UNIVERSITY OF St.Thomas

CENTER FOR MICROGRID RESEARCH

School of Engineering

Department of Commerce

Center for Microgrid Research Grant

Project Report

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Principal Investigator:

Mahmoud Kabalan, PhD, PE

Mahmoud.kabalan@stthomas.edu

THE GREAT SEAL OF THE STATE OF MINNESOTA
L'ETOILE DU NORD
1858

COMMERCE DEPARTMENT

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By leveraging the current legislative appropriations, CMR announced a multi-year **$11M** joint development program to address the reliability and resiliency of microgrids between University of St. Thomas **Center for Microgrid Research and U.S. Army Engineer Research and Development Center (ERDC)** in August 2023. This program, which would not have been possible without the legislative appropriations and support of CMR, will develop, test, and demonstrate microgrid technologies including advanced and cyber-secure controllers and electric vehicles as power sources.

The microgrid expansion engineering designing and planning continued as a joint effort between the Center for Microgrid Research (CMR), UST Facilities Management, and Hallberg Engineering (Engineer-of-record). By the end of Q3 2023, the electrical designs and drawings are at 50% ready. Current plans include a new switchgear, multiple tier 4 diesel generators, energy storage system, a 13.8 kV power distribution network, load bank, and building electrical infrastructure retrofits (to connect buildings to the microgrid). The main challenge facing the engineering team is locating large electrical equipment such as diesel generators, energy storage system, load bank, and switchgear. The engineering and regulatory constraints that the team has to considered include, but not limited to, required setbacks, makeup and exhaust air, HVAC/air ventilation issues, costs, and noise levels. The team completed an exhaustive analysis of possible locations on the UST Saint Paul campus to find a suitable location. The six (6) possible locations that the team analysis and considered are shown in Figure 1. By the end of this quarter, the team confirmed that Options 1, 2, 3, and 6 were not feasible due to a variety of reasons such as cost, ventilation issues, setback limitations, accessibility, and technical losses (voltage drop). The design team finalized the general location to be south of Owens Hall (OWS) and was considering options 4 and 5. Option 4 was being considered to co-locate the new diesel generators in vicinity of the current OWS emergency generator while option 5 would locate all necessary equipment east of the greenhouse (south of OWS). The design team deemed it necessary that an Architect be involved to design the new space that can house the desired equipment. The Architect would ensure, through civil engineering designs, that the new structure would meet code, ventilations constraints, and structural loading needs. A public RFP was opened from August 15, 2023, till September 22 to solicit bids from Architectural Design Firms to. By the end of this quarter, UST had interviewed two design firms and will be awarding the contract at the start of the Q4.

In parallel to the above, Hallberg Engineering and CMR continued to compile the technical specifications for the desired equipment for microgrid operations. Of special attention was the air intake, make-up air, and exhaust requirements for the diesel generators, heat production, and noise generation by the electrical equipment. Operational requirements for microgrid operations were also being compiled along with drafting plans for the expanded microgrid's standard operating procedures (SOPs). Current plans include three operating modes for the microgrid: grid-connected mode, island-mode, and research mode. In grid-connected mode (normal mode), the microgrid would be connected to the local utility and used for peak load shaving and shifting. In island-mode (emergency), the microgrid would separate from the utility and feed power to multiple buildings on campus. In research mode, the microgrid would separate from the campus's electrical infrastructure to complete research objectives when necessary. Throughout this quarter, the project team continued to have regular meeting with Xcel Energy to ensure that proper paperwork was filed and any technical requirements were included in the electrical designs. The design team also solicited the services of a microgrid control and protection engineering firm to provide preliminary investment audit level study.

CMR improved the Steady-State simulation model (created in the PowerWorld software) of the proposed expansion that was initially created in Q2. To improve the model's accuracy, the team compiled specifications from the expansion engineering design plans, as well as the established values from the current microgrid and configured each component in the model to reflect reality. This included detailed specifications of line impedances, DER power ratings, transformer type and impedances, and breaker locations. CMR ran the power flow simulation on the model and updated it to display voltages and phase angles at each bus, as well as active and reactive power on each conductor and DER. By conducting this power flow analysis, the team gained valuable insights into the performance of the planned microgrid expansion. This simulation initiative allows the team to validate the microgrid expansion design and will allow for validation of any future changes to the design from a power flow perspective to ensure the final design results in a reliable, balanced system.

