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Workforce development to meet global demand for microgrids

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ABSTRACT
Microgrids are scaling to meet the growing need for resilient energy, but the workforce to support this growth remains insufficient. This paper opens with a Training Needs Analysis framework that defines key roles and skill areas within the sector. It uses Knowles' adult learning principles to design training that meets the self-directed and experience-based preferences of professionals. A unified microgrid development process is introduced to build foundational knowledge and create a shared framework that supports collaboration across disciplines. Training pathways are identified for microgrid managers, designers, operators, and technicians, with role optimizations informed by delivery to over 3000 learners through more than 100 programs. The paper concludes with best practices to guide the development of training programs that can keep pace with the evolving landscape of microgrid technology, policy, and business models.

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Microgrids; microgrid design; microgrid development; training; workforce development; adult learning principles

1. Introduction

Grid-connected microgrids and off-grid mini-grids are increasingly prevalent solutions that provide energy resilience, access, security, and reduced costs around the globe. The global microgrid market is expected to grow by a factor of 2–3 between 2025 and 2030 (Fortune Business Insights, 2025; Grand View Research, 2023; MarketsandMarketsâ„¢, 2025), and looking just to the United States, microgrid capacity is slated to grow by approximately 3.5 times from 2020 to 2030 (Guidehouse, 2021). This rapid increase in microgrid demand is creating a complimentary demand for skilled workers in microgrid specialties including design, integration, operations, controls, security, and maintenance, which in total amounts to 496,700 new jobs across the US over the next decade according to figures by Guidehouse (Guidehouse, 2021). Emerging markets and developing countries also have a high demand for microgrids, either for grid-connected areas with unreliable power or for off-grid electrification (Greentech Media, 2024; United Nations, 2025). An estimated 220,000 off-grid microgrids are needed by 2030 to achieve universal energy access (World Bank, 2025), and the current deployment trajectory is too slow with an outlook of powering just 80 million of

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the 750 million without electricity (Blodgett et al., 2017; International Energy Agency, 2024). Addressing this gap will require scaling and training the workforce.

The microgrid sector is also still developing common terminology, standards, regulation, training and credentialing, and other characteristics of becoming a distinct profession. Job titles specific to microgrids exist, but are not common, and those that do exist often lack clarity around job qualifications, differentiation of responsibilities relative to other positions, and credentialing or certification requirements. This lack of standardization makes it difficult to identify target audiences and training needs due to unclear job title, professional preparation, and responsibilities. Furthermore, technical barriers such as regulatory compliance, economic modeling, stakeholder engagement, and cross-sector coordination can be significant roadblocks for microgrid adoption. This challenge is compounded when noting that fundamental microgrid standards are still in development (IEEE, 2017, 2018a, 2018b; NAVFAC, 2016; Rebollal et al., 2021). Consequently, limited academic literature exists on structured workforce development models for this sector.

Our work here helps address this challenge by:

- Discussing the unique skill and knowledge transfer pathways required for adult learners in the microgrid sector and applying theoretical frameworks including Bloom's taxonomy of cognitive learning, Knowles' principles of andragogy, Kolb's experiential learning model, and the TNA framework to align learning design with learner experience, motivation, and role-specific competencies (Section 2),
- Completing a review of third-party microgrid training programs to look for similarities, uniqueness, and gaps for training needs (Section 3),
- Developing and conducting our own microgrid training programs using principles from andragogy and experiential learning to meet growing workforce needs, and employing continuous feedback and innovation to create standardized processes, knowledge sets, skills, and delivery formats (Section 3),
- Creating a generalized microgrid development process that serves as a backbone and foundation of knowledge development for any audience (Section 4),
- Developing training content that packages into larger programs to meet needs of unique job roles in the microgrid profession (Section 5),
- Identifying best practices for creating and delivering microgrid training that advances with the increasing pace of change in microgrid technology, business models, and policy (Section 6).

This work provides a common design paradigm to permit stakeholders with different project roles and career tracks to share knowledge and work collaboratively towards a common vision. Drawing on Knowles' andragogical principles, Kolb's experiential learning model, and the TNA framework, the training approach enhances communication and professional development through pathways crafted for adult learners and provides a structured framework for improved learning, adaptation, and advancement of the profession. A collection of market research, trainee interviews, and our training experiences is reflected from over 100 training events delivered for more than 3000 people between 2016 and 2024 at Arizona State University (ASU). All interview and survey protocols were reviewed and approved by the Institutional Review Board at Arizona State University.

