Department of Commerce

Center for Microgrid Research Grant

Project Report

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Principal Investigator:

Mahmoud Kabalan, PhD, PE

Mahmoud.kabalan@stthomas.edu

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The project team continued to make progress on the project objectives to create a state-of-the-art research and education Engineering Research Center on the Saint Paul South Campus of the University of Saint Thomas. The project objectives:

1. Growing the Center for Microgrid Research’s (CMR) research, education, and partnership capabilities
2. Expanding the CMR’s on-campus microgrid by increasing the on-campus power sources and connecting to multiple buildings
3. Augmenting the CMR’s modeling, prototyping, and simulation of new technologies with hardware-in-the-loop testbeds, and,
4. Attracting national and international partnerships on state-of-the-art federal research proposals.

In this report, an update is provided on the status of the project objectives. To grow the CMR’s research, education, and partnership capabilities, a Research Engineer was hired in Q2 of 2023. Given the complexity of the microgrid expansion, the CMR has also been receiving support from UST Facilities Management Department such as Electrician and Project Management services. As part of this grant, the following goals have been identified for the microgrid power and physical expansion:

1. Expand educational and research opportunities and maintain a state-of-the-art microgrid facility.
2. Allow for peak load shaving and shifting of existing and new South Campus loads to minimize the cost of summer peak load.
3. Allow for Off-grid or island mode operation via islanding of APF (Anderson Parking Facility), FDC (Facilities and Design Center), OWS (Owens Science Hall), O'Shaughnessy Science Hall (OSS), and Schoenecker Center (SCC) and paralleling generators.

Current proposed on-site power equipment include MW-level tier 4 diesel generators, 500kW/1.5MWH energy storage system (ESS), EV charging infrastructure, switchgear, and 13.8V power distribution network. During Q2 2023, the project team explored multiple possible locations to house the proposed power equipment. Factors considered include cost, noise levels, intake and exhaust air for the generators, accessibly, and local code compliance. Given the [announcement] of the proposed Multi-Purpose Arena (MPA), the project team explored housing the majority of the equipment in the basement level of the MPA. The team explored creating a 8,500 sf room in the basement level, a freight elevator to access the basement floor, and a utility tunnel to access the elevator

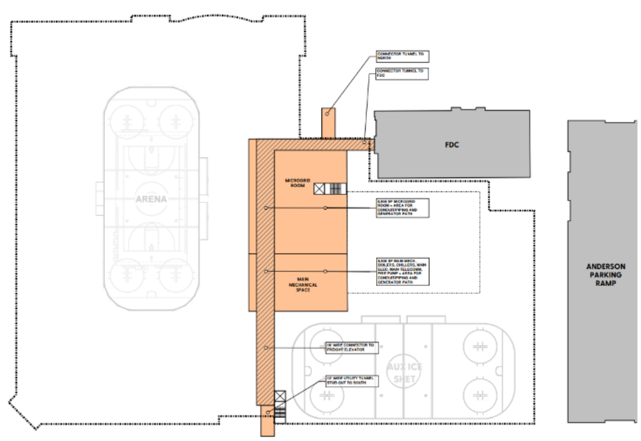

Figure 1: MultiPurpose Arena (MPA) and Proposed Microgrid Space

and current microgrid space in Facilities and Design Center (FDC) as shown in Figure 1. This concept proved to be cost prohibitive due to accessibility issues and the need for complex mechanical systems for intake and exhaust air. The team is now exploring other potential options such as locating some of the equipment south of Owens Hall or in other locations on South campus. Some of these options are shown in Figure 2. Engineering studies continue to explore costs and viability of those options.