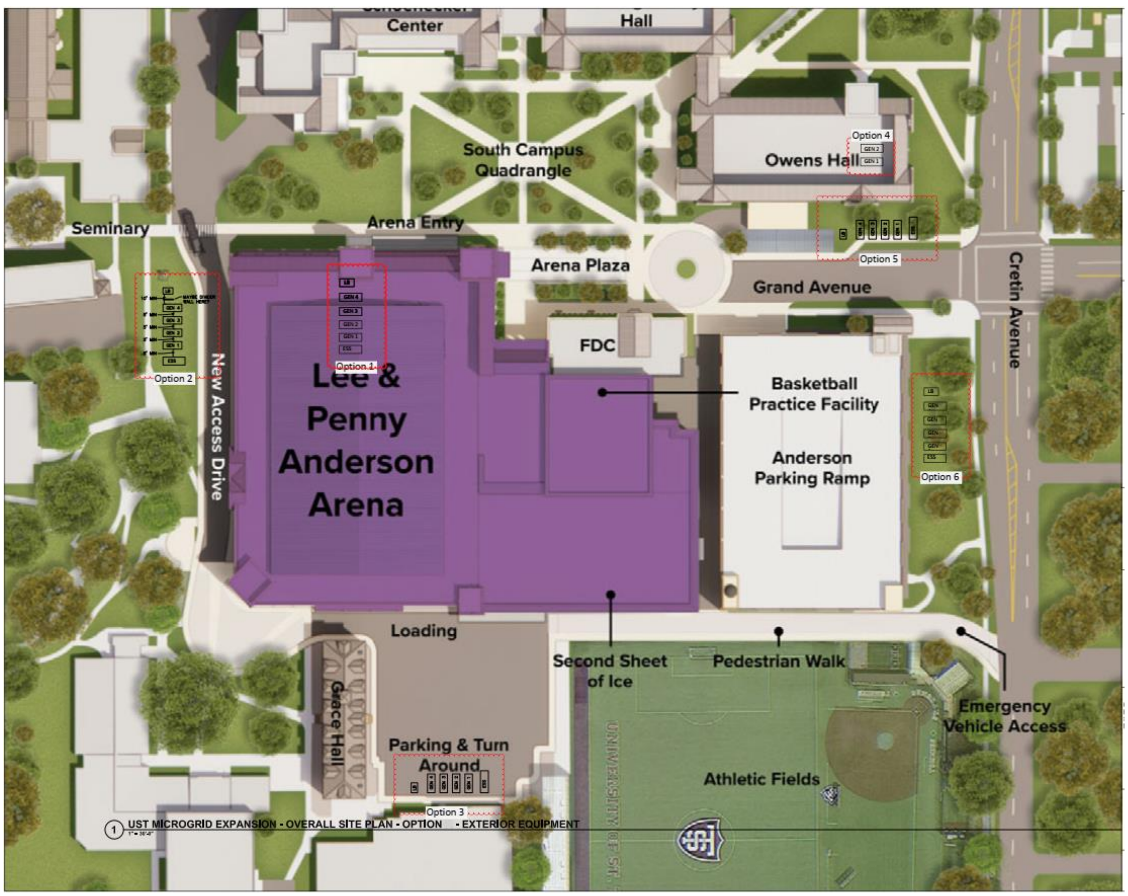

Figure 1: Possible locations to locate needed electrical equipment for the microgrid expansion

During this quarter, educational opportunities for engineering students included education on power systems concepts such as the functionality of protection components and relays, steady-state modeling, and modeling in state-of-the-art hardware- in-the-loop HIL software.

