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ENERGY STORAGE AND MICROGRID CONSTRUCTION

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ABSTRACT

Energy storage and microgrid (ESM) systems introduce capabilities to dramatically improve the resiliency and efficiency of electrical grids as well as enable the introduction of renewable energy systems to new and existing power distribution infrastructure. Multiple market forces have converged to enable the feasibility of ESM construction in many regions of the world. These forces include dramatic drops in the cost of solar photovoltaics and energy storage; regional shifts in the availability of low-cost natural gas; increased interest in resiliency among utilities and facility owners; and emerging capabilities among developers, builders, and finance professionals to conceive, design, finance, build, and operate ESM systems. The development and construction of ESM projects require significant levels of innovation, endurance, and responsiveness to project specific conditions. Collaborative and integrative methods have emerged as critical process management methods that facilitate the planning, construction, and operation of energy storage and microgrid projects. These unique challenges of ESM project also require specialty skills and capabilities across project developers, managers, engineers, and skilled workforce. This paper presents the patterns emerging from multiple microgrid development projects and an integrative approach to building capacity to pursue and execute ESM projects among utility professionals, electrical workers, and electrical construction project managers. New curriculum designs are presented based on lessons learned in the design, construction, and operation of a living laboratory for ESM systems and experiences gained through the development of a hybrid microgrid system including combined heat and power, solar photovoltaics, and multiple types of battery energy storage systems. The implications of ESM system growth on a global scale are also discussed, including the need for integrative research and education programs at regional levels to support the growth of ESM markets and system deployment.

Keywords: Energy storage, battery, microgrid, electrical, construction, engineering, education

1. INTRODUCTION

Energy storage and microgrid (ESM) systems introduce capabilities to dramatically improve the resiliency and efficiency of electrical grids as well as enable the introduction of renewable energy systems to new and existing power distribution infrastructure. Multiple market forces have converged to enable the feasibility of ESM construction in many regions of the world. These forces include dramatic drops in the cost of solar photovoltaics and energy storage; regional shifts in the availability of low-cost natural gas; increased interest in resiliency among utilities and facility owners; and emerging capabilities among developers, builders, and finance professionals to conceive, design, finance, build, and operate ESM systems. The development and construction of ESM projects require significant levels of innovation, endurance, and responsiveness to project specific conditions. Collaborative and integrative methods have emerged as critical process management methods that facilitate the planning, construction, and operation of energy storage and microgrid projects. These unique challenges of ESM project also require specialty skills and capabilities across project developers, managers, engineers, and skilled workforce. This paper presents the patterns emerging from multiple microgrid development projects and an integrative approach to building capacity to pursue and execute ESM projects among utility professionals, electrical workers, and electrical construction project managers. New curriculum designs are presented based on lessons learned in the design, construction, and operation of a living laboratory for ESM systems and experiences gained through the development of a hybrid microgrid system including combined heat and power, solar photovoltaics, and multiple types of battery energy storage systems.

1.1 Microgrid Systems Defined

Microgrid systems represent a unique construction sector based on the variety of systems, technologies, and operational modes that can be achieved through combing energy generation, storage, and load management. These systems can also exist at a variety of scales. The U.S. Department of Energy Microgrid Exchange Group has authored a widely accepted definition of a microgrid as (DOE :

- Group of interconnected loads and distributed energy resources (solar, wind, generators)
- Clearly defined electrical boundaries
- Acts as a single controllable entity with respect to the grid
- Can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode

Perhaps the most defining characteristic of a microgrid is the capability to operate in a variety of operational modes that may be connected to the electric grid, or disconnected. Figure 1 illustrates a basic grid infrastructure in which multiple electric feeders and respective loads at connected to the grid while also connected to multiple distributed energy resources (DER) such as solar photovoltaic power generation, combined heat and power generation, and battery energy storage. In normal operation, these DER elements contribute to fulfilling power and energy requirements of all feeders as a supplement to the electric grid. Figure 2 represents and same system operating in “islanded” mode. In this case, due to a loss of utility, a portion of the systems (Feeders A and B) operate while disconnected from the grid. Feeder C, designated with non-critical loads, would be inoperable in these conditions. Figure 3 represents an alternative scenario in which no grid connection is affiliated with the system, and in which the generation and storage resources alone are used to address the load requirements in the system.