2. Theoretical foundations

The development and delivery of microgrid training programs were informed by established learning and instructional design frameworks. This study draws on six key models: the Training Needs Analysis (TNA) framework, Kolb's experiential learning cycle, Bloom's taxonomy of cognitive learning, Knowles' andragogy, Legitimate Peripheral Participation (LPP), and Social Constructivism theories. Together, these theories and frameworks support the creation of structured, role-specific training that aligns with learner needs, professional contexts, and evolving technical demands in the microgrid sector.

The TNA framework serves as the foundation for identifying gaps in skills, knowledge, and competencies across job roles. This model systematically evaluates needs at the organizational, task, and individual levels (Iqbal & Khan, 2011). Findings from using the TNA have been synthesized in Table 1 to create a structured competency framework that identifies the targeted technical skills and professional dispositions required for success in the microgrid workforce. This framework centers on the four roles identified as Manager, Designer, Operator, and Technician, and continues to reflect both the curriculum's focus areas and broader industry relevance. Table 1 is adapted from internal TNA findings (ASU, 2016–2024) and educational frameworks by Knowles, Kolb, and Bloom (Bloom et al., 1956; Knowles et al., 2015; Kolb, 1984).

Stakeholder feedback captured during the TNA, practical task analysis embedded in the training design, and national energy workforce reports informed the competencies

Table 1. Competency profile for microgrid career specializations.

Career Track	Key Technical Skills	Professional Dispositions	Learning Strategies
Manager	Project coordination and scheduling; Workflow integration; Resource allocation across disciplines	Systems thinking; Strategic decision-making; Collaborative leadership	Case-based learning; Peer collaboration and planning exercises; Evaluating and Creating levels of Bloom's taxonomy; Reflective journaling (Kolb: Reflective Observation)
Designer	Sizing and modeling of systems; Software-based simulation; Interconnection & code compliance; Financial analysis of project scenarios	Detail-oriented problem solving; Cross-functional collaboration; Innovative thinking	Technical software labs; Iterative system design projects (Kolb: Active Experimentation); Vendor interactions and site walk-throughs; Analyzing to Creating in Bloom's taxonomy
Operator	SCADA interface management; Real-time monitoring & fault detection; Load balancing; Basic diagnostics	Adaptability under pressure; Situational awareness; Clear communication	Role-playing simulations; System interface walkthroughs; Scenario-based decision-making drills; Applying and Analyzing levels of Bloom's taxonomy
Technician	Equipment installation & setup; System commissioning; Routine maintenance; Field troubleshooting & safety protocols	Responsiveness and accountability; Commitment to safety; Collaboration with operators and engineers	On-site hardware tasks (Kolb: Concrete Experience); Mobile training platforms; Group troubleshooting; Maintenance record analysis; Understanding to Applying in Bloom's taxonomy

throughout content development, delivery, and iteration. The U.S. Department of Energy's U.S. Energy and Employment (U.S. Department of Energy, 2023) and NREL's National Wind Energy Workforce Assessment: Challenges, Opportunities, and Future Needs (McDowell et al., 2024) both emphasize the growing need for roles capable of managing integration, diagnostics, controls, and cross-functional communication which are core to the microgrid environment. Likewise, workforce development research highlights the value of transferable dispositions such as adaptability, systems thinking, and collaborative problem-solving across technical pathways (Carnevale et al., 2013).

The competency framework maps critical job capabilities to the training curriculum, showing how specific modules target workforce gaps. This synthesis enhances the practical value of the manuscript and provides reviewers with a clear, evidence-based rationale for how the training pathways meet sector-specific needs.

