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13.8 kV, 5 MVA Medium Voltage Test Facility: Design, Implementation and Lessons Learned

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ABSTRACT Hands-on, testing laboratories are fundamental to technical learning environments in universities. The need for modern equipment in these labs to support industry research and testing is often cost prohibitive and students and professors rely on a random collection of donated and often outdated equipment. This article focuses on the creation of a state-of-the-art medium voltage electrical power technologies lab highlighting the design, implementation and lessons learned for a modern 5 MVA system.

INDEX TERMS Academia, business cases, laboratories, lessons learned, medium voltage, power engineering.

I. INTRODUCTION

Medium voltage (MV) product design (1 kV–35 kV) and testing needs will continue to grow with advancements in renewable energy technologies, transportation (air, ship, and vehicle) electrification with associated charging infrastructure, and power semiconductors operating at higher withstand voltages. However, although product roadmaps exist to operate at these MV levels, test facilities in practice are limited and, even worse, MV curriculums in universities that focus on the operation and appropriate safety protocols in using this equipment are extremely limited. In this article, the narrative describes a MV power laboratory at the University of Pittsburgh (Pitt), rated up to 13.8 kV operating up to 5MVA of power capacity, with equipment and services donated by Eaton, Emerson Process Management, PEPCO, Duquesne Light Company, Sargent Electric, and Cannon Design.

The article is divided into the following sections. In Section II, the narrative describes the state-of-the-art academic facilities in the United States with capabilities higher than at least 480Vac. Section III describes the low voltage undergraduate education power laboratories at Pitt that were designed and commissioned in 2013 before the realization of the MV facility that was energized in 2021. The details of the MV facility are described extensively with one-line diagrams and pictures in Section IV. Once this lab is sufficiently described along with its functions, the authors wrote a lessons learned piece in Section V that described the deep challenges that any design team will encounter that can be easily overlooked from the start. In Section VI, academic arguments for a strong business case are written for such a facility investment and we conclude the piece in Section VII.

II. STATE-OF-THE-ART ACADEMIC HIGH VOLTAGE FACILITIES

The benchmarking assessment comes with a few constraints. The authors evaluate academic facilities in the United States only and have electrical systems that exceed 480Vac and the system is not simply a point of interconnection for equipment. By bounding the review, the following universities fit this classification besides Pitt: University of Arkansas, Florida State University, Ohio State University, Mississippi State University, North Carolina State University, University of North Carolina at Charlotte, and Clemson University. The capabilities of each program will be summarized.

University of Arkansas: The National Center for Reliable Power Transmission (NCREPT) was established for investigating solid-state solutions for the electric power grid. NCREPT is a 7,000 sq. ft. power electronic test facility with three, 2MVA distribution-level test circuits. Power regeneration can occur at the 2MVA level at 480 V, 4.16 kV, and 13.8 kV. DC capability is 750 kW and variable 3-phase power (voltage and frequency) is available up to 750 kVA, [1]. A one-line diagram of the facility can be found in [2].

Florida State University (FSU): The Center for Advanced Power Systems (CAPS) was established at FSU in 2000 to perform basic and applied research to advance the field of power systems technology, with emphasis on application to electric utility, defense, and transportation. Over the last 20 years, FSU-CAPS established a very unique hardware in the loop (HIL) test facility. It combines the capability of simulating a portion of an electric power and energy systems of interest (SOIs), in real time at time steps in the 100s of nanosecond range with the ability to allow those models of interest (MOIs) to interact with controller or power equipment (i.e., the hardware of interest – HOI) at the MW scale. To facilitate this, FSU-CAPS obtained a variety of COTS real time simulators (RTS) such as RTDS, OPAL-RT, Typhoon, and Speedgoat. Moreover, high power amplifiers for medium voltage ac and dc provide the means to establish power HIL (PHIL) simulations with multiple pieces of HOIs. The facility also features extensive controller HIL (CHIL) capabilities, [3].

Mississippi State University: The Paul B. Jacob high voltage laboratory hall is about 9,000 sq. ft. with minimum ceiling heights of 50ft. The lab is equipped with a 5-ton crane, full-scale wet test system, faraday cage, and grounding mesh. The lab is equipped with a 2750 kV impulse generator, 1MVA / 1 kV transformer, 400 kV DC supply, 400 kV impulse generator, multiple dielectric test sets, climate chambers, porosity test setup, and accelerated aging chamber. The lab commonly tests insulators, overhead line components, composite materials, switches, disconnects, fuses, measurement transformers, and other items. The topics the lab specializes in are impulse testing and measurements, partial discharge, measurement transformers, and electrical breakdown characteristics, [4].

