Y9.GEH1.2: FREEDM Single-SST Residential Demonstration

Project Leader: David Lubkeman

Faculty: Ning Lu, Len White

Students: Jian Lu, Fuhong Xie, David Philpott, Michael Brown

Staff: Hulgize Kassa, Salina Zabin

1. Project Goals

The objective of this task is to develop a mobile and readily available test node for a 10kVA Solid State Transformer (SST) as envisioned in the FREEDM System. This test node will provide the backbone and architecture to validate and test center developed DESD, Plug and Play DRER and DGI/RSC as well as developments from the SST team. The platform will be mounted on a trailer as shown in Figure 1. The delivered trailer will incorporate an assortment of DC and AC loads coordinated by an energy management system that manages both grid-connected and off-grid operation. Additionally the system will be designed to readily integrate delivered PV DRER, SST, and DESD from associated projects. This task will leverage work done in the GEH on the Smart House and associated home energy management applications. The use cases to be showcased include a variety of single-SST Intelligent Power Management (IPM) and Intelligent Energy Management (IEM) functions for both grid-connected and islanded operation. This demonstration will serve as an intermediate step from FREEDM devices demonstrated in the GEH lab to a future household demonstration. The project is expected to last for two years and will tie to several undergraduate senior design projects.

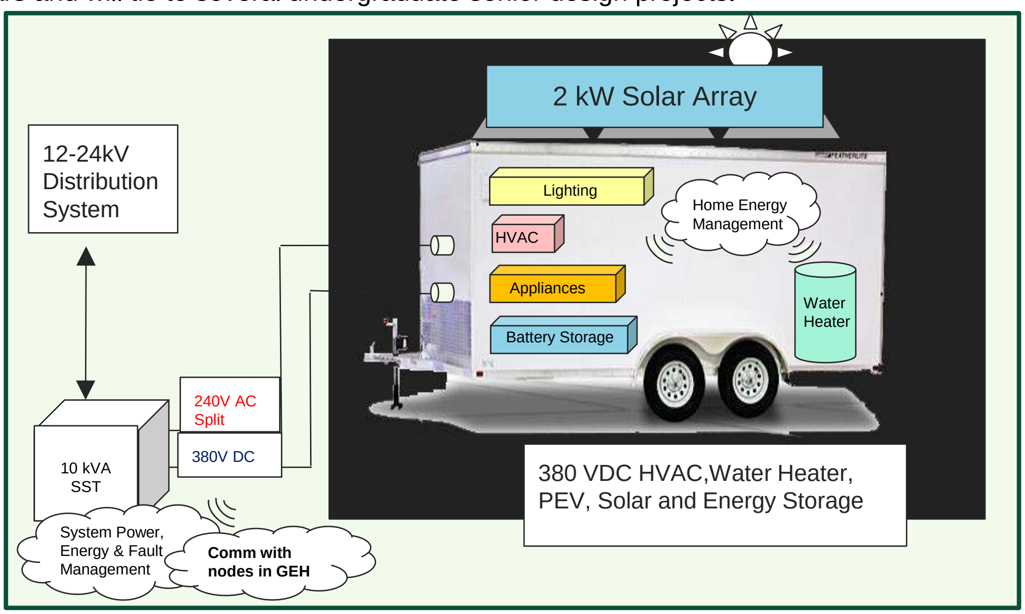

Figure 1: Configuration of FREEDM Demonstration Trailer.

2. Role in Support of Strategic Plan

This project will showcase past and current work on the SST, DRER, DESD and both single-household power and energy applications using a mobile facility housed in a trailer. This will showcase the benefits of FREEDM system technology for utilizing renewables with storage for grid-connected conditions and providing enhanced reliability during grid-outage conditions.

3. Fundamental Research, Technological Barriers and Methodologies

This task leverages results from Year 7 and Year 8 activity on developing home energy management functionality in the GEH lab. The home energy management software is capable of monitoring both load and renewable generation, generating load and renewable forecasts, and then utilizing forecasts in conjunction with utility rates to economically dispatch storage and control load demand.

This task also involves integrating various components such as SST and DESD into a working household system with rooftop PV. One of the major challenges is the selection of the proper DC voltage levels to be utilized for the internal household wiring and how the interface to the solid-state transformer will actually take place.

4. Achievements

Activity has focused in four areas: (1) Development of home energy management functionality, (2) Developing the wiring interface between the SST and household components, (3) Selection of a portable FREEDM demonstrator platform and (4) Integration of various software systems. These are described in more detail below.

Development of Home Energy Management System (HEMS) Functionality

Previous Year 7 and 8 effort focused on building up a smart home demonstration with typical home appliance loads, as shown in Figure 2. This smart home can be powered by either conventional AC service or an SST. The house features an HEMS system with graphical interface that can monitor and control AC loads. The HEMS system interfaces with the SST, monitors PV system output, controls load and dispatches energy storage. Various energy algorithms such as time of use rate optimization and peak energy response have been implemented. The house has been augmented recently so it can serve as a thermal chamber for testing heating and cooling load applications as well. An ECOBEE smart thermostat facilities the temperature and humidity control. The overall effort in home automation has resulted in six conference papers [1-6] and two journal papers [7,8] referenced below.