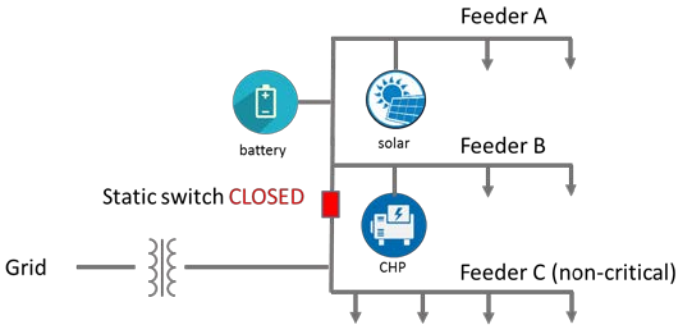

Figure 1: Microgrid Operational in “normal” operational mode (Grid Connected)

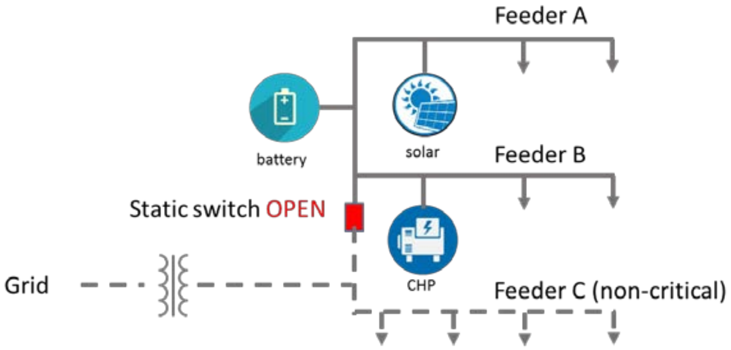

Figure 2: Microgrid Operational in “islanded” mode (Disconnected from Grid)

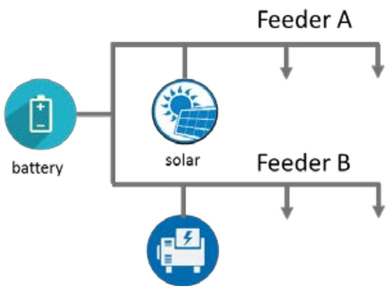

Figure 3: Independ microgrid system designed to operate independently from the grid.

Due to the flexible nature of microgrid systems and the capabilities of energy storage technologies, microgrids can provide multiple value adding processes to energy systems including:

- Enable renewable energy and distributed generation
- Integrate, store, and distribute energy to and from multiple sources
- Fulfill energy requests when the centralized grid suffers from heavy demand, such as during peak usage hours
- Lower demand costs by kicking in during a heat wave, when the peak pricing of electricity is high
- Coordinate control with the central grid to anticipate events and act instantaneously without significant interruption of service.
- Allow quality-of-service premium offering to customers that require such services
- Optimize energy collection, storage, and delivery — thus opening up new revenue streams for microgrid providers.

The versatility and value of microgrid systems is becoming evident to investors, utilities, and the owners of facilities. While some aspects of microgrids might be more attractive to some entities than others, the overall value proposition of microgrids is increasingly understood to include: (1) **Efficiency** through lowering energy intensity and distribution losses; (2) **Reliability** based on the ability to maintain 100% uptime for critical loads; (3) **Security** through enabling cyber and physical security of assets; (4) **Quality** via stable power and ability to meet exact consumer energy requirements, and (5) **Sustainability** be enabling the expansion and deeper penetration of renewable energy.

Despite the potential of microgrid systems, significant challenges exist. For example, although many microgrid-related technologies are in current use, they have rarely been combined in comprehensive systems. Existing applications include advanced metering and power systems networks, distributed energy production, energy storage, and advanced power management techniques. Also, while the idea of a smart grid is not new, a new understanding of grid needs, potential benefits, and challenges has produced a wide range of federal and state initiatives and policies that vary from region to region. Navigating regional policies and electricity markets is thus a significant barrier to microgrid development. Implementation challenges also exist, as microgrid systems need to be conceptualized, designed, approved for interconnection, built, commissioned, and operated in the midst of rapidly evolving technologies and markets. The challenge that is the focus of this effort however, is the fact that the talent needed to realize the potential of microgrid development is in short supply, and is increasingly needed at all levels of the workforce.