North Carolina State University (NCSU): The power electronics and power system research lab is a 10,000 sq. ft. research laboratory in NCSU's Centennial Campus and part of the NSF FREEDM Systems Center, [5]. The lab is powered by a dedicated 1MW transformer that supports low- and-medium voltage research and development for smart grid systems and electric vehicle R&D. The lab is equipped with various three-phase systems (208 V, 480 V, 12 kV). It has 40 kW of solar generation, 20 kWH battery storage and 10PHEV charging stations, all connected to a centrally controlled 1MW Green Energy Hub microgrid, [6]. The 1MVA Green Energy Hub Testbed has a 1MVA dedicated transformer providing a controllable 3.6 kV to 12.47 kV three-phase loop power deliverer feeder in a safe and controlled environment. Three high voltage SSTs (two, 3.6 kV/10 kVA SST and one 7.2 kV/20 kVA SST) are available as part of the physical and real-world testbed. The SST powers various loads at 120 V/240 V 60Hz AC level as well as at 380Vdc level.

University of North Carolina at Charlotte: The Flexible Energy Laboratory Suite (FEL) contains a power cable and conductor load cycle testbed rated at 4kA, a high voltage insulation test system rated at 100 kV and upgradable to 300 kV, a 1MVA rated grid simulator including a 4.16 kV medium voltage testbed, a 200 kW back-to-back motor-generator dyno set for drive testing, and medium voltage supply (12.4 kV up to 200 A). The lab has the ability to test power converter cores, testing AC components (switchgear) up to 4.16 kV, opportunities for testing cable, overhead wire, and other high voltage equipment, [7].

Ohio State University (OSU): OSU has a renowned high voltage and power electronics laboratory which consists of a 3600 sq. ft. high voltage facility, [8]. The lab is strongly supported and heavily utilized by aviation industry, air force research laboratories (AFRL) and NASA. The laboratory has multiple high voltage dc sources (up to 150,000 volts), high voltage ac sources (up to 250,000 Vrms), and high voltage surge generators including a 10 kV SiC based high dv/dt pulse generator. An array of medium voltage inductive and resistive loads is also available for test purposes. Test capabilities include withstand, partial discharge and breakdown tests on gases, liquids and solids, electric and magnetic field tests, reduced-scale model tests, and shielding and attenuation experiments.

Clemson University: Located in North Charleston, Clemson operates the Dominion Energy Innovation Center. This facility is the home of the Duke Energy eGRID and the most advanced wind turbine drivetrain testing facility. In 2009, Clemson was awarded a $45 million grant to design, build, and operate a facility to test, at full-scale, next-generation wind turbine drivetrain technologies. The eGRID facility is a 15 MW rated hardware-in-the-loop grid simulator. The facility is rated up to 24 kV with a nominal power level of 15MVA, although the system can be pushed up to 20MVA. There are 2 identical and isolated test bays rated up to 4.16 kV and 3.75MVA of power capacity. Downstream from these bays are two additional test systems for testing wind turbines up to 15MW and 7.5MW. The facility is equipped to study steady-state operations, perform power quality evaluations, perform grid fault ride-through testing, replicate events in the field, and HIL experiments as needed [9], [10].

III. LABORATORY FOUNDATION: UNDERGRADUATE TEACHING FACILITIES FIRST

In 2008, a partnership was established between Pitt and Eaton primarily in the area of electric power engineering workforce development, [11]. At the time, the collaboration was established on seven strategic goals including senior design project support, curriculum support, joint research program developments, professional society contributions, community service and outreach, and student recruitment.

The most visual of the goals is the establishment of an electric power systems laboratory used currently for undergraduate education. A picture of this facility is found in Fig. 1, [12]. The lab provides opportunities for faculty and students of all types to explore electric power phenomena in the areas of AC system layout, smart grid technologies, variable speed drives, power electronic devices and converters, power quality, renewable energy systems, controls and communications, automation and relaying, distribution engineering, and other emerging electric power technology areas. Supplied by a

FIGURE 1. Eaton's electric power systems laboratory at the University of Pittsburgh [12].

FIGURE 2. Energy innovation center. The right of the figure shows the traditional classroom style high school building and to the left was the location of all the trade shops with high bay ceilings.

75-kVA feeder at 480 volts, the lab incorporates a diverse mix of generation, including photovoltaic panels, and the traditional grid tie. Through variable system strength, these generation sources feed a variety of 208 V loads, centered on innovative laboratory workbenches combining passive and motor loads in a system with advanced metering and control. Capabilities for testing equipment in cases of voltage surges and sags are also incorporated throughout the lab through a custom designed sag generator designed by a senior design team.

IV. MEDIUM VOLTAGE LABORATORY FACILITIES

Pitt's main campus is a city campus. The university shares its geographical location with the University of Pittsburgh Medical Center, the region's largest hospital network, and is directly adjacent to Carnegie Mellon University. For the engineering program to expand, the university started to explore off-campus facilities to fit applied engineering laboratory needs. In 2013, after a facility search, the Pitt Swanson School of Engineering (SSOE) chose the Energy Innovation Center (EIC) for the location of their energy-based laboratories including MV power laboratory, magnetics laboratory, energy storage laboratory, and harsh environment materials laboratory.