In our work, the TNA process supports both the review of third-party training offerings and the customization of ASU's microgrid programs (Section 3). For instance, the needs assessment revealed that most external programs lacked systems-level integration, leading to our development of standardized microgrid development process (Section 4). The assessment also found little progress to formally identify skillsets within the sector. Entities that are common players within the industry such as the US Department of Labor does not have O*NET definition of the required skills for microgrid workers (U.S. Department of Labor, 2023), and IEEE, stated that 'The competency and abilities needed to meet future demands in the energy sector will be more sophisticated, complex, diverse and interdependent. . . . The complete skillset required will be clarified, as industry comes to understand the needs' (IEEE-USA Energy Policy Committee, 2018). Therefore role-specific content pathways for managers, designers, operators, and technicians were identified and defined. (Section 5). Complementing this approach is Knowles' andragogy, which emphasizes adult learners' need for self-direction, relevance, and immediate application (Knowles et al., 2015). Many trainees enter with prior experience in fields such as energy, construction, or facilities management. Training formats – such as modular tracks, case-based exercises, and flexible pacing reflect the andragogical principle that adults learn best when the material connects directly to their professional responsibilities.

Kolb's experiential learning theory provides further structure by emphasizing learning as a cyclical process involving concrete experience, reflection, conceptualization, and active experimentation (Kolb, 1984). This cycle is clearly evident in hands-on components such as interactive microgrid testbeds, commissioning simulations, and operator troubleshooting labs (Section 6). Participants are not only exposed to real hardware and situational scenarios but are also guided through structured reflection and group debriefs to internalize what they've learned and test it in new contexts. Finally, Bloom's taxonomy helps scaffold learning objectives and assessments to ensure learners move from foundational understanding to higher-order application and analysis (Bloom et al., 1956). Training modules are mapped to Bloom's six cognitive levels starting with remembering and understanding (e.g. defining microgrid configurations) and onto applying, analyzing, evaluating, and creating (e.g. designing and optimizing microgrid systems for specific use cases). Knowledge checks, post-course assessments, and project-based tasks are designed to measure retention and the learner's ability to apply knowledge in complex, real-world settings.

These frameworks and theories suited for microgrid professional development are additionally rooted in widely accepted theoretical constructs including LPP and Social Constructivism. LPP, a concept introduced by Jean Lave and Etienne Wenger, emphasizes that the most effective way to learn about a profession is through active engagement in its real-world practices. This involves carrying out authentic professional tasks, even if at a lower level, and gradually increasing responsibility over time. Learners start on the periphery, performing simpler tasks while gaining exposure to the broader scope of the profession. Learning happens in collaboration with a diverse group of people such as experienced practitioners, peers, and others with adjacent expertise who share their insights and experiences. Importantly, those teachings are embedded in the profession themselves, making the learning deeply contextual and practical. LPP highlights the idea that learning is a social process, best achieved by participating in a community of practice where newcomers develop their skills and understanding through shared activity (Lave & Wenger, 2001). Additionally, Social Constructivism is based on constructivist theory in which reality is understood as being actively created and constructed through human experience and interaction. In the same way, knowledge is not passively absorbed but is built through engagement with the world and with others. Because of this, learning is most effective as a social process in which learners collaboratively engage in meaning-making. When a group of individuals comes together to explore a topic, either through a structured learning activity or a more informal approach, they co-construct understanding by drawing from their diverse perspectives, experiences, and interpretations. This collaborative process reflects the core principles of constructivism and emphasizes that knowledge is shaped through active participation and social interaction (Adams, 2006; Kim, 2001).

The integration of these three frameworks and three foundational learning theories ensures that training programs are evidence-based, adaptable, and responsive to the professional learner and industry needs. This approach supports the development of a competent, future-ready workforce to meet the growing global demand for microgrids.

3. Training courses and programs

Third-party training courses and programs are first summarized and compared, then a description of ASU training courses and programs follows with complementary statistics and descriptions provided.

3.1. Third-party training courses and programs

Existing third-party microgrid education and training programs can be summarized into three categories: academic credit-bearing, professional credentialing, and continuing education. These courses include components of microgrid education such as distributed energy resources (DERs), resilience, energy economics, and grid connection, but are often missing systems-level integration, cybersecurity, business model concepts and project financing, and operation and maintenance (O&M) models required for microgrid projects to meet performance expectations.

A total of 26 courses and programs were reviewed as of 2024, of which 20 courses were offered by unique providers and the remaining 6 offered by the same entity. Of the 26

Table 2. Topics of microgrid courses from third party.