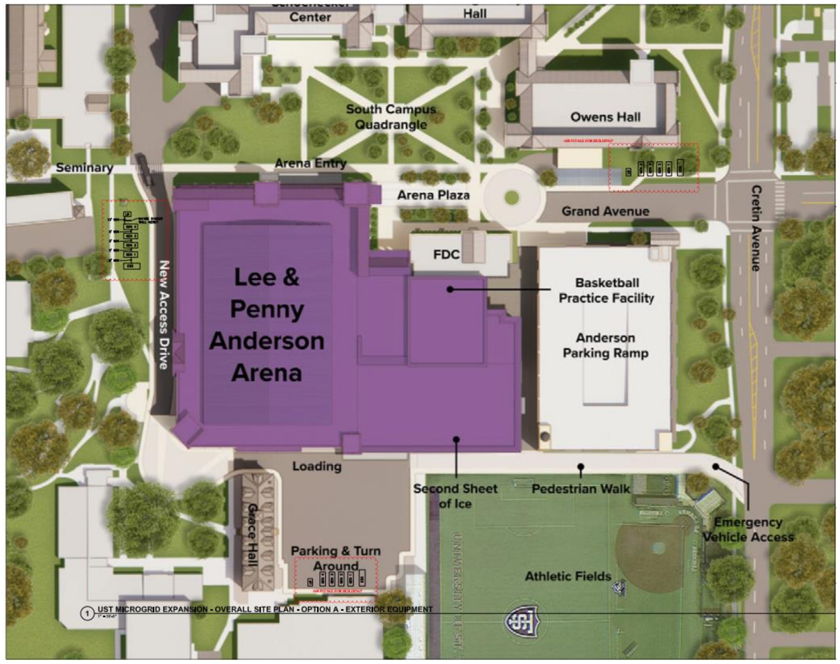

Figure 2: Potential sites for Microgrid Expansion

As part of the expansion design and analysis, the project team created a computer-simulation model of the existing microgrid and the planned expansion of the microgrid in PowerWorld, a software tool used for power flow calculations. Power flow studies allow power engineers to understand how electric power (active and reactive powers) flow in the system to ensure that loads are served without overloading power lines or transformers. An image of the model is shown in Figure 3. The model includes the 5 buildings that the expansion would cover which are STEAM (Science, technology, Engineering, Arts, and Mathematics), Oshaughnessy Hall (OSS), Owens Hall (OWS), FDC, and APF. It also includes the current microgrid power assets which are 48 kW solar PV, 125 kW ESS, and 50 kW diesel generator along with the new proposed additions such as 500 kW diesel generators and 500 kW ESS. The Figure also shows the

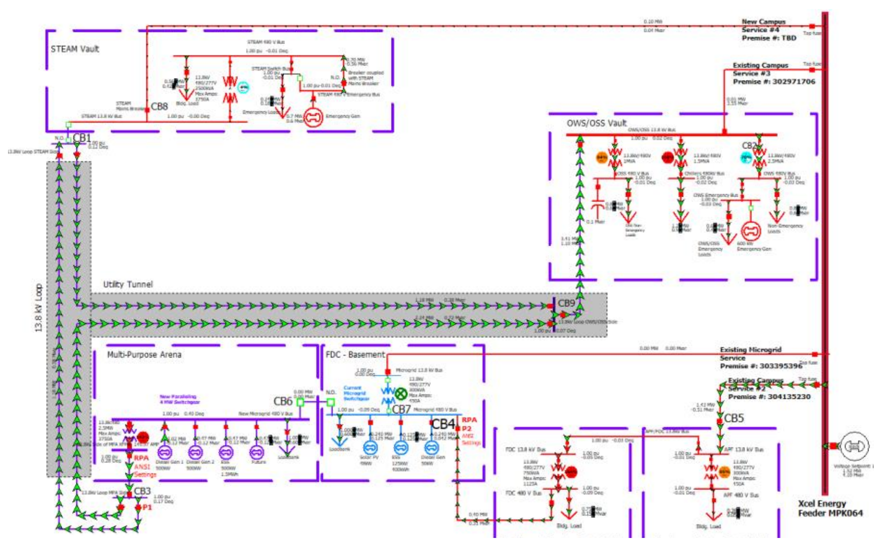

Figure 3 Microgrid Expansion Computer Simulation in PowerWorld

new proposed 13.8 kV loop that will get routed by the newly constructed utility tunnel. The computer model shed light on certain design parameters that the team will take into consideration such as transformer and power line sizing.

Hardware in the loop (HIL) testbeds are a type of testing environment used in engineering and technology fields to test and validate complex systems, such as grid technologies or automotive systems. HIL testbeds use physical hardware components, such as sensors, actuators, and controllers, along with virtual models and simulations, to create a realistic testing environment for the system under development.