Multiple U.S. Department of Energy initiatives support the development of industries and a skilled and professional workforce needed to face the challenges of transitioning the United States to a clean energy economy. Recent increases in funding dedicated to smart grid meter installation and network improvements will create a surge in workforce demand, yet companies supporting smart grid technologies, energy efficiency efforts, vehicle-to-grid innovations, and renewable energies indicate a serious inability to hire and retain skilled and professional workers. New systems and technologies associated with the smart grid create the need to train and re-train current professional engineering and construction management related workers in specialty topics. Coordinated with this effort, education programs are needed support the introduction of smart grid technologies to new and incumbent skilled workers via electrical and technology trade education programs. The diversity of the smart grid marketplace also demands that an inclusive approach is taken to convene utility, energy management, manufacturing, and engineering communities and work closely with these stakeholders to coordinate smart grid technology transfer and workforce development efforts.

2. METHODOLOGY

The diverse nature of the education and workforce needs in the microgrid industry inspired the pursuit of an integrative approach to education research and service and the development of a long term investment in infrastructure in the form of a living laboratory. The setting and infrastructure investments pursued through this effort are briefly summarized below.

2.1 Living Lab Design

A key strategic decision in this effort was to embed in an emerging microgrid system in a metropolitan setting. The Philadelphia Navy Yard (PNY) is home to a growing population of businesses pursuing sustainable facilities and business practices, and continues to attract growth and investment. This project capitalizes on a strategic decision by Penn State to launch multiple Department of Energy centers at the PNY. These centers pursue education, research, workforce development, and outreach activities, and include matching funding from the Commonwealth of Pennsylvania, and intense investments of time and energy from Penn State leaders, faculty, and staff. These efforts and the associated risks taken by the Penn State to launch new programs at the PNY have laid the foundation for a holistic approach which seeks to lead to a vibrant, resilient, and internationally prominent endeavor in energy and sustainability.

Figure 4: The Philadelphia Navy Yard as a Living Laboratory for Energy, Sustainability, and Microgrid Development

2.2 Smart Grid Experience Center

The GridSTAR Smart Grid Experience Center is a result of a 3-year DOE investment in education and training for sustainable energy systems. Active systems of the GridSTAR Center include energy efficiency, solar technologies, energy storage, and electric vehicle infrastructure and enable immersive research and learning experiences. To compliment these assets, Penn State has also completed two new facilities at The Navy Yard including a demonstrative deep energy retrofit and a new energy education and innovation center that will each offer unique settings for building-scale microgrid learning and experimentation. Figure 5 describes the key features of the GridSTAR Center.

Three additional co-located Department of Energy Centers helped to launch rich opportunities for undergraduate research experiences through collaborative relationships and technical expertise in distributed energy generation and efficiency. The Consortium for Building Energy Innovation includes industry and research partners, and will provide classroom space for the program in its newly constructed facilities. The Mid Atlantic CHP Technical Assistance Partnerships focuses on the advancement of combined heat and power projects and has established education and training relationships with electrical engineers, contractors, and utilities. The Northern Mid Atlantic Solar Application and Resource Center is a participant in the Department of Energy Solar Instructor Training Network (SITN), and provides both experience and training infrastructures for professional development of electrical technicians, engineers, and instructors.

GridSTAR Center Features:

1. Advanced electric charging infrastructure (V2G) Level 2 and 3 chargers
2. Smart Grid Demonstration Residence with energy storage, generation, and demand response controls
3. Solar PV training infrastructure in Training Center available for utility, commercial and residential demonstrations and installs
4. 125 kW Grid interactive utility scale energy storage unit maintained by Solar Grid Storage
5. Penn State's Center for Building Energy Education & Innovation
6. Penn State's Center for Building Energy Science and Engineering

Figure 5: GridSTAR Smart Grid Experience Center Infrastructure at the Navy Yard

3. ENERGY STORAGE AND MICROGRID CONSTRUCTION EDUCATION

Three unique construction engineering and workforce programs have emerged from the experiences of building and operating the microgrid assets of the GridSTAR Center. These include a unique summer program for undergraduate students, and new Graduate Certificate, and a workforce development initiative in energy storage and microgrids. Each of these programs is summarized below, with an emphasis on the energy storage and microgrid training efforts.

3.1 Undergraduate Program Design

Realizing microgrid energy systems requires innovative approaches to creative problem solving as much as any other issue we face today. Across the globe, institutions of higher education are seeking new ways to prepare their students for successful sustainable endeavors. Immersive experiences in tangible sustainability systems are widely recognized as a critical learning experiences in education for sustainability. In many cases, the creation of these experiences and relevant real-world context is challenging to create in traditional classroom settings. In response, a new undergraduate program in sustainable energy and microgrid systems has been developed.