The EIC, traditionally referred to as the Connelley Vocational High School, was built in the 1930s and was considered one of the premier trade schools in the country. A picture of the facility is found in Fig. 2. High school students throughout the city had the opportunity to be introduced to careers in construction by learning trades such as carpentry, masonry, and plumbing. In 2004, the building closed and what existed of the trades program was implemented into a few Pittsburgh Public high schools, [13].

In 2011, Pittsburgh Gateways, a non-profit economic development support organization, purchased the former school and began to transform the building, with the help of the local Richard K. Mellon foundation, into an urban complex that promotes energy research while creating pathways for job creation, entrepreneurship and urban revitalization. Pitt, Penn State, and Robert Morris University are current academic entities throughout the facility.

A. VISION FOR ESTABLISHING AN ACADEMIC HIGH VOLTAGE FACILITY

When designing a new facility, Pitt wanted to ensure that the university was distinct and non-repetitive compared to those schools described in Section I. The broad vision that came with the laboratory design was to: 1) create a consortium focused on serving the electrical manufacturers and government entities, 2) evaluate and assess both major industry-wide and company specific issues, and 3) work in collaboration with various partners towards the development, demonstration, and first-generation deployment of solutions across a broad area of electrical technologies and designs. Historically, Pittsburgh, because of the Westinghouse Electric roots, is considered a national visionary for the design and manufacturability of electrical products. This benefits the university when developing academic programs and is a catalyst for success.

When casting the vision for the electrical capabilities, the team settled on four major points from which all other design decisions would come. First, the MV lab should be rated up to 13.8 kV and 5MVA of power capacity. The lab should also have the ability to scale down to 4.16 kV in the same geographical area as the 13.8 kV rated gear. The system design should also not be a simple point of interconnection as most university labs have but a ring bus must be established that is reconfigurable using distribution reclosers.

Within the EIC, faculty were given in total 10,000 square feet to carve out distinct areas with features and capabilities that would be attractive to industry but also functional for graduate students. The footprint of the facility and dedicated regions is found in Fig. 3. Several of the regions relevant to this article will be discussed in forthcoming subsections.

B. UTILITY EQUIPMENT TO ESTABLISH THE MEDIUM VOLTAGE LAB

A general one-line diagram of the medium voltage lab is found in Fig. 4, [14]. The portion of the one-line that is dashed in blue is equipment that sits outside the EIC. The green and orange lines represent bus bars or equipment that is rated for 13.8 kV and 4.16 kV, respectively. Around the EIC, Duquesne Light's distribution voltage is 23 kV. To transform the voltage

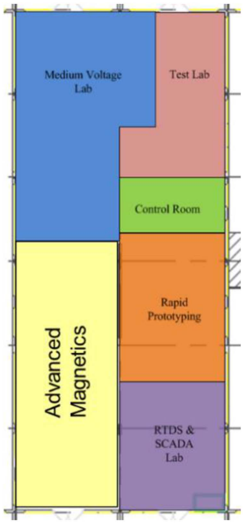

FIGURE 3. Regions of the electric power technologies laboratory with advanced magnetics laboratory.

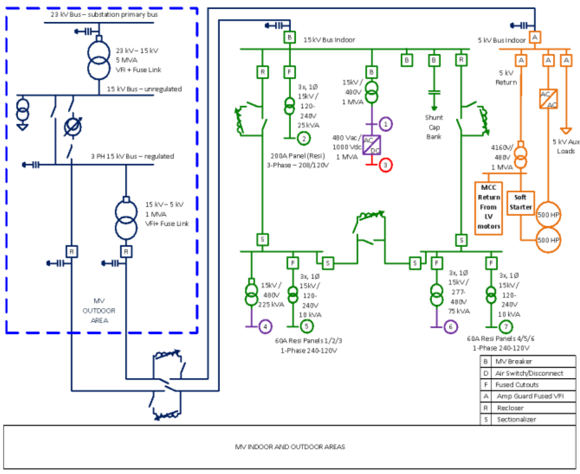

FIGURE 4. One-line diagram of medium voltage laboratory.

FIGURE 5. Cross section of modular integrated transportable substation (MITS) serving the pitt laboratory facilities.

FIGURE 6. Medium voltage AC laboratory.