The HIL testbed setup typically involves connecting a real system (e.g., an inverter or generator controller or an electric motor) to a simulation environment. The simulation environment is programmed to mimic the behavior of the other components of the system that are not present in the physical setup. For example, in an electric grid testbed, the generator controller may be connected to a simulation of the generator's mechanical and electrical systems, allowing the test to simulate how the controller would perform under different generator operating conditions. By using HIL testbeds, engineers can test and validate the behavior of a system in a controlled and repeatable environment before deploying it in the field. This helps to identify and address any issues or bugs in the system early in the development process, reducing the risk of costly failures or malfunctions in real-world use. Moreover, HIL testbeds can be used for workforce development by providing a safe and realistic environment for engineers and technicians to learn about complex systems and gain hands-on experience. HIL testbeds can contribute to the development of new technologies and innovations in the energy sector, which can help drive economic growth and create new job opportunities.

To augment the CMR's modeling, prototyping, and simulation of new technologies with hardware-in-the-loop testbeds, three Typhoon HIL hardware-in-the-loop testbeds were delivered to CMR. The testbeds included a microgrid HIL rack, shown in Figure 4 left, that includes a Typhoon real-time computer, a signal processing unit, two inverter control boards from EPC Power, a diesel generator controller from Woodward (EasyGen 3500), a power relay from SEL (SEL 451), and a system controller from SEL (RTAC 3555). This microgrid HIL would allow the prototyping and testing of advanced grid and microgrid technologies. A Power HIL (PHIL) testbed was also delivered which allows the testing of equipment at voltages up to 300V and 30kW. The PHIL testbed is shown in Figure 4 right. Software licenses were obtained for the Typhoon HIL testbeds and the CMR team installed the software and began

Figure 4: Typhoon HIL testbeds. Left is microgrid HIL and right is PHIL

training in preparation of using the equipment upon commissioning.

After constructing the proof-of-concept education and training kits in Q1, the team commenced the work on creating education and training lessons for use by students and trainees. The goal of these lessons and modules is to mimic the design, commissioning, and operation of real-world electrical energy systems. Thus, giving students and trainees a sandbox to learn and experiment as a steppingstone before using and operating equipment at high power and voltage levels. The team is currently working on two training modules: 1) Power Engineering Protection Module and 2) Power Engineering Automation Module.

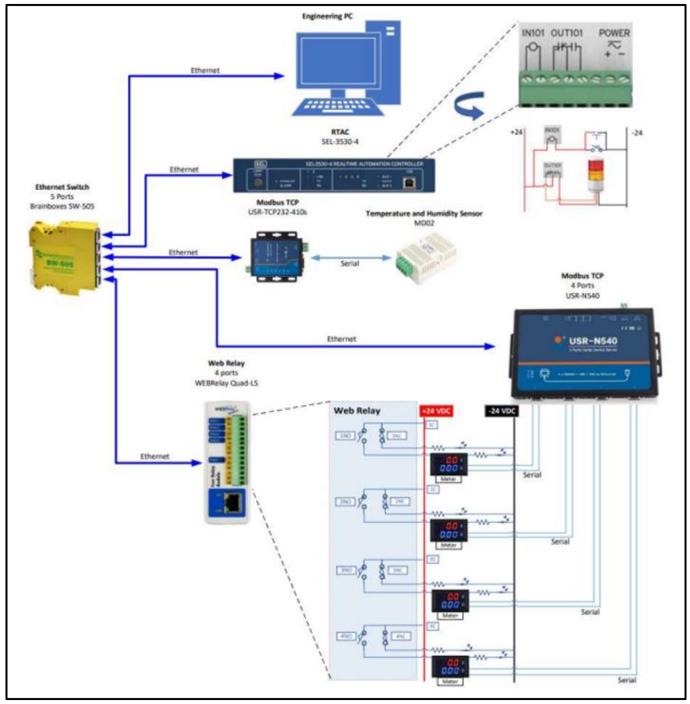

Figure 5 Power Engineering Automation Training Module Diagram

As an example, the automation module diagram is shown in Figure 5. In this educational module, the trainees learn how to connect to industrial sensors to measure voltages, currents, and temperature via industrial communication protocols (such as Modbus), how to issue open/close commands to relays, and how to write automation programs to read, write, and control devices. The automation programs are written in a leading industrial control language, the IEC 61131-3. Moreover, trainees learn how to design and implement Human Machine Interfaces (HMIs) which allows human operators to interact with industrial equipment via a computer screen. An example HMI is shown in Figure 6. The team is exploring the creation of training modules for generator control and basics of closed-loop control. During this quarter, students supported the above tasks and learned topics as such power flow modeling using computer software, learning and applying industrial communications basics, and creating a communication network. The team continues to improve those educational training modules to