Topic	Percentage
Microgrid concepts, configurations, and definitions	77% (20/26)
Challenges to microgrid implementation	8% (2/26)
Microgrid design considerations	46% (12/26)
Business models	23% (6/26)
Integration and implementation	38% (10/26)
Microgrid control and operation	46% (12/26)
Component-specific topics (solar, wind, energy storage)	38% (10/26)
Software-specific topics	15% (4/26)

courses, 45% offered by these entities were industry or consulting firms, 35% were academic institutions, and 20% were non-profits or government organizations. Tables 2 and 3 define the topics and formats offered in the 26 reviewed courses, and detailed information supporting these tables is given in Table A1. Courses introducing relevant software tools, component-specific topics (solar, wind, energy storage, etc.), and smart grids were included in the review, but courses on a single component (e.g. switchgear) or job specialty (e.g. solar installers) were excluded.

Topics in these courses varied in discipline and complexity. Common topics were collected and summarized in Table 2 based on the learning objectives and descriptions accessed through program web pages. No course covered all topics, and no single topic was covered by all courses. The most common topics were introductory content including microgrid concepts, configurations, and definitions, followed by microgrid control and operation, and then microgrid design considerations. Training organizations commonly include introductory topics plus 1–2 more job-specific topics per course delivered to a targeted audience. These courses provide value by offering specific content that directly supports professional development in a defined topic area, such as how to size the battery system based on the size of the solar photovoltaic (PV) array or how to size conductors in microgrid networks (Arguello et al., 2015; Eddy et al., 2017; Moncecchi et al., 2020). A few resources support all aspects of microgrid design but expect the learner to have in-depth prior knowledge of microgrids or power systems (Joos & Farhangi, 2019). Another challenge is that a person seeking a comprehensive skill set may attempt to take all training from a single provider, which then leads to unnecessary duplication of some content while missing certain critical content that simply is not provided by that instructional institution. A person can seek training from multiple institutions to fill gaps but this is difficult when organizations don't map their content or skills to a standardized framework.

Live training formats were more common (58%) than their asynchronous counterparts, and virtual formats (68%) were more common than in-person[1] formats and hybrid[2]

Table 3. Training formats of microgrid courses from third party.

Topic	Percentage
In-person1	4% (1/26)
Asynchronous Virtual2	35% (9/26)
Live Virtual3	31% (8/26)
Hybrid4	27% (7/26)
None Specified	4% (1/26)

formats where the courses had both in-person and virtual components, as shown in Table 3. Asynchronous virtual[3] courses had content placed online in the form of videos and/or educational text, sometimes complemented by downloadable readings, and users could progress through content at their own pace without a restricted timeline of completion. Asynchronous virtual courses can include some instructor facilitation or office hours, but of the reviewed courses most of the reviewed courses did not. Such courses provide several advantages including the ability to create self-contained training content that requires minimal to no additional human resources to deliver, and the content can be accessed immediately by any number of learners on their own schedule. Similarly, live virtual[4] training can reach many learners by avoiding the logistical limitations of travel and site hosting needs of a traditional in-person classroom setting. Live training provides real-time interaction between instructors and learners, which is helpful for learners to explore newer and evolving concepts within the microgrid professions. Moreover, virtual training can reach a wider audience of learners from anywhere in the world and is expected to have grown in prevalence because of the recent COVID-19 pandemic. While virtual learning formats have logistical advantages for both learners and content-delivering organizations, some topics may not be applicable for virtual environments, such as integration, commissioning, testing, operations, and maintenance that benefit from hands-on practice to gain skills and evaluate competency.

Of the 26 courses, 13 (50%) provide certificates of completion or achievement, some offer professional credentialing (11%), continuing education units (CEU) (15%), or academic credit (8%), and many did not advertise credentialing of any kind (27%). The higher number of certificates of completion could indicate that credentialing options do not exist for these topics, or that employers do not require credentialing for these roles. Further definition of job roles and skills can promote the formalization of career pathways and associated training to support advancement of the microgrid profession.

