only need web browser for running the simulation.
2. In PLECS web based simulations, adjustable parameters and result waveforms are specified by simulation designers and user interface is much simplified.
3. Adapting PLECS default web based simulation examples for FREEDM website.
4. Interact with other researchers to determine the type of simulation studies and specific system-level and component-level parameters that need to be enabled for user modification that will be of most interest and beneficial to the users of different backgrounds.
5. Designed DESD and DRER models as reference for demonstrating complete functions.

4. Achievements

Previous year:

- Developed 3-stage SST control structures for grid connected, grid islanded and emergency mode.
- Detailed digital controlled switching model of SST has been developed and simulated in PLECS.

This year:

SST CCA model: By studying the signal processing and sampling effect of digital controlled SST, a CCA SST model has been derived. And close matching between the CCA model and digital controlled switching model has been demonstrated in PLECS simulation shown in Fig. 1. In Fig. 1 green trace is the digital controlled switching model result and the red trace is the analog controlled CCA model result. A 2 kW to 20 kW ac load step happens at 0.7 second. The two waveforms overlap with each other, showing the close matching of the CCA SST model with its switching model.

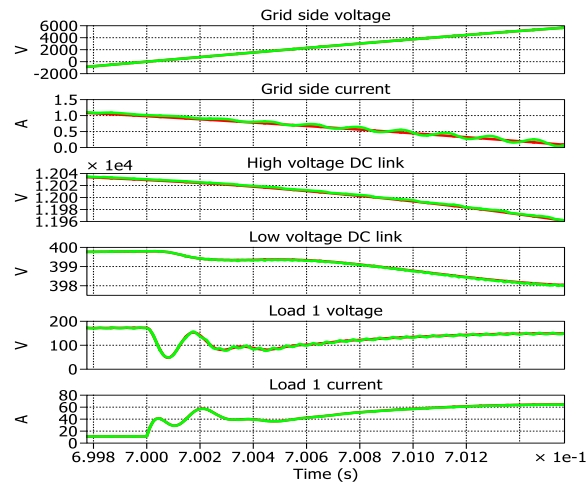


Figure 1: SST CCA and switching models response to ac load step

Website: A web based simulation website is designed for FREEDM. This can be presently accessed at <http://demo.plexim.com/asu/freedm/>. The webpage screenshot is shown in Fig. 2. It contains SST, DESD and DRER the major power electronics device models in FREEDM systems. The simulations available at the time of the report are:

- 3.6 kV GEN II SST Model
- 7.2 kV GEN II SST CCA Model
- 7.2 kV GEN II SST Switching Model
- 7.2 kV Switching and CCA Model
- 6.5 Ah 800 V DESD Model
- 250 W PV DRER Model

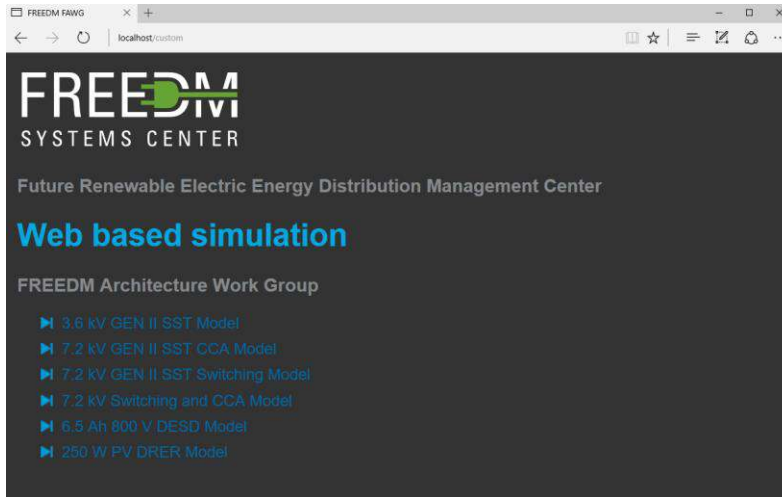


Figure 2: FREEDM WBS website screenshot

WBS SST Models: 3-stage SST model is developed with CCA model, digital controlled switching model and their comparisons. Users can interact with the system by changing the P and Q commands. Users can look into the different blocks for hardware implementation details. The simulation webpage and the P command setting interactive window is shown in Fig. 3. The simulation result on the right hand side can be zoomed in for detailed switching waveforms. The rectifier stage detailed schematic is expanded at the bottom left hand side.