The team continued to refine the improve the educational and training materials being developed. CMR drafted a new training program around industrial controls and industrial programming referred to as "Automation Controls Software." This training program is centered around programming industrial controllers (referred to as PLCs for Programmable Logic Controllers) and designing and implementing Human Machine Interfaces (HMIs). CMR chose a device similar to a PLC that is used in power system as the platform to base this training program on. This device is called the SEL Real-time Automation Controller (RTAC). The agenda encompasses various aspects, beginning with a review of the Automation Training Kit architecture, going into more detail of the connection between devices, then guides the trainee through setting IP addresses, reading and writing to Modbus registers, and using functionalities of the RTAC software. The training includes opening and logging in to software, creating new projects, adding devices, configuring settings and registers, and controlling devices. Additionally, trainees learn to create a Human Machine Interface (HMI) using AcSELerator Diagram Builder, including learning how to add data displays and control widgets for devices i.e. using a computer screen to interact with an industrial process without accessing the underlying code. The training further extends to advanced programming topics such as using function blocks and the tag processor and concludes with practical exercises for reinforcing the components of the training. As an initial trial for the "Setting Up the Automation Training Kit" and "Automation Controls Software" training programs, an undergraduate student was asked to complete both trainings without prior involvement in the creation of those kits. This process proved to be educational to the student and provided the team with valuable feedback on gaps in the training materials. That feedback was incorporated to improve clarity and a final version of the training document was created and archived. Moreover, the project team started working on the Protection training kit final design and will initiate fabrication in the upcoming months. This kit will include a power relay, a breaker, voltage and current transformers, and two 3 phase inputs/outputs to enable the user to program and learn the basics of power protection.

CMR completed the installation and commissioning of two controller hardware in the loop (CHIL) racks from Typhoon HIL. Installation and commissioning work continues on the power hardware in the loop (PHIL) rack. The two CHIL racks were commissioned, and the team was able to establish communication with controllers included in these testbeds such as the SEL 451 relay and the Woodward EasyGen controller. As an example of the capabilities of these CHIL platforms, Figure 2 shows how a virtual model, running in real-time, can interact with real-world controllers and relays. In that Figure, the virtual model that's created in the Typhoon real-time computer is shown in the bottom right. That model contains a diesel generator, breaker, relay, load, transformers, and a utility (grid) connection. Voltage and current signals are sent from the real-time computer to a signal conditioning device which creates higher voltage and current signals that are routed to the Woodward EasyGen controller and SEL 451 power relay. The controllers use those signals from the virtual environment to issue control and command signals that are fed into the virtual model. Thus, the real-world controllers are interacting with the virtual model to control their respective systems, in this case the Woodward EasyGen controls the generator while the SEL 451 controls the breaker. On the top right, the model computes the rpm, voltage, and active power that the virtual diesel generator is operating at, and those values are reflected in the real-world on the display of the Woodward EasyGen controller (middle left). These platforms are powerful prototyping platforms that allow users to lower the risk of experimentation by modeling the high-power systems while allowing real-world controllers to interact with the virtual model.