The goal of this program is to offer innovative immersive learning experiences in energy and microgrid systems that will lead to a revenue-producing capstone semester and enhance student success in critical fields needed to pursue microgrid project development and construction. The project leverages newly developed Penn State programs and sustainability courses across multiple campuses and the unique Living Laboratory potential of The Navy Yard. It is intended to attract and serve students from multiple disciplines across Penn State campuses, and eventually other universities. Utilizing the established relationships developed in the design and construction of the GridSTAR Center, energy focused companies from start-ups to international leaders in grid modernization are matched with interested students seeking internship experiences as well as unique course offerings in energy and sustainability.

The Immersive Summer Experience in Energy and Sustainability couples hands-on coursework with internship experiences at The Navy Yard and leverages the unique learning environment and relationships at this location. It also demonstrates an innovative and sustainable approach to providing engaged scholarship and undergraduate research experiences in key sustainability topics. Two successful summer offerings of this program have demonstrated the viability of the program and the value of two key strategies employed be the program design:

1. Physical Learning Environment – *The project utilizes the GridSTAR Smart Grid Experience Center as a core hands-on learning environment for the students. This facility was built to accelerate the adoption energy efficiency and renewable energy systems through immersive learning programs that builds upon and advances the culture of sustainability and clean energy.*

2. Relationships – *The project combines strong existing educational, industrial and partner relationships to provide for-credit courses, undergraduate research experiences and student internships. These relationships link the deployment of relevant courses and industry experience for students with access to sustainable energy-focused students for local businesses & organizations.*

Figure 6: Hands on teaching and learning opportunities at the GridSTAR Center

3.2 Graduate Program Design

The unique facilities and expertise that have emerged from the GridSTAR Center development also revealed the need for graduate level continuing education in support of microgrid project design and construction. Rapid growth in the development of distributed energy resources such as wind, solar, and combined heat and power systems coupled with needs for improved electric grid efficiency and resiliency have created a broad need for expertise in grid modernization practices. Professionals in the utility, energy management, and electrical manufacturing fields need the knowledge and skills to plan, design, build, and maintain modern electrical grid systems.

The graduate certificate in Distributed Energy and Grid Modernization is designed to respond to this need, and is specifically for current and aspiring practitioners who seek advanced skills for advancing the electric power generation, distribution, and energy management sectors. To accommodate participation by working professionals who can only study part-time and at a distance, the program is offered through a combination of online and face to face offerings. Students are required to take the following courses:

EE 588 – Power Systems Control and Operation (3cr). Steady-state and dynamic model of synchronous machines, excitation systems, unit commitment, control of generation, optimal power flow.

A E 862 – Distributed Energy Engineering and Management (3cr). Smart Grid Principles, Market and Economic Aspects, Distributed Systems, Metering and Security, Grid Integration for Renewables, CHP Strategies, Transport System Integration.

Students may also choose 6 credits from the following courses:

A E 868 – Advanced Solar Electric Systems (3cr). Market and Feasibility, Systems Design, Technologies, Codes and Safety, Interconnection, Economic Analysis, Systems Integration, Project Construction and Commissioning (Also available through World Campus)

A E 878 – Solar Project Development (3cr). Project Processes, LCC Analysis, Cost Accounting, Policy Impacts, Solar Supply Chain, Financial Analysis, Cross-Systems Integration, Project Marketing, Innovations and Emerging Technologies (Available through World Campus)

AERSP 886 Engineering of Wind Project Development (3) An overview of the wind project development process and technical considerations for onshore and offshore applications. (Available through World Campus)

CSE 543 Computer Security (3cr). Specification and design of secure systems; security models, architectural issues, verification and validation, and applications in secure database management systems

INFSY 563 Network Security. (3cr) – Fundamentals of Information Science). Contemporary security issues; security management processes, architecture and models; risk analysis and management; security planning, analysis and safeguards; security policies development and administration; contingency planning, incidence handling and response; and security standards and certification processes

3.3 ENERGY STORAGE AND MICROGRID CREDENTIAL DESIGN

The challenges faced in the design and construction of the GridSTAR Center, coupled with increasingly expanding microgrid and energy storage project has also created the need to develop new workforce training programs. The purpose of this specific effort is to create an education and training program (and credential) that will help prepare electrical workers for the safe and effective assembly, commissioning, maintenance and retrofitting of energy storage and microgrid systems. This Energy Storage and Microgrid Training and Certification (ESAM-TAC) effort is pursued in a way that leverages expertise in the manufacturing, construction, and energy sectors which are participating in the design and construction of residential, commercial, and utility scale energy storage and microgrid systems. In doing so, this project will help advance the growing potential of energy storage systems by contributing to the growth of the high quality workforce needed to build an efficient and resilient electric grid and at the same time, support the deep penetration of renewable energy in the marketplace.