FIGURE 7. 13.8 kV MV front-accessible switchgear.

and supply the power from the distribution circuit to the Pitt laboratory, Eaton makes a product referred to as the MITS. The MITS stands for modular integrated transportable substation that receives the 23 kV feed and transforms the voltage into 13.8 kV and 4.16 kV for the lab environment. A picture of the MITS is found in Fig. 5. One of the primary pieces of equipment within the MITS is the vacuum fault interrupter (VFI) switchgear, which provides a safer and more reliable approach to MV switching and protection. In the case of Pitt's system, the high side of the MITS transformers are continuously connected to the distribution system and the VFIs are triggered from the Emerson Ovation control system when voltage is needed within the lab to drive power to the loads.

Moving indoors, a picture of the medium voltage lab is found in Fig. 6. Note that this room is represented by the dark blue region of Fig. 3 and green lines of the one-line diagram in Fig. 4. Including the MITS, Eaton has invested around $3 million in infrastructure that includes circuit breakers, overhead switches, large and smaller motor drives, distribution and pad-mounted transformers, reclosers, and ground fault indicators. PEPCO, based in Ohio, donated the steel seen throughout the facility.

The MV Lab has a 13.8 kV loop system designed to add impedance (inductance) in the loop to simulate longer lines (1, 5, 10 mile, for example) each with bypass switches to remove the extended lines as necessary. 13.8 kV breakers housed in a MV switchgear lineup shown in Fig. 7, allow connection to some of the feeds from the system and allow for load connection for testing. A 1000 kVA, 15 kV/480 V

FIGURE 8. Pole-mounted transformers (480 V and 240 V secondary).

FIGURE 9. 4.16 kV rated eaton ampgard motor control equipment.

FIGURE 10. 4.16 kV 500 HP MV drive.

FIGURE 11. 480 V variable frequency drives (VFD).

pad-mounted transformer is connected to the 13.8 kV loop and a second 1000 kVA 4160/480 V transformer is connected to the 4160 V feed from the MITS. Both transformers feed segments of equipment in the 480 V test lab labeled as the pink cell in Fig. 3.

Five sets of pole mounted transformers are used to simulate various power configurations from the 13.8 kV loop. Some of them are three-phase banks intended to simulate a commercial application with 480 V secondary and some are intended to represent residential applications with split-phase 240 V outputs, as shown in Fig. 8. Above the main lab door inside the lab are bypass switches. If the bypass appears "opened", current will flow to the 13.8 kV breaker to ultimately energize the 13.8 kV/480Vac padmounted transformer. If the switches are latched in the "closed" position, current flows down the center of the lab to energize the pole mounted transformers.

On the 4160 V feed, there are two sets of motor control configurations protected with Eaton's Ampgard technology. Ampgard is utilized for soft starting motors at the MV level with unit shown in Fig. 9. The Ampgard unit interfaces to a 4.16 kV, 500HP rated drive seen in Fig. 10. Other lower voltage drives exist rated up to 480Vac with one illustrated in Fig. 11.

The MV lab also has a 15 kV capacitor bank for varying power factor as required during testing currently located on the mezzanine level in the MV room above the induction motor pictured in Fig. 6. Load banks, motors and other electrical loads can be added as necessary for testing. Finally, the MV lab is designed to connect to each of the voltage levels with fuses, breakers or reclosers (Fig. 12) for fault protection and control allowing flexibility for testing with manual switches to reconfigure the system as necessary.

C. MEDIUM VOLTAGE LAB FEEDING LOW VOLTAGE TEST LAB

Adjacent to the MV laboratory is the low voltage laboratory rated up to 480 V. In Fig. 13, the 480 V panels are shown in the far right with DC panels consuming the majority of

FIGURE 12. Three-phase reclosers and disconnect switches.

FIGURE 13. 480Vac electrical panels (far right) and DC electrical panels (no electrical feeds entering DC panels currently).

the image. What is important to emphasize is that both MV transformers (green pad-mounted in Fig. 6) feed this laboratory as illustrated by the piping conduit feeding the top of the master AC electrical panel. The 1000 kVA, 15 kV/480 V transformer feeds the AC electrical panels and the 1000 kVA 4160/480 V feeds a motor control cabinet (MCC) in the low voltage room. The advantage of this approach is that the lab is truly interconnected as an academic system from medium voltage to low voltage. The disadvantage is that you need to operate the medium voltage room to operate the low voltage room, which will be elaborated upon in a future section.

Directly across from the AC electrical panels is an electrical cage as shown in Fig. 14. This area is being electrically upgraded to allow researchers to connect 208 V or 480 V to electrical equipment depending on need through a double throw switch. The chamber will also have NEMA plug configurations with 60 A, 30 A, and 20 A receptacles. Emergency stops will be installed at the testing cage and near the testing power panels. As shown, two Magtrol dynamometers were purchased for electric machine testing and evaluation.

D. COMMUNICATIONS AND SAFETY

To control the MV gear (primarily the MITS, indoor reclosers, and the 4.16 kV circuit breaker), Emerson's Ovation platform

FIGURE 14. Protective barrier for testing up to 480 V and 60 A.