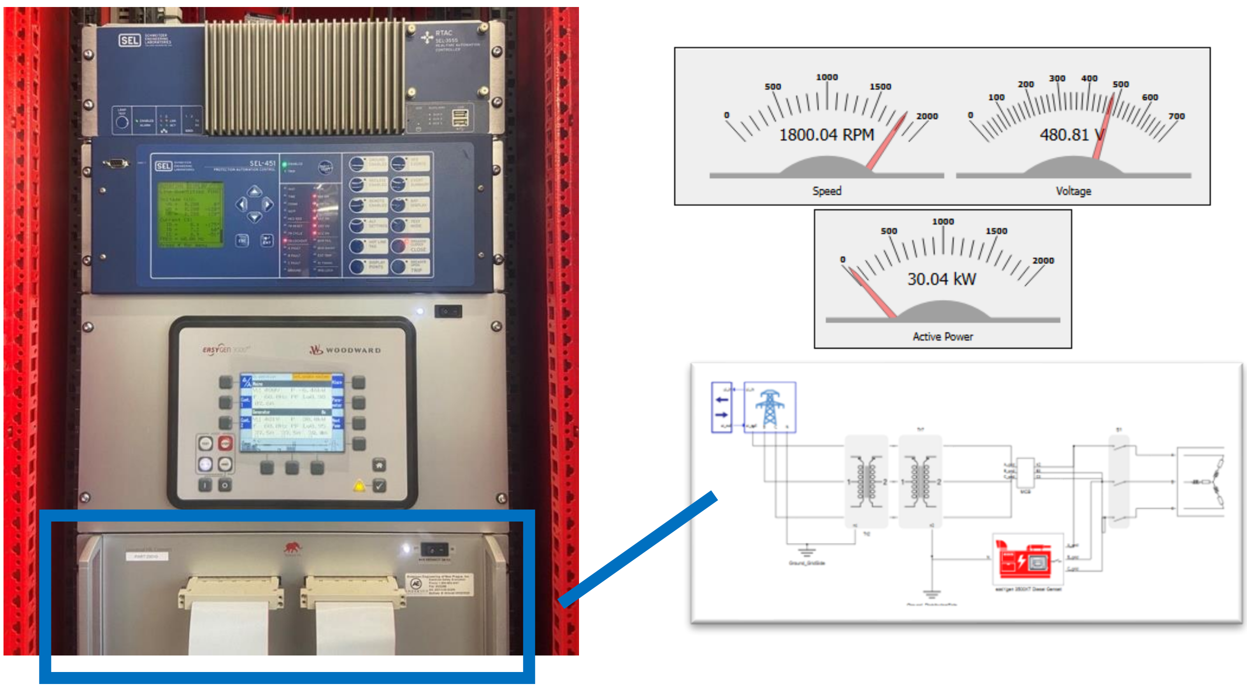

Figure 2: CHIL testbed: On the left, from top to bottom: SEL RTAC 3555 industrial controllers, SEL 451 power protection relay, Woodward Easy Gen 3500XT, and Typhoon Real-time computer and signal conditioning. On the top right, diesel generator model rpm, voltage, and active power. On the bottom right, diesel generator virtual model that includes a diesel generator, load, breaker, relay, and grid connection.

CMR continued to refine processes and procedures to optimize data collection and storage along with experimenting with new data acquisition (DAQ) systems. The team experimented with a new DAQ system and used it to collect experimental data on the operation of grid-forming and grid-following inverters. As an example, Figure 3 shows the data collected from three experiments. On the top left, a grid-following inverters was dispatched to increased its power output from 0 kW to 50 kW while on the bottom left the inverter was dispatched to increase its power output from 0 kW and 0 kVAR to 125 kW and 25 kVAR (Images on the left show output current). In Figure 3 right, a grid-forming inverter was connected to a load and the load was changed from 0 kW and 0 kVAR to 125 kW and 25 kVAR. The images show the output voltage (top right) and output current (bottom right). It can be seen that the output current responds in a matter of 10-20 milliseconds while the voltage drops down and slowly increases to a new steady-state since the inverter is in droop-control mode.