Figure 2: A residential home hardware test bed that can serve as a thermal chamber and emulate residential home load.

Interconnection of a Residential House with a Utility Solid-State Transformer

The GEH Y9 demonstration home will be powered by a Low-Voltage SST, which contains both an AC port (120/240 V) and a DC port (380 V). The goal of this subtask is to design a panelboard (Figure 3.) that can interconnect the AC/DC sources to the AC/DC loads, provide adequate protection, and measure voltages and currents of each branch circuit. Given the current rating of each source and load, a miniature circuit breaker would be an adequate solution to supply each AC/DC circuit. Some advantages of the MCBs include cost, size, availability, and modularity. Circuit monitoring will be completed using circuit breaker measurement sensors to provide voltage, current, and power readings. The data will be transported via the communication module and Modbus into a LabVIEW user interface, where the user can actively monitor of the loads in the house. The ability of circuit breaker control would make the panelboard useful in completing the smart home concept. With the additional functionality, HEMS algorithms can be created to utilize the power generated by DESR components in a more cost effective and efficient manner by controlling the circuit sources and loads.

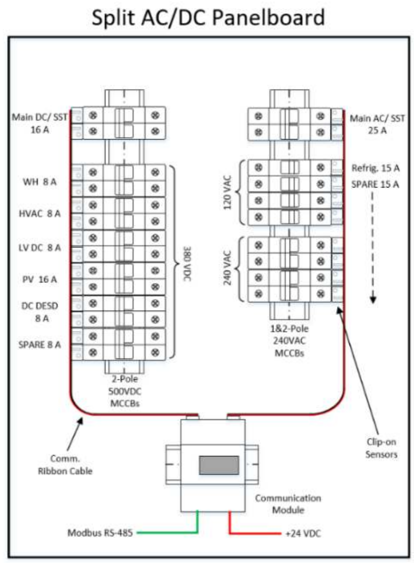

Figure 3: Layout of AC/DC Panelboard for Household Wiring Interface.

Selection of a FREEDM Residential Demonstration Platform

Starting in Year 9 we have been working on the Green Energy Hub Demonstration unit. We have been working on a trailer-based demonstration that will be used to set up a residential house system that includes a solid state transformer, a circuit monitoring system, and a home energy management system to control the house. As a whole, the goal was to find a unit that is easily mobile, models a residency, and provides sufficient space for the demonstration. In the process of looking for a suitable unit, three trailer types were identified: cargo trailers, mobile office trailers, and tiny home trailers. After looking at the advantages and disadvantages of each option, tiny homes were chosen due to their mobility, size, and similarity to a home as shown in Figure 4. At this point, contact has been made with a tiny home builder, and a floor plan is in the initial planning stages. Once the tiny home is built, we will be able to install the residential system and begin testing the unit.

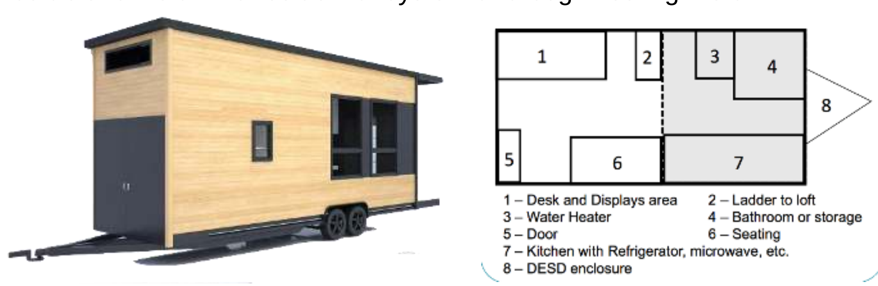

Figure 4: Example of Tiny Home and Possible Floor Plan.

Development of Software System Interfaces

An overview of the various FREEDM devices and software systems being integrated together is shown in Figure 5. A LabVIEW user interface is being developed to monitor all data from FREEDM devices using data extraction from XML log files generated by MQTT clients running in SCADA.

Each FREEDM device will run its own MQTT client that will publish or subscribe to any data it needs. The SCADA MQTT client will only monitor the status of those data in this monitoring system.