3.2. ASU training courses and programs

The Laboratory for Energy And Power Solutions (LEAPS) at ASU has provided more than 100 training courses and programs to over 3000 individuals on microgrid project development. These courses were developed, iterated on, and formalized between 2016 and 2024 to create a core set of foundational knowledge for the microgrid development process. The process that went into designing these courses had a cyclical effect on the creation of the microgrid development process and iteration of the trainings, providing a synergetic effect on both. These programs sought to fill the gaps of existing third-party microgrid trainings, such as a lack in structured progression, job-specific content, hands-on practice, and flexible delivery formats. By doing so, the training programs aim to be a reflection of current market needs. Training programs were designed based on principles of experiential and active learning, which suggest that hands-on, problem-based approaches enhance skill acquisition and retention, especially for technical occupations (Kolb, 1984). Applications and skills development tailored to the microgrid sector and job roles were presented and delivered in flexible formats for each audience need. Training deliveries were also tailored to meet unique needs of each audience by updating design goals, standards, project examples, financing mechanisms, ownership and operation requirements, and other considerations for specific microgrid market segments (e.g.

data centers, military bases, real estate developments, hospitals and critical public services, islands, off-grid communities, and more). Each course delivery included program assessments and trainee evaluations, formulated using the TNA framework, on general content, career-specific content, market segment-specific content, and delivery format. Example training programs are summarized and discussed in this section, with forthcoming sections describing outcomes of these programs to generate a common set of job roles, corresponding knowledge and skills, training delivery approaches, and best practices.

All training courses included a survey before and after the course to evaluate training content and delivery, and a knowledge assessment before and after the course to evaluate learner skill gain and knowledge transfer. Feedback received from participants was reviewed and training content and format updated accordingly. This created a continuous feedback and revision cycle to advance the quality and content to match the pace of technology change and job needs.

Training participants received a certification of completion and were given the option of obtaining CEUs. None of the training programs were given for academic credit and instead focused on industry-level workforce development and job requirements.

A detailed summary of LEAPS microgrid training courses is given in Table A2 and Table A3. Table 4 summarizes these programs. All programs include sessions on foundational microgrid concepts to level-set knowledge and terminology across diverse audiences, reflecting the remembering and understanding stages of Bloom's taxonomy. Remaining topics are selected and emphasized based on job roles (e.g. designers, operators), ensuring alignment with the specific skills and knowledge required for each specialization. Consistent with Knowles' principles of andragogy, semi-tailored trainings offer participants the flexibility to select learning paths that match their professional background, motivation, and immediate application needs. Program activities also incorporate elements of Kolb's experiential learning cycle by combining conceptual instruction with interactive, real-world applications to reinforce learning through experience and reflection.

Table 4. Topics of microgrid courses from LEAPS.

Topic	Percentage
Microgrid concepts, configurations, and definitions	100% (8/8)
Challenges to microgrid implementation	100% (8/8)
Microgrid design considerations	87.5% (7/8)
Business models	50% (4/8)
Integration and implementation	87.5% (7/8)
Microgrid control and operation	75% (6/8)
Component-specific topics (solar, wind, energy storage)	75% (6/8)
Software-specific topics	50% (4/8)

Table 5. Training formats of microgrid courses from LEAPS.

Topic	Percentage
In-person	50% (4/8)
Asynchronous Virtual	12.5% (1/8)
Live Virtual	12.5% (1/8)
Hybrid	25% (2/8)

Training courses are most commonly delivered in an in-person format, as shown in Table 5, reflecting the importance of experiential learning in building technical competencies. In-person sessions are particularly effective for hands-on activities aligned with Kolb's experiential learning cycle and applied here for during training for microgrid integration, commissioning, testing, safety, and operations and maintenance. These sessions support the applying and analyzing levels of Bloom's taxonomy by allowing learners to practice skills in real-world contexts. Consistent with Knowles' emphasis on the value of practical experience for adult learners, in-person delivery also enables greater learner engagement and retention. Training is conducted at ASU, off-site host locations, or through mobile platforms designed to increase access for distributed learners while maintaining the integrity of experiential instruction.

These trainings led to the development of a standardized microgrid development process, primary microgrid career tracks and their requisite training, and best practices for effective training in the microgrid sector. The next sections go into these in detail.

4. Microgrid development process

Here, we introduce a comprehensive generalized framework for microgrid development, applicable and adaptable to any microgrid project and complemented by targeted training for various job categories within the profession. The microgrid development process described in Figure 1 consists of seven steps, with complementing information in Table 6 defining inputs and outputs for each step. The development process can be used end-to-end as a workflow tracker for project managers and executives, with each step going into greater technical, financial, or regulatory depth for experts in those fields. The generalized microgrid development process also provides a common set of terminology and interfaces to improve communication and coordination within the emerging microgrid profession. This permits each job specialization to better assess the responsibilities of their own role, define and adapt them based on their specific contextual requirements, and determine how they need to collaborate with other entities towards successful project realization.