FIGURE 15. Operations center for controlling MV AC equipment.

is utilized. The operations center for where the human machine interface (HMI) is displayed to interact with Ovation is found in Fig. 15. The server and control cabinet are shown in the left and center of the image found in Fig. 16 , respectively.

When the HMI is triggered to energize a piece of equipment, a signal is sent to the main control cabinet to take a particular action. Fiber optic cables are used to transmit the bulk of the signals to the MITS given the distance between the controller and physical equipment.

The control cabinets are equipped with more than enough input/output modules and with redundancy in the case of

FIGURE 16. Server (left), emerson ovation platform (center), schweitzer relays (right).

failure. Once the equipment is energized, a vast number of electrical and digital variables can be displayed to the television screens found in Fig. 15.

Most electricians are accustomed to the Lockout/Tagout of electrical equipment or Kirk Key approach to interlocking switches but may not be covered in traditional electrical engineering curriculums. Thus, this point is worth emphasizing as the concept ties to laboratory safety measures. As shown in Fig. 18, the reader will see one entrance into the MV lab from the low voltage lab. In the top right is a strobe light and towards the bottom is a bolt and chain. If the medium voltage room is to be energized, the bolt is inserted into the cylindrical chamber such that when positioned correctly the key can be turned and can be pulled out. This key is 1 of 2 keys that is inserted into the electrical unit shown in Fig. 19. In Fig. 19, if both LEDs are red, the Emerson Ovation control system becomes armed. If the light combinations are anything but both being red, the control system is blocked.

When the control system is armed, the Ovation platform can be triggered through the human machine interface found on the computers in Fig. 15 to close the VFIs at the MITS resulting in voltage at appropriate locations throughout the medium voltage laboratory. When done, the two strobe lights will switch from green to red with one shown in Fig. 18.

There are many circuits coming into the EIC as a whole. It would be possible for the EIC to lose power but the MITS still operating in the back of the building. In this case, the Ovation platform would lose communication with the MITS, all strobe light indicators would not be electrified, but voltage would be in the medium voltage room assuming the lab was energized prior to the blackout. For this reason, four emergency stops are located throughout the facility. Two are inside the high voltage bays as shown in Figs. 18 and 19, one is external to the lab space for any staff member of the EIC to press and one is outside of the EIC near the front entrance for emergency personnel to press. These emergency stops are hardwired into the building electrical system. An option does exist such that the emergency stops can be controlled from the Ovation platform. The issue with the latter is that if the Ovation platform loses power, there is no way to de-energize the MITS.

Within the MV laboratory, you will see a bright yellow beam that runs across the floor by the large transformers as shown in Fig. 11. This is strictly for oil containment in the case that both transformers leak at the same time. Grounding is another question that often is discussed. Grounding is no different from a typical substation. To the right of the 13.8 kV circuit breaker in Fig. 7 is the lab's common ground point with sample grounding shown in Fig. 8 (see green ground conductor with copper running along the floor). Finally, fire rated glass and frames surrounded the MV laboratory with 1-hr fire rated drywall behind the circuit breakers and motor drive.

E. RENEWABLE ENERGY SUPPLY

The roofline of the EIC shown in Fig. 2 is angled, South-facing and suitable for capturing maximum sunlight throughout the day. A 50 kW solar system was installed directly above the MV laboratory. The one-line diagram of the solar system is found in Fig. 17 with associated indoor electrical equipment in Fig. 20. In both images, one will notice that we have both an AC and DC transfer switch. The majority of the time, the solar system is helping to offset electricity costs for the EIC, thus, all the DC generated power is converted to AC. If the DC power needs to be utilized for a research project, the DC transfer switch can be engaged to direct the power to the DC electrical panels mentioned in Fig. 13. Currently, there are no feeds coming from the DC switch to the DC electrical panels but that is an opportunity for future electrical expansion with the core components on site.

F. DATA ACQUISITION APPROACH THROUGH EMERSON OVATION

The Ovation System is comprised of Drops – Ovation Controllers or Ovation Computers – interconnected to form a network or "data highway." These drops pass data to one another via an Emerson-proprietary protocol called "DDBs" or Dynamic Data Blocks. Ovation Controllers receive signals from hardwired IO (such as the emergency stops). The Ovation IO modules take in these signals, send them to be processed by the controller, and are broadcast out on the highway from there.

When the team needs to bring in *non-Emerson*, non-Ovation signals into Ovation, this is done with a "datalink." Various Ovation components can accomplish a datalink, but the team must specifically use the Ethernet Link Controller (ELC) Ovation module to do so. The ELC is a module that can be licensed to speak to a variety of 3rd party protocols (ex. Modbus, DNP3, GSM, EIP/Native, etc.). As an example, the Eaton equipment mentioned can act as Modbus Servers, so we are able to configure the ELC to be a Modbus Client & pull data from Eaton into Ovation.