3.3.1 Why is ESAM-TAC Needed?

ESAM-TAC was created in response to a central belief that the economic and physical conditions that will drive the energy storage and microgrid market are in place and will rapidly expand in both domestic and global markets. This pending growth will require a significant expansion of electrical contractors and electricians who have the expertise in microgrid and energy storage systems. Industry expansion is creating a significant demand to develop and offer that technology specific education and training to electrical storage industry workers. As such, ESAM-TAC is not a response to today's workforce need, but rather the much larger workforce we will soon need – the workforce that will play a major role in the development of an efficient and reliable electrical grid that embraces and facilitates the deep penetration of distributed and renewable energy generation.

3.3.2 Philosophies Guiding Credential and Curriculum Design

The following philosophies reflect the shared understanding of the various stakeholders in the EMS industry including financial institutions, manufacturers, facility owners, insurance professionals, policy makers, instructional designers, and education and workforce development professionals.

1) The credential will support industry growth and cultivation of talent: A key guiding philosophy of this project is that the education and training program conceived for the ESAM-TAC will build potential to attract, retain, and propel high quality electrical industry workers into the workforce and support their advancement. This outcome will be achieved by building skills and cultivating qualifications needed across multiple sectors in which energy storage systems are increasingly deployed including residential settings, commercial buildings and facilities, community energy solutions, utility scale grid systems, and the automotive industry.
2) The credential design needs to be rigorous: To ensure the credential is respected by training, manufacturing, and policy makers, it will need to be developed and maintained in a manner that reflects recognized practices for Job Task Analysis (JTA) and Developing a Curriculum (DACUM) and will ultimately require certification by a third party process such as the standards defined by EPRI.
3) The credential needs to be obtainable if it is to become recognized and contribute value to the ESM industry. To limit the level of specialty training designed for the credential, a significant level of prerequisite knowledge of electrical work is required to achieve the credential.
4) The need for and design of credential is driven by nuances of ESM systems: ESAM-TAC credential is believed to be vital to the safe and productive assembly, commissioning, operation, and maintenance of microgrid and energy storage systems based on the following nuances of this form of work:
    a) ESM systems are often added to existing energy infrastructure and require work in and around existing equipment and systems of variable age and condition – capability to recognize hazards and design safe procedures for project-specific condition must be emphasized.

b) ESM systems consist of a wide variety of components with unique characteristics and handling requirements. Basic knowledge of the most common system components and respective electrical characteristics is needed to support interaction with application engineers and manufacturers' representatives.
c) Energy storage systems are evolving rapidly and have unique requirements for safe handling and assembly coupled with unique hazards based on chemical properties, thermal management requirements, ventilation requirements, and safe operating conditions. Capabilities are needed to recognize and manage the unique hazards and requirements of energy storage systems.
d) ESM systems include distributed generation and energy storage capabilities that can create conditions in which systems are energized in multiple conditions and on both the grid and downstream side of components. Capabilities to recognize system conditions (islanding) switching conditions and capabilities, and isolation of components are needed.
e) ESM systems are increasingly viewed as capable of providing resiliency to disruptive events such as loss of utility and variable power quality and loading conditions. Capabilities for testing of systems in variable operational modes, and the assessment of post-event condition of systems are required.
f) Two distinctive roles exist in ESM-Construction – (1) the assembly and interconnection of components based on approved permit drawings and safe work practices, and (2) the highly variable and technology specific activities required to commission, operate, troubleshoot, and maintain ESM systems. The design of the credential needs to account for these variable roles.

3.3.3 Guiding Principles

The following set of principles has been developed by the project team and will be utilized to guide decisions pertaining to the project concepts, strategies, and design.