4.1. Goal setting

This step initiates microgrid development through goal setting, potentially co-created with multiple stakeholders, and gathers information on major needs and constraints that

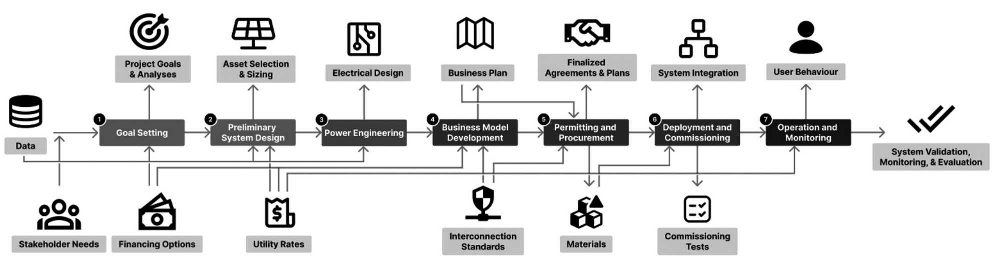

Figure 1. Microgrid development process.

Table 6. Microgrid development process with details on steps, inputs, outputs, and primary stakeholders.

Design Process Step	Inputs	Outputs	Primary Stakeholders
Goal Setting	Existing electrical network information	Project goals	Microgrid owner
	Project financing options	Load data analysis	Beneficiaries
	Load data	Initial understanding of feasibility due to policy or ownership limitations	Developer
	Natural resource data		Utility
	Policy and regulation		
	Stakeholder objectives and constraints		
Preliminary System Design	Load data	Asset selection and sizing	Microgrid owner
	Natural resource data	Asset dispatch routine	Developer
	Technical asset data	Financial estimate	
	Project goals	Environment impact assessment	
	Rate structure data		
	Emission requirements		
Power Engineering	Existing electrical network information	Draft one-line and three-line diagrams	Developer
	Asset selection and sizing	Balance of system	Equipment vendors
		Time-series analysis	
		Asset placement	
Business Model Development	Financial incentives	Warranty agreements	Microgrid owner
	Loan options	Maintenance agreements	Developer
	Full bill of materials	Ownership and operation models	Financial partners
		Cashflow models	
Permitting and Procurement	Technical standards	Stamped drawings	Developer
	Interconnection standards	Final one-line and three-line diagrams	Utility
	Interconnection costs	Scheduling and ordering	Regulators
	Land availability	Powerhouse and civil work design	Technology vendors
Deployment and Commissioning	Communication standards	System integration	Developer
	Final one-line and three-line diagrams	Commissioning tests	Utility
	Pass/Fail functionality metrics	Test results	Technology vendors
	Site preparation	Digital and physical security measures	System integrators
		As-built drawings	Inspectors
Operation and Monitoring	Asset dispatch routine	Maintenance plan	Developer
	Performance metrics	Performance reports	Technology vendors
	User behavior	System validation, monitoring, and evaluation	Financial partners
	Emission requirements		

influence the scope and direction of the microgrid project. Such constraints may include land availability or land quality, interconnection policies and processes, ownership allowances, and emissions limitations. Further data should be collected on the existing electrical network and infrastructure, possible financing options, existing critical and non-critical loads, natural resources associated with the site, any policies and regulations that constrain or fix attributes of the microgrid. There are also often limitations of who can own and operate the microgrid, and ownership options often guide the scope of technical design and financial modeling.

Primary stakeholders can vary, but commonly include the microgrid owner, beneficiaries, developer, and the interconnecting utility, with secondary stakeholders including the regulatory authority, technology vendors, and any specialized consultants needed for the project. Goals and uses of the microgrid are typically set by the owner and beneficiaries for a self-funded project, but in projects with a mix of financing and ownership options, a design session or Design Charrette can be used to co-create and establish a set of common goals that represent stakeholder needs and shared value among entities. Some example goals include energy access, increased reliability, lower energy or utility costs, resilience, increased renewables, energy sovereignty (a desire to own and manage one's own power), or other interests. Quantitative and qualitative metrics should be assigned to each goal, along with associated target values for each metric.