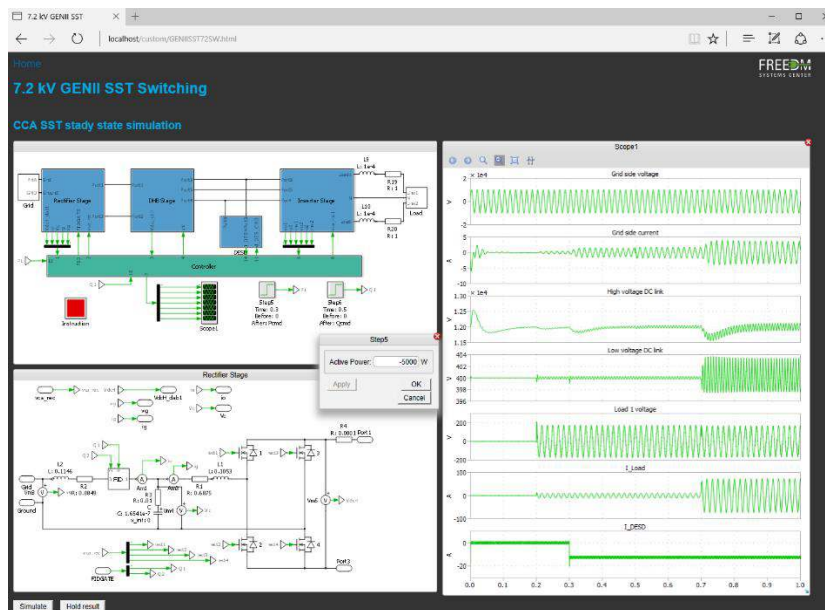


Figure 3: 3-stage SST web based simulation

WBS DESD Model: DESD converter is modeled as a buck. The energy storage is formed by four serial connected battery packs used in Prius hybrid electrical vehicles. Each of the battery pack is rated at 6.5 Ah 200 V. The battery model is designed and developed in PLECS. The model used can reflect the state of charge (SOC) effect on battery terminal voltage [2]. And its model discharging curve is shown in Fig. 4.

Users can set initial SOC and the power drawn from DESD. Zooming into the result waveforms the buck converter switching waveform is shown as in Fig. 5.

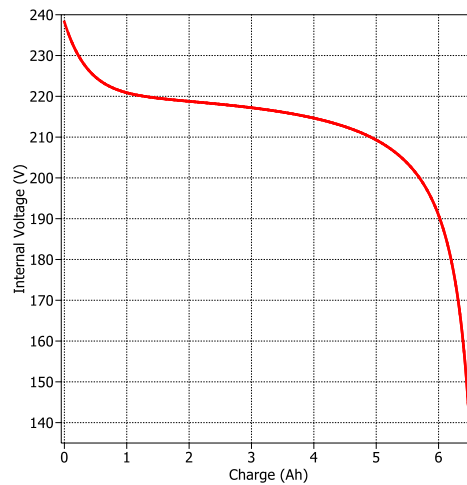


Figure 4: 6.5 Ah 200 V battery pack discharge curve with 13 A discharge current-

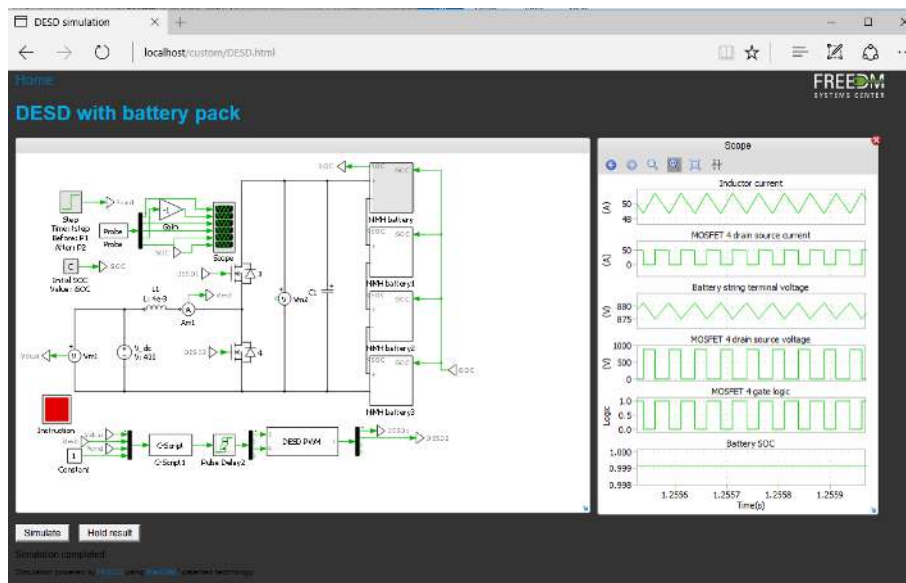


Figure 5: DESD WBS and its switching level result

WBS DRER Model: DRER is demonstrated with a PV micro-inverter. The PV panel is modeled with 3 substrings which can have different insolation for partial shading conditions as shown in Fig. 6 [3]. The green curve shows the PV panel power-voltage (P-V) curve with 1000 W/m² insolation, the red curve shows the P-V curve with one substring having 500 W/m². The PV inverter topology can be expanded as shown in Fig. 7. The simulation result is shown in the scope plots. Users can set the change of insolation on each substring.