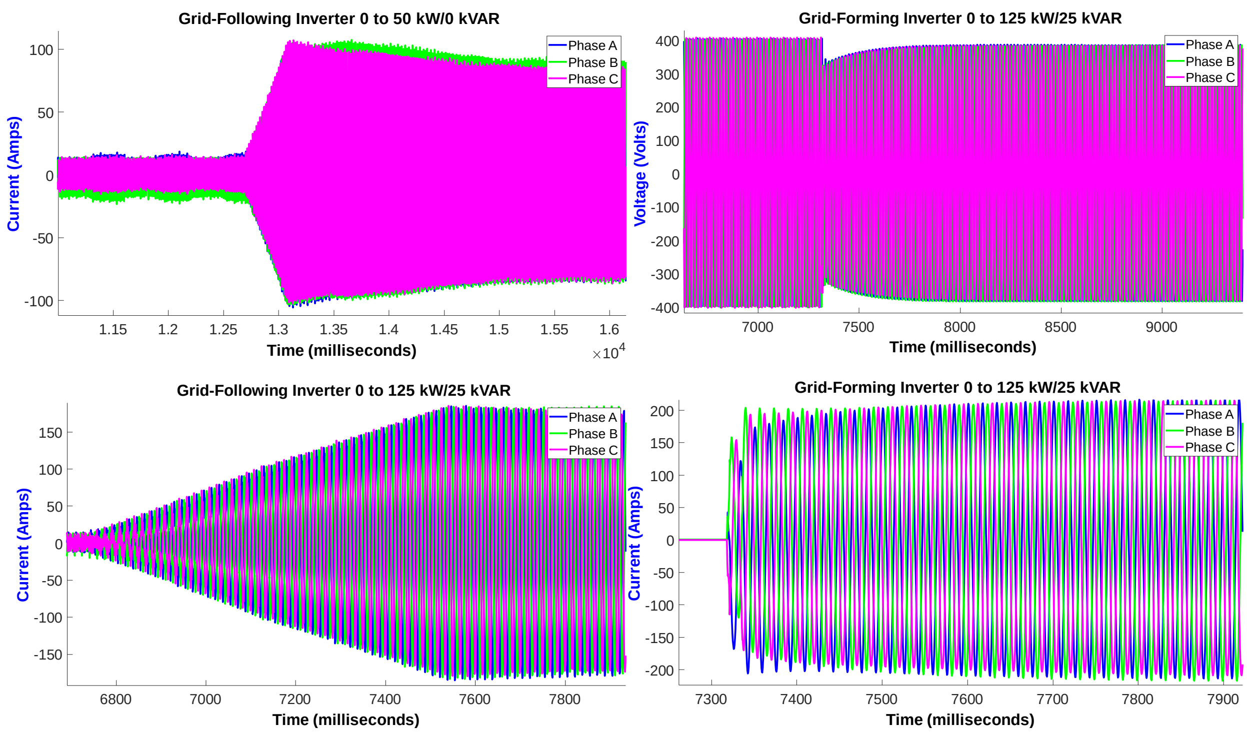

Figure 3: Experimental Data capture for: top left: grid-following inverter going from 0 kW to 50 kW (0 kVAR), bottom left: grid-following inverter going from 0 kW to 125 kW and 25 kVAR, top and bottom right: grid-forming inverter supplying a load that increasing from 0 kW to 125 kW and 25 kVAR.

In addition to DAQ hardware experimentation, CMR worked on refining data collection system software. The team created Python scripts and InfluxQL scripts to facilitate the process of gathering and sorting data from InfluxDB, which is an open-source time series database. As an example, the team worked on compiling and sorting CMR's solar photovoltaic (PV) system output power and weather data. CMR is in a geographical area that has been affected by wildfire smoke and possesses long term solar PV output data. CMR is having ongoing conversations with a professor from an east coast university to use this data to study the effects of air quality and wildfire smoke on solar PV power production.

The team is exploring the creation of a public data repository to foster open data sharing and collaborative research while being mindful of data rights and statutes. To enable that, CMR is exploring the usage of a Github repository which can be accessed at https://github.com/UST-Center-for-Microgrid-Research. The goal would be to populate this Github repository as the project continues.

In recognition to CMR's growing national presence, CMR director chaired a panel at the IEEE Power and Energy Society (PES) General Meeting in Orlando, FL on July 19th, 2023. The panel's title was "Microgrids as Hands-On Experiential Learning Mediums for Power Engineers of the 21st Century" and included experts from National Technical University Of Athens, Greece, United States Military Academy, National Renewable Energy Laboratory (NREL), Xcel Energy, and Schweitzer Engineering Laboratories, Inc. CMR director's talk was titled "Hands-on Microgrid Education For Undergraduate and Graduate Students" and covered the unique educational experience of students at CMR.

To expand partnerships, disseminate knowledge, and grow industry collaborations, the Center hosted more than 50 attendees during multiple tours that were open to the public. CMR was also engaged with the newly created Minnesota Clean Consortium and attended meetings. Moreover, there were multiple meetings with State Representatives on July 21, 27, and Aug 1st. A reporting team from WCCO TV interviewed CMR's director, staff, students, and got footage of the work being done, shown in Figure 4. The resulting story that WCCO broadcasted serves as a valuable platform for highlighting the center's initiatives, educational opportunities, and what CMR offers to potential partners. It also gave CMR undergraduate students experience with being interviewed by journalists and effectively communicating about the center. The story is here: https://www.cbsnews.com/minnesota/news/st-thomas-research-into-microgrids-may-help-reimagine-future-power-distribution/.

Figure 4 Images from the WCCO News Report