4.2. Preliminary system design

The main purpose of this step is to identify the scale and scope of the project in technical and financial terms. This is synonymous with a feasibility study and includes techno-economic analysis to identify optimal asset types and sizes, potentially in multiple configurations or designs, and then ranks these preliminary microgrid designs according to the metrics and targets identified during goal setting. This information is used to guide a 'comparison of alternatives' dialogue to establish project direction before detailed engineering and financial planning occurs. This step requires load data and natural resource data, technical asset data of the desired assets and pre-existing assets, rate structure data for the interconnecting utility, policy and regulatory limits (system size, emissions, etc.), land space limitations, and related data. Primary stakeholders involved in this step include the microgrid user/owner and the developer, with secondary stakeholders including the interconnecting utility and financial sources. Outputs of this step should include the desired assets and sizes, a corresponding asset dispatch on energy supply and use by asset, microgrid capital and operational costs, cost savings, and reliability and resilience targets. A geospatial analysis of the generation facility and distribution network may be created in this step or with Power Engineering.

4.3. Power engineering

This step performs power engineering analysis of the distribution network including details such as single-phase or multi-phase systems, voltage levels, voltage regulation devices, conductor sizing, transformer sizing, switchgear, protection and coordination equipment, and interconnection ratings to maintain voltage quality and current within standard limits. Power flow analysis is conducted under normal and abnormal operating conditions, and transient analysis is used to simulate microgrid transition events. Complementing analyses include short circuit, arc flash, and coordination studies leading to selection of protection devices and other balance-of-system equipment. Primary stakeholders involved in this step are the developer and equipment vendors. This step generates a comprehensive bill of materials that feeds into business model development and identification of long-lead items. Other expected outputs from this step would be professional engineering drawings and documents such as drafted one-line and three-line diagrams, equipment list, asset placement within the microgrid network, and simulated output of microgrid operation under a variety of steady-state and transient conditions.

4.4. Business model development

This step performs a comprehensive analysis of project cash flow, including all costs, revenues, incentives, and project financing needed to create a full business model. The combination of a business model in this step with the technical and siting analyses from prior steps results in a front-end engineering design (FEED) study that is often used for submittals of quotes or bids. Costs are evaluated according to the bill of materials for capital costs, civil works and construction costs, taxes and fees, any environmental study or remediation costs, interconnection costs, project financing costs, and expected O&M. Special attention is given to warranties and organizations responsible for each asset-level and system-level warranty. Revenues may include tariffs applied to tenants of the microgrid, a feed-in tariff for overproduction, renewable credits, or potential revenue from services sold to wholesale markets if allowed. Incentives can be applied to assets (e.g. solar PV subsidies) or broader elements of the full system (e.g. energy efficiency or percent penetration of renewable energy generation). Project financing is tied to the ownership strategy and includes consideration for such factors as the debt-to-equity ratio, cost of debt servicing, desired payback and return on investment periods, loan periods, and other factors. Primary stakeholders in this step include the microgrid owner, developer, and financial partners. Resulting outputs include warranty and maintenance agreements, as well as what ownership, operation, and cash flow models would be best for the end-user(s).

4.5. Permits and procurement

This step consolidates all the necessary documentation and information needed to ensure the microgrid project meets standards for technical, environmental, and legal permitting, and develops a plan and timeline for procurement of all materials. The primary stakeholder in this step is the developer, with support or information provided by the utility, regulators, and technology vendors. Documentation needed for this step includes technical and interconnection standards that will impact or relate to the system and a work plan for how the system will be procured, constructed, and commissioned. Completion of this step will yield finalized stamped drawings, engineering documents with one-line and three-line diagrams, geospatial layout of the system, and a finalized work plan schedule agreed upon by all stakeholders. Equipment procurement can then begin and timelines coordinated across the various contractors, vendors, integrators, and inspection crews for installation and commissioning.

4.6. Deployment and commissioning

The main purpose of this step is to construct the microgrid, verify if the system is operating in accordance with safety expectations, and verify component-level and system-level functionality is meeting performance and operational expectations. Key inputs of this step include communication standards, final one-line and three-line diagrams, system installation steps, test requirements and metrics (used to verify that all assets and operational systems are working as intended), bill of materials, a punch list or check list to verify completion, and any preparation completed of civil works or construction. Component-level tests should include basic operational and safety evaluations for each asset, which may occur on-site or be certified by the vendor from their manufacturing facility. Integration tests evaluate the physical and cyber connections between assets at the system-level and must be completed on-site during deployment and commissioning. Some example standards and tests include IEEE Standard 2030.8 for the Testing of Microgrid Controllers and IEEE Standard 1547 for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces (IEEE, 2017, 2018a).