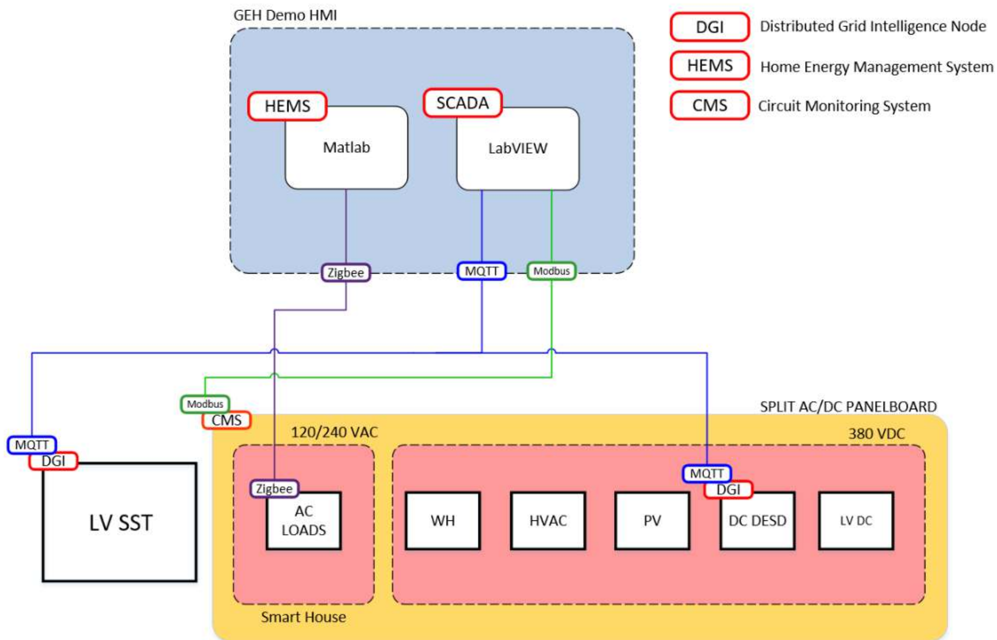

Figure 5: Single-SST Demonstration System Integration.

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

We are commercializing the algorithms developed with a FREEDM-member company.

6. Milestones and Deliverables

Q3 (Sept 2016) - Design concepts drawings for the residential trailer demonstrator
Q4 (Dec 2016) – Evaluate options for portable FREEDM demonstrator
Q1 (March 2016) – Interface low-voltage SST to loads and home energy management system
Q2 (May 2016) – Initial GEH lab demonstration of trailer demonstrator components.
Q3 (August 2016) - Trailer wired for initial GEH demonstration with low-voltage SST, PV array, energy storage and loads
Deliverable for May 2017: Expected deliverable for SV will be initial demonstration of trailer demonstrator system connected to lab AC & DC sources with a mix of AC and DC load, a PV system, energy storage system all coordinated by a household energy management system.
Final Deliverable August 2017: Expected deliverable for Year 9 will be an initial demonstration of trailer system including low-voltage SST, PV DRER, PV DESD and a mix of AC and DC load.

7. Plans for Next Five Years

a) Develop, test and deliver home energy management systems and commercialize them with our industry members.
b) Work towards developing a complete FREEDM residential solution that could be deployed in a comprehensive demonstration outside of the FREEDM Green Energy Hub lab.

8. Member Company Benefits

We will provide the center and our industry members a combined software and hardware testing platform for innovation in the area of home and building energy management as well as solutions involving both AC and DC microgrids.

9. References

[1] J. Yan, H., Zheng, N, Lu, “Temperature-Load Sensitivity Study for Adjusting MISO Day-ahead Load Forecast,” Proc. of 2016 IEEE Power & Energy Society General Meeting, Boston, MA, 2016.

[2] J. Lu, N. Lu, X. Wu, and J. He, “Short-term HVAC Load Forecasting Algorithms for Home Energy Management,” Proc. of 2016 IEEE Power & Energy Society General Meeting, Boston, MA, 2016.

[3] Xinda Ke, Anjie Jiang, and Ning Lu, 'Load Profile Analysis and Short-term Building Load Forecast for a University Campus' Proc. of 2016 IEEE Power & Energy Society General Meeting, Boston, MA, 2016.

[4] Xiangqi Zhu, Jiahong Yan, Lining Dong, and Ning Lu, “A Matlab-Based Home Energy Management Algorithm Development Toolbox”, Proc. of 2016 IEEE Power & Energy Society General Meeting, Boston, MA, 2016.

[5] Xiangqi Zhu, Jiahong Yan, and Ning Lu, “A Probabilistic-based PV and Energy Storage Sizing Tool for Residential Loads” Proceeding of the 2016 IEEE PES Transmission and Distribution Conference and Exposition, Dallas, TX, May, 2016.

[7] Xiangqi Zhu, Jiahong Yan, and Ning Lu, "Energy Storage Sizing Strategies for High Solar Penetration Residential Feeders," Accepted by the IEEE Trans. on Smart Grid, 2016.

[8] Maziar Vanouni and Ning Lu, "A Resource Prioritization Based Framework for Participation of Thermostatically Controlled Loads in Regulation Services," Accepted by the IEEE Trans. on Smart Grid, 2016.

[9] Xiangqi Zhu, Gonzague Henri, Jiahong Yan, and Ning Lu, “A Cost-Benefit Study of Sizing Residential PV and ES Systems based on Synthesized Load Profiles,” Accepted by the Proceeding of 2017 IEEE PES General Meeting, Chicago, IN, 2017.