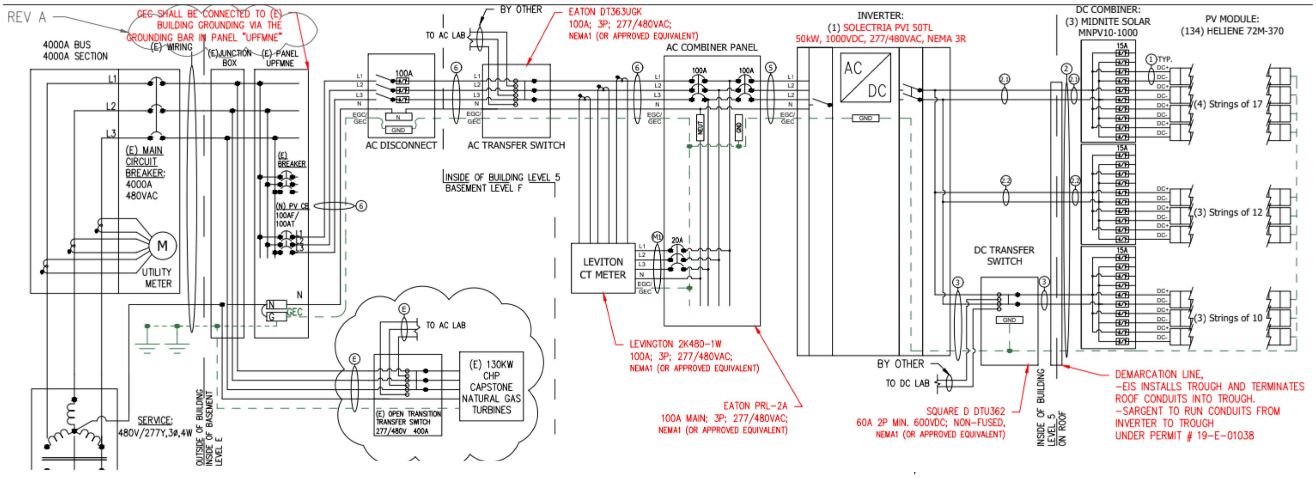

FIGURE 17. One-line diagram of 50 kW solar array.

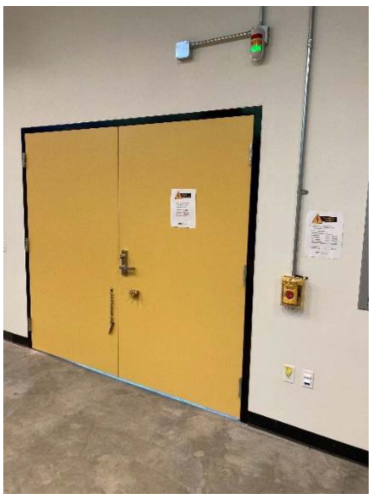

FIGURE 18. Entrance to MV lab with emphasis on key and chain combination and strobe light.

FIGURE 19. Indictor for arming ovation control system with emergency stop.

FIGURE 20. AC (far left) and DC (right) transfer switches along with inverter.

With Modbus, a Client will send read or write requests and a Server will serve those requests. Eaton can supply their available Modbus registers to be read/written to and are mapped within the ELC. This will tie Eaton's Modbus registers into Ovation points. Once mapped to an Ovation point, data will be updated periodically & displayed throughout the Ovation system.

A sample of figures are provided next to show what is currently available in the lab for monitoring the MV gear. Note that the lab was de-energized when the figure captions were taken. Fig. 21. HMI for Controlling MITS provides the HMI screen that triggers the vacuum field interrupters on the 13.8 kV and 5 kV points at the MITS. One will notice also how the fire alarm is programmed at this screen as well as the Kirk key system, which is currently disabling any action to be done by the Ovation platform. Fig. 22. Electrical signals monitored in the control room regarding the status of the MITS. shows all the signals that are necessary to be monitored

FIGURE 21. HMI for controlling MITS.

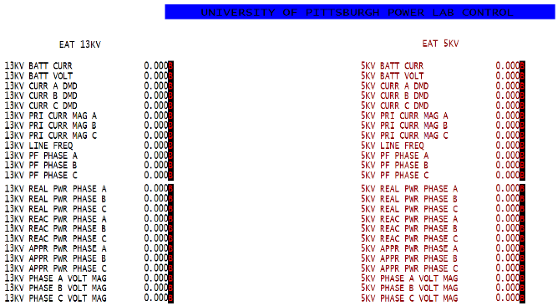

FIGURE 22. Electrical signals monitored in the control room regarding the status of the MITS.