Commissioning tests then follow to evaluate performance of the microgrid in accordance with steady-state and transition states needed for the project to meet stated goals. Testing also verifies whether the system meets cyber and physical security standards. Failure during any of the testing will result in assessments and troubleshooting until the system meets performance expectations. Primary stakeholders include the developer, utility, technology vendors, system integrators, and inspectors. Outputs of this step include as-built drawings, test results, and digital and physical security measures.

4.7. Operation and monitoring

This step verifies whether the long-term operation of the microgrid meets performance and warranty expectations as contracted. Inputs to this step include the asset dispatch routine, microgrid performance goals, equipment limitations, emissions requirements, user behavior, and cash flow model. Stakeholders including the developer, technology vendors, and financial partners work to establish data needs and procedures to monitor and evaluate system performance. They also identify the appropriate remediation action and/or financial penalty if performance falls below contracted expectations. Key outputs of this step include roles and responsibilities of each entity for ensuring contracted expectations are maintained, with complementing output including a maintenance plan, performance report needs, and a data collection procedure for monitoring and evaluation.

5. Career specialties

Topics summarized in Table 6 encompass many of the necessary skills and knowledge required for microgrid development, yet there is no training effort that categorizes and emphasizes topics for particular career specialties, largely because those titles and roles are still in development. Definition of roles and a subsequent mapping of skills to roles would allow audiences to identify the appropriate professional development pathway to fit their needs. We explored this concept through (a) review of secondary data on microgrid projects and key roles, (b) examination of roles in adjacent or related professions, and (c) collection of primary data from interviews and surveys of microgrid vendors, developers, utilities, policy makers, customers and beneficiaries of microgrids, financing institutions, government and non-governmental organizations, and individuals seeking training for professional growth.

This research led to the development of four generalized microgrid career specialties that require a common set of foundational knowledge in the microgrid profession and advanced knowledge specific to each specialization: manager, designer, operator, and technician. Each specialization is addressed with instructional strategies informed by Kolb's experiential learning model, Knowles' andragogy, and Bloom's taxonomy, ensuring content is role-relevant, experience-based, and built to support cognitive progression from foundational knowledge to applied expertise (Bloom et al., 1956; Knowles et al., 2015; Kolb, 1984). A visual summary of the core and specialized content is given in Figure 2, with subsequent sections going into further detail for each career specialty.

5.1. Manager

The microgrid manager consists of organizational or project management roles that require introductory knowledge of all parts of microgrid development workflow and a detailed understanding of the interfaces between processes, people, and organizations essential to the construction and operation of a microgrid. They must also identify any data requirements, stakeholders, and inter-dependencies, and take action to mitigate risk. This role may take leadership in goal setting and early design iterations with clients and stakeholders. Managers benefit from learning experiences that emphasize conceptual integration and systems thinking – core aspects of the analyzing and evaluating levels of Bloom's taxonomy (Bloom et al., 1956). Content delivery modalities for managers include case study reviews, concept-based lectures, workflow and project management activities, written activities, study tours, and small group discussions.

5.2. Designer

The microgrid designer is a broad term for electrical, mechanical, civil, and system engineers who are responsible for different aspects of microgrid design. This role may lead or support early design iterations and techno-economic analyses, and then apply specialized knowledge for power engineering, equipment specifications, controls and operation, site assessment and civil works, communications, cybersecurity, protection and coordination, and interconnection studies. Instructional strategies for designers are guided by TNA framework findings that highlight the need for both domain-specific knowledge and cross-disciplinary systems thinking that pulls in design requirements from multiple perspectives (Iqbal & Khan, 2011). Designers benefit from training in modeling and simulation to acquire knowledge and skills for system economics, controls planning, power flow, and transition events. Modeling and simulation can be coupled with detailed technical standards and practices to evaluate the impact of design designs. Vendor interaction through guest lectures, interviews, and site visits support Kolb's concrete experience phase and enable higher-order learning outcomes such as design