- Place utmost priority upon the safety of the workforce and first responders as well as the protection of mission critical assets to reduce the risk of investments in ESM systems
- Seek to enhance existing education and training programs at community colleges and electrical industry training programs
- Focus on key attributes unique to grid-interactive ESM systems that will be necessary for electrical workers, electrical systems managers, and first responders.
- Align with competency-based and blended learning environments that respond and appeal to next generation learners as well as the use of educational technology in electrical education and training programs.
- Portability and scalability of curriculum will be pursued to support adoption in electrical industry training centers that work with the Electrical Training Alliance, colleges, and universities.
- Aligned with emerging standards under development by the National Electrical Industry Standards (NEIS) organization, and the National Energy Manufacturing Association

3.3.4 Approach

The approach planned for this project will be to convene subject matter experts and experienced designers and builders of next generation ESM systems to define knowledge, skills, and key competencies required to assemble, commission, maintain and retrofit grid interactive ESM systems. Tasks for the credential will be defined by experts in the ESM industry, and verified through the observation of actual ESM construction on select case study projects. The knowledge, skills, and competencies for each task will then be defined with corresponding testing and skills demonstration requirements for each. Curriculum and online learning modules will be designed, including simulation tools and active learning exercises that address the gaps in existing education and training programs. These tools will then be evaluated for effectiveness in classroom and online learning settings including the trial offering of a train-the-trainer workshop in which participants who are likely adopters of the materials are provided opportunities to experiment and provide feedback.

3.3.5 Program Design

The Energy Storage and Microgrid Training and Certification includes a two-part course and credential concept. Part A focuses on a component-level understanding of ESM systems and the development of knowledge of ESM components and construction skills. An emphasis is placed safe working practices and the assembly of energy storage systems. Part B focuses on a systems-level understanding of ESM systems and the processes and skills required to support the commissioning, operation, and maintenance (C-O&M) of ESM systems. An emphasis is places on the electrical skills and safety competencies needed to support the safe execution of C-O&M activities in a way that likely includes working with factory technicians and applications engineers that do not possess the ESAM-TAC credential. Due to the specialty nature of ESM construction, and the variety of hazards and risk associated with this work, it is expected that participants in this program have significant prerequisite knowledge and the skill levels of a typical journeyman-level electrician.

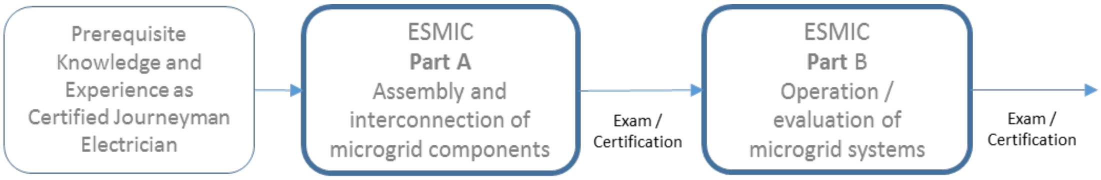

Figure 5: Energy Storage and Microgrid Installation Certification Program Design Concept

Part A: Energy Storage and Microgrid Systems Construction Certification

Description: This credential is designed to recognize knowledge and skills required for the safe and productive assembly of micro grid systems with an emphasis on the construction of large stationary battery systems. The training and certification process is designed to build upon a robust background in electrical construction including knowledge of safety codes and standards. A significant emphasis is placed on the knowledge of micro grid system components and attributes related to safe assembly and handling, and the interconnection of micro grid system components. The laboratory portion of this certification focuses on the handling and assembly of battery cells, assembly of strings in open and cabinet conditions, and the steps required to energy and de-energy strings of cells in support of safe assembly and cell removal/replacement.

Part B: Energy Storage and Microgrid Commissioning, Operations, and Maintenance

Description: This advanced credential will build upon Part A and will focus on the development of systems-based competencies of energy storage, photovoltaic, and microgrid systems and the knowledge and skills that will enable the recipient to support the commissioning, operation, maintenance, troubleshooting, upgrading, and replacement of microgrid components and systems. This credential is intended to prepare the recipient for roles including: (1) supporting functions required to interface and coordinate with component systems and respective manufacturing and application engineering professionals; (2) performing tasks associated with regular testing, maintenance of energy storage and PV systems; and (3) maintaining documentation and communications related to operations and servicing of microgrid systems. Prerequisites for Part B will include Part A as well as experience working with customer relations and servicing of occupied and/or operational facilities.

4. CONCLUSION

This paper summarized the results of a multi-year effort to respond to the challenges and opportunities represented by grid modernization and microgrid development. A unique approach to develop a multi-purpose living laboratory is described in which diverse elements of microgrid systems are established and operated in a manner that directly informs and supports professional education and workforce training. This experience has driven the development of new programs targeting undergraduate, graduate, and workforce needs. The value of the living laboratory approach to supporting microgrid construction education is increasingly evident through the design and piloting of each of these efforts.

5. ACKNOWLEDGEMENTS

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