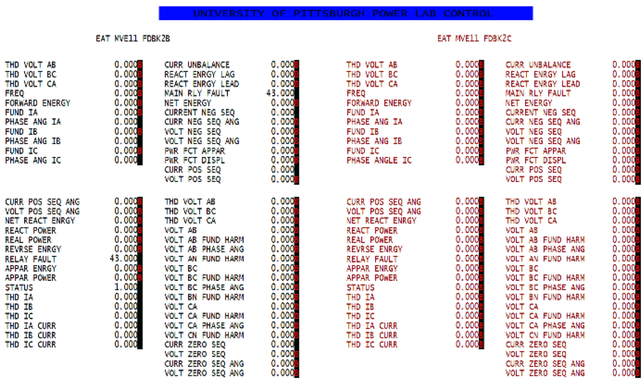

FIGURE 23. Electrical signals monitored in the control room regarding the 13.8 kV circuit breaker.

at the MITS and can be broadcasted to the television screens shown in Fig. 15.

As electricity enters the medium voltage laboratory, more refined data might be necessary such as observing current unbalances, total harmonic distortion, power factor, angular measurements of the currents, etc. With a wealth of signals available to the equipment owners, the team selected those found in Fig. 23 for monitoring the 13.8 kV breaker (Fig. 7) in the MV room.

V. LESSONS LEARNED FOR ACADEMIC INSTITUTIONS

As mentioned, not many institutions are taking the initiative in building test laboratories especially in academia. Not many engineers are given the opportunity to start with a piece of paper and bring the concepts to reality, likely due to implementation costs and safety concerns. For Pitt, the team had a conceptual one-line diagram put on paper by February 2013 but the lab was only energized in August 2021 remembering that COVID-19 slowed progress starting in early 2020. For those who are going to take on the ambitious task of building an electrical testing facility, there are a number of key items to be concerned with that you will experience along the journey.

Layout Mistakes: Visualizing the final layout of all the equipment will be challenging. There are a few "mistakes" that are worth noting for future research groups. First, the distance between the control system and MV laboratory is significant. In Fig. 3, the Ovation equipment is in the "RTDS and SCADA Lab". Future groups should put the control equipment close enough to the MV equipment to see the equipment turning ON or OFF. Be sure to put enough LED indicators in the room indicating status. The equipment vibration is minimized so well that it can be challenging to determine if the equipment is energized.

Second, establish a circulating path for current to enter the device under test and the existing facility. This is critical for reducing electricity bill costs and cooling system sizing in the facility. For this laboratory, higher cooling needs were emphasized for the room that has the hardware-in-the-loop capability and overlooked the MV laboratory. This will be something the team will be investigating in the future. Tied to cooling, be careful with conditioning the environments that the equipment is located. The equipment inside the MV laboratory is air conditioned because of the EIC chilling system. The MITS sits outside and experiences a wide range of temperature conditions in Pittsburgh. When the MITS arrived on site, it was not energized right away and went through changes in season (humid summers and cold winters). When the team was ready to energize the MITS, the cabinets were opened and mold lined the inner cabinets. When equipment arrives, the rule-of-thumb is to get it in-service so internal cooling within the cabinets is regulated. Heaters were installed in the MITS to avoid moisture buildup but control power to the heaters was not connected to avoid this issue.

Zoning and Costs: First, ensure that you hire an electrician firm with inside engineering capability and project management capability. Such a partner is incredibly valuable when dealing with the national electric code and handling your local city regulations when it comes to permitting. Tied to zoning and permitting, the common person would naturally think that placing a 30-foot piece of equipment on the ground should not be a problem if you get the approvals from the landowner. One lesson learned was tied to variances. The MITS extended the property lines by 18 inches and required city engagement to adjust the boundaries. Realize, this can put a delay in your planning. Today, the MITS has its own street address.

Second, electricians are accustomed to seeing a final set of drawings, equipment arriving when it should, implementing the equipment and moving to the next job. This is a linear process but will be very challenging to abide by giving the capital investment necessary for a university lab. For this project, the university team was doing business development (seeking investments, company donations and sponsors, working on the contracting, etc.) in parallel with the equipment installations.

This process can create setbacks and alterations to floor plans that require additional costs.

Third, work closely with your utility company well in advance. Faculty are used to the university covering electricity bills for basic needs. A number of distribution, transmission, generation, and surcharges that scale with the kilowatts used is set by the public utility commission. The advice is to set the kilowatt level low (250 kW as an example) and scale up when needed.

Fourth, convince university leadership to invest into personnel for operating a lab at this scale. For the control cabinet, three engineers were needed (set-up, graphics, and communication protocols) alone. Three field service engineers were onsite to start up the MITS. If it is too challenging to hire initially until activity begins to increase, set up an open purchase order agreement with your electrician team.