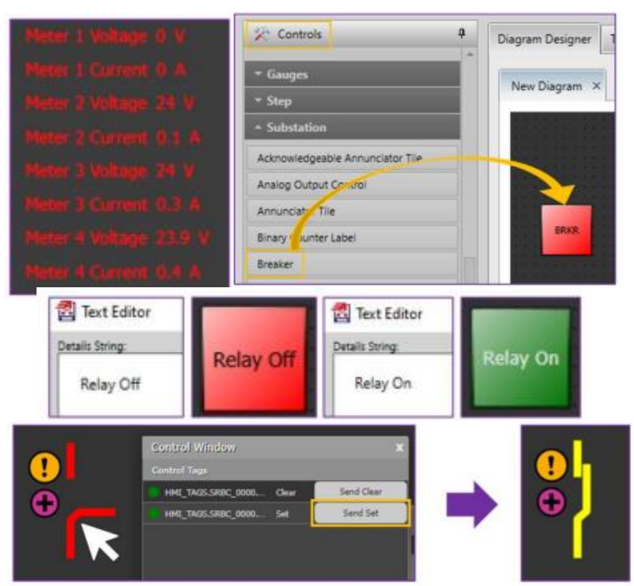

Figure 6: Human Machine Interface (HMI) design example

optimize their effectiveness and give students and trainees a realistic real-world hands-on educational experience.

The project team has been exploring and creating computer models of advanced inverter control algorithms such as grid-forming and grid-following controls. Grid-forming inverters are systems that can create a voltage and frequency source i.e. create their own "grid" Grid-forming inverters are typically operated with energy storage systems and are able to operate with (grid-connected) or without a grid (island). Thus, grid-forming inverters are an enabling technology for microgrids and play an important role in microgrid systems. An example of the advanced control loops that a grid-forming inverter needs in shown in Figure 7. The Center for Microgrid Research has multiple grid-forming inverters which were used to collect experimental data to guide the modeling effort. The CMR's grid-forming inverters utilize the droop control algorithms in island-mode to create a voltage and frequency reference. A sample of experimental data of a grid-forming inverter is presented in Figure 8. In that test, the inverter is subjected to a load change from 0 to 50 kW and back to 0 kW. The Figure shows that the inverter responds almost instantaneously to the load change. Although noteworthy is the harmonic content of the output current which is a characteristic performance trait of current grid-forming inverters.

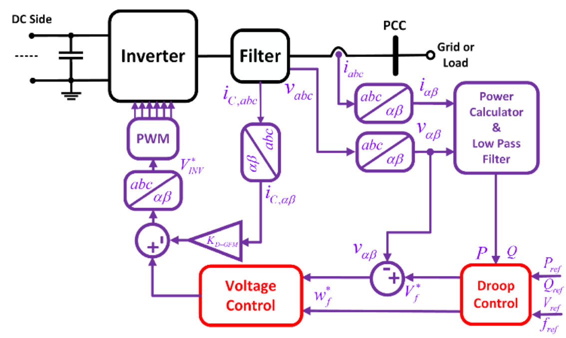

Figure 7: Advanced Control Loops of a Grid-Forming Inverter.