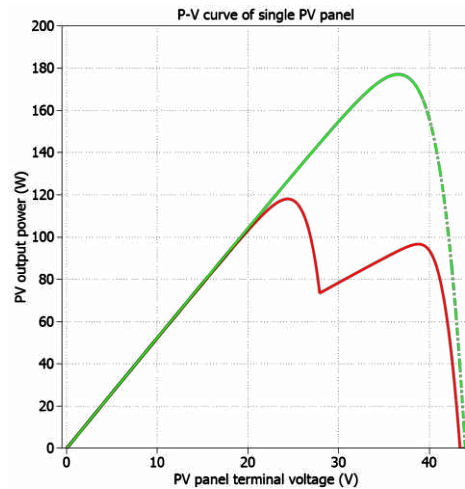


Figure 6: P-V curve of a single PV panel with full insolation and partial shading

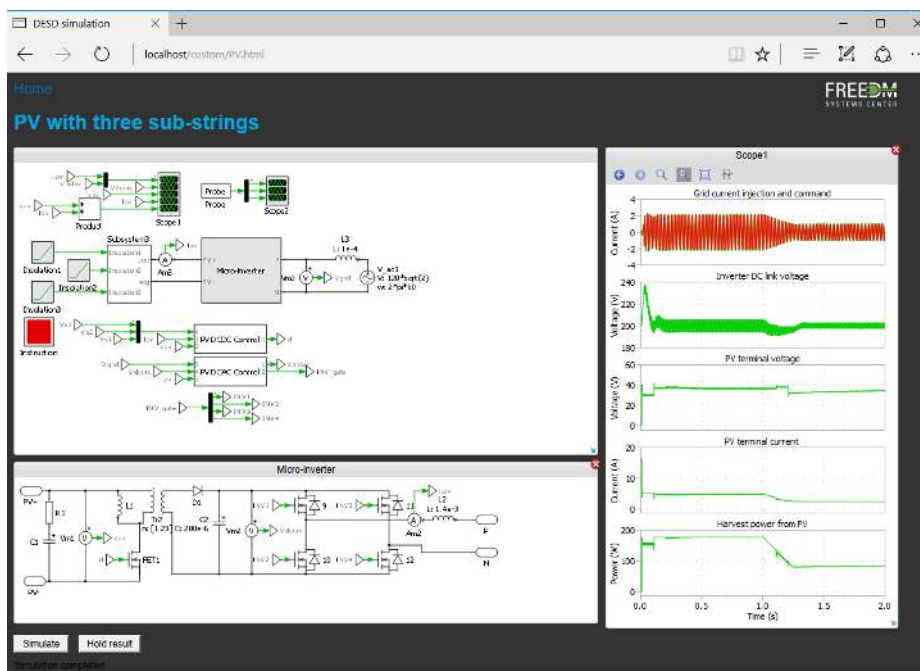


Figure 7: DRER WBS and results for PV insolation variations

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

The concept of WBS is being explored by industries such as WBG device manufacturers to promote their products by allowing potential customers to experiment and compare their devices in various applications through the freely accessible WBS.

6. Milestones and Deliverables

Web based simulations with SST, DESD and DRER available on website (<http://demo.plexim.com/asu/freedom/>) for researchers to experiment with.

7. Plans for Next Five Years

Sustain the web based simulation development and dissemination efforts and add new component and system level simulations. Develop capability such that users can implement different control algorithms on the WBS models enabling WBS to be used as a design and verification tool.

8. Member Company Benefits

WBS facilitates a deeper system-level perspective and helps disseminate various FREEDM system components and control methods. It also helps in workforce training, for example providing converter-level perspective to device engineers and system-level perspective to converter designers.

9. References

[1] PLECS WBS: https://www.plexim.com/products/plecs_wbs

[2] O. Tremblay, L. A. Dessaint and A. I. Dekkiche, "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles," 2007 IEEE Vehicle Power and Propulsion Conference, Arlington, TX, 2007, pp. 284-289.

[3] T. Yao and R. Ayyanar, "Maximum-voltage-unit-guided MPPT algorithm for improved performance under partial shading," 2013 IEEE Energy Conversion Congress and Exposition, Denver, CO, 2013, pp. 2428-2434.