Finally, do not underestimate the requirements needed to make this type of facility safe for students, faculty, and visitors. Safety has to be the top priority of any electrical lab but this type of high-power facility has additional and significant requirements. The engineers and contractors that design and install your system must test and verify that every safety system is working properly during startup, commissioning, and on-going maintenance procedures. Be sure the latter statement is tied into the contract.

VI. BUSINESS CASES FOR LABORATORY

While touring the facilities, the “jewel” is the MV laboratory. However, faculty express to personnel that the lab environment is simply a tool. Another analogy that is often used to non-technical tourists is that the lab was designed to be like a sandbox. Meaning that the core components of a distribution system are in place and then it is up to the customers to provide the load to be evaluated. In this section, we will provide a sampling of use cases that have garnered the attention for using such a facility.

First, the value proposition of having such a facility is tied to proof of concepts associated with government agency proposals. When proposing, every funding announcement asks for the type of facilities that are available. If you are going to do higher power research, you can’t test prototypes at low power levels and expect the products to respond similarly at higher powers. Because a university is neutral to manufacturer competition, a facility like what was designed can be used by anyone especially for the purposes of demonstrating achievements of a government program at the end of the funding cycle.

Second, it is not an easy task to acquire lab time to test products because of the limited facilities in the United States. Imagine a scenario where your organization books one week of time with a test facility but, as the test week gets closer, something unexpected happens (personnel illness, equipment lead-time issue, delays in prior planning, etc). Once the corporate test facility locks the customer in, the time cannot be adjusted because others are in-line waiting to use the lab. With a university, fee-for-service opportunities are not the priority of the operation plan and, therefore, adjustments can be made with enough lead-time. The other advantage the university has is that facility time can be allocated such that there is enough buffer time between equipment coming on site, tested, and shipped out so the environment remains private.

Third, many companies have heightened interest in performing steady-state evaluations of their products. The interest here lies in attempting to push products to about a TRL level of 6 to 7 and so one needs to be able to evaluate the equipment in an actual system. This laboratory is not a simple point of interconnection like most universities might operate. Thus, this lab environment can be used as a beta site prior to true field installment.

Fourth, many companies appreciate the idea that it is an actual system with a controlled environment meaning that special accommodations do not need to be sought to test equipment (like with a utility for example). A scenario that is on the rise is evaluating sensor technology for “edge of the grid” applications. What better place to evaluate sensor performance and benchmark their precision and accuracy with leading manufacturer products. As an example, if Eaton equipment is measuring 13.8 kV and the sensors are not, what better way to know and diagnose issues quickly rather than waiting to get additional lab time, which can have up to 6 months of lead time.

Finally, throughout this article, the emphasis was placed on the lab facilities but what about training personnel. It is not easy to go into a substation because they are energized continuously. With this facility, people can enter and see large equipment when de-energized instead of looking at pictures, advanced graduate students are beginning to be exposed to these assets under direct supervision, and manufacturers can use the lab as a tool for marketing performance of their products to future customers if integrated within the lab for a period of time.

VII. CONCLUSION

This article describes a design of an academic power laboratory rated up to 13.8 kV and 5MVA of power capacity. Unlike other academic facilities in the United States, this lab is an actual distribution system formed by manufactured equipment and controlled with industrial grade controllers and associated software. The system put together is interlocked meaning the MV infrastructure feeds the lower voltage infrastructure and not segmented like other academic labs in the country. The Pitt lab was designed general enough to accommodate growing trends in electric power engineering whereas other academic facilities might be more distinctly focused on specific R&D areas (like HIL or dielectric testing).

As mentioned throughout the article, a facility investment like what was described does not happen instantaneously and in a short time frame. Champion faculty members and champion industry partners must be working for extensive periods of time, set realistic goals initially, and then push towards more challenging goals over time. For example, the Pitt-Eaton partnership is continuing to run strong 15 years after the first committee was formed between both organizations. This is why the low voltage, educational lab was explained briefly before embarking on the discussion of the MV facilities, the much more challenging achievement.

In the article, the key rooms that form the MV facilities were described extensively with their purpose. The key item to remember is that a lab is never complete, and this is just the start for faculty at Pitt who maintain and operate the lab. The other thing to note is that the facility is a tool, although a very expensive tool. Faculty should not feel the pressure to continuously operate such a facility unless it is absolutely mandatory in achieving R&D results for a funded program simply for the sake of individual safety around high voltages and power levels.

As mentioned, not many universities are building out MV labs and, so, there is no "best practices" book to follow because the ones that do exist are tailored to that university's strengths. For the purposes of this article, the authors provided their layout mistakes and zoning and cost issues that every team is expected to face. Hopefully with the major ones that were documented, future teams will read and account for these issues at the start of a future build-out. Finally, the authors organized a set of business cases based upon feedback that they have received over the years from potential clients that sets the value proposition for other universities who choose to take the next step with such an investment. The list is nowhere near complete, but it is a start for others to expand upon.

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