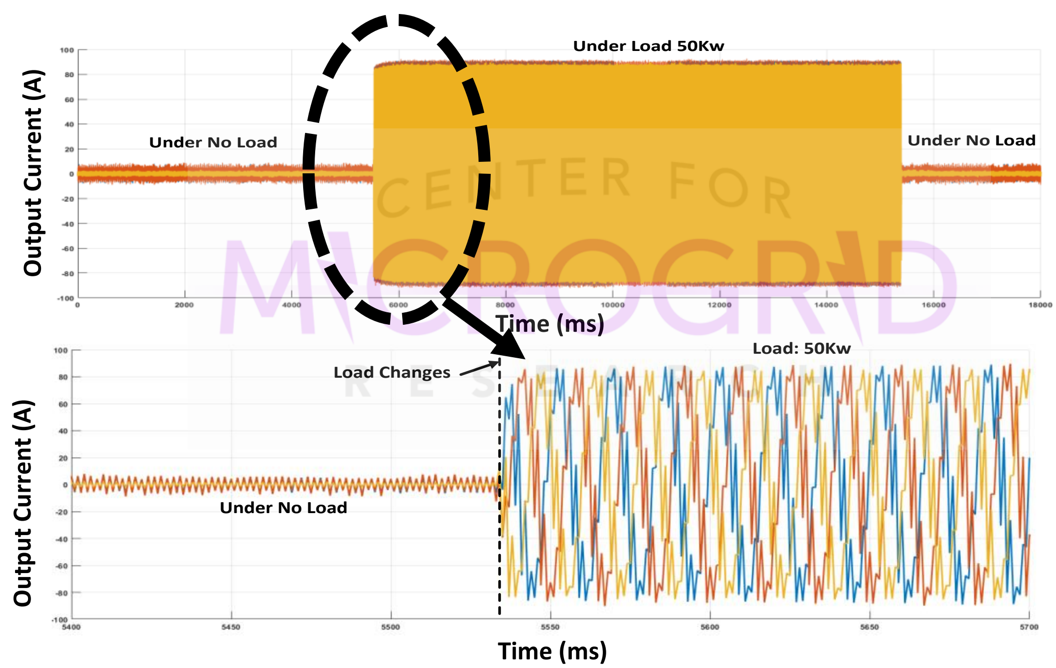

Figure 8: Experimental Data of a grid-forming droop control inverter in island-mode

Grid-following inverters are typically inverters operating with solar photovoltaic systems or grid-connected energy storage systems. Grid-following inverters need a voltage and frequency source to operate i.e. they need a "grid". Grid-following inverters employ control algorithms that synchronize and lock to the grid's voltage and frequency in order to operate. An example of the control loops of a grid-following inverter is shown in Figure 9. Real-world experiments were conducted on the CMR's grid-following inverters to guide the modeling effort. Figure 10 presented a sample data of the grid-following inverter's performance once the power setpoint is increased from 0 to 50 kW and back to 0 kW. The data shows the inverter's ramp feature that is a requirement for grid-connected inverters per the IEEE 1547 standard. The CMR has automated 24/7 data archiving programs for both the microgrid and other buildings on campus. This continuous data collection and archival will facilitate the creation and expansion of a public repository for distributed energy resources and microgrid data.

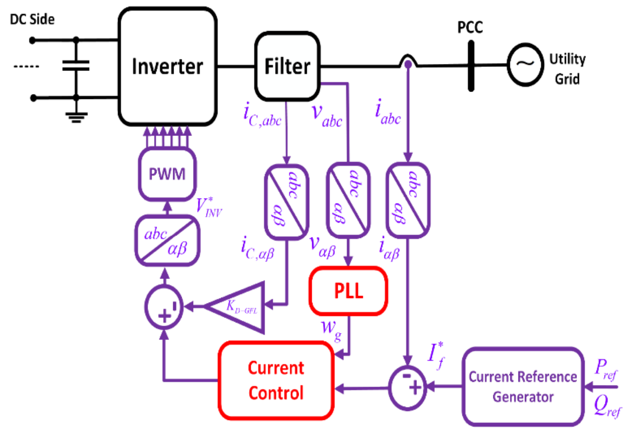

Figure 9: Grid-Following Inverter control loops

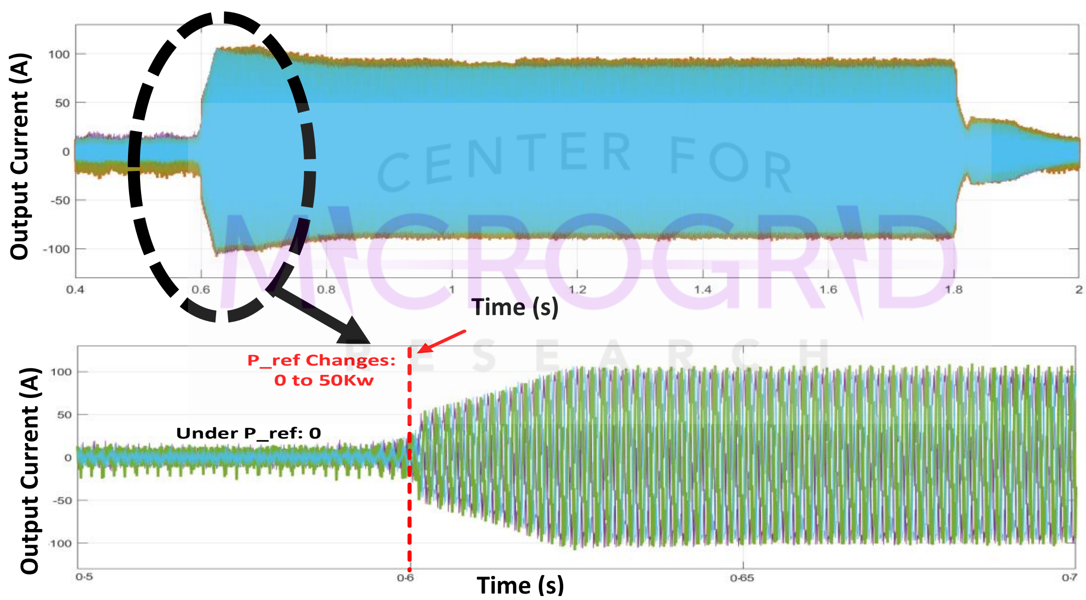

Figure 10 Experimental Data of a grid-following inverter in grid-connected mode

As part of the CMR's ongoing efforts to be a resource local and State partners to transition to carbon-free electricity, the CMR was a STEM Pathway Sponsor for the Minnesota Cleantech Innovation Day on June 7 at the 3M Innovation Center. With over 50 companies in attendance, the CMR team connected with startups, gaining insights into emerging technologies and potential collaborations. This event provided valuable insights into the needs of startups in the green technology space, helping the CMR shape future initiatives to align with industry and community needs.

The CMR was proud to sponsor and participate in the Cleantech Career Pathways Event held at Saint Paul College on June 8th, event flyer shown in Figure 12. This event, tailored for community college students interested in green jobs and clean technology, provided an excellent platform for engagement with students, faculty, government employees, and the community. The event not only welcomed attendees from the broader community but also emphasized outreach to historically under-represented and community college students. The CMR team had the opportunity to connect with community college students during a shared lunch after the event presentations. This allowed the CMR team to converse with students about the hands-on educational opportunities offered at the center, provide information about what a job at CMR would look like, and encourage students to apply to open student jobs. Additionally, the CMR team met and formed connections with faculty members from the community college during this event. This strengthens ties between CMR and other educational institutions and facilitates possible future partnerships.

Figure 11 Minnesota Cleantech Innovation Day. The CMR was the STEM Pathway Sponsor for this event.

Figure 12 Cleantech Career Event which the CMR co-sponsored (left). The CMR team with Nina Axelson, founder of Grid Catalyst (right)

To expand partnerships, disseminate knowledge, and grow industry collaborations, the Center hosted numerous on-site tours and conversations with potential partners and collaborators such as: NeoCharge, Minnesota Municipal Utilities Association (MMUA), Connexus, Siemens, National Sports Center, Rochester Institute of Technology, Army Research Lab, Cummins, Macalester College, Neighborhood Development Center, Renewable Energy Partners (North Minneapolis Resiliency Project), 3M, Sunnova, North Dakota State University, Fluence, Mortenson, and University of Arkansas. The team also met with the Dept of Commerce representative on June 29th to discuss the project's progress. The CMR's director also gave a talk on Resiliency and Microgrids to the American Association of University Women meeting on April 17th.

The CMR hosted more than 100 people for on-site tours during this quarter. As an example, the CMR hosted an Electric Vehicle (EV) get-together organized by MN EV Owners, photos shown in Figure 13. Welcoming over 75 attendees, the event included informative tours of CMR's microgrid, control room, simulation equipment, and educational tools. The CMR has plans to integrate new EV fast chargers into the microgrid and valuable connections were made with the MN EV Owners group to potentially borrow EV chargers and EVs for testing at the CMR.

Figure 13 MN EV Owners Event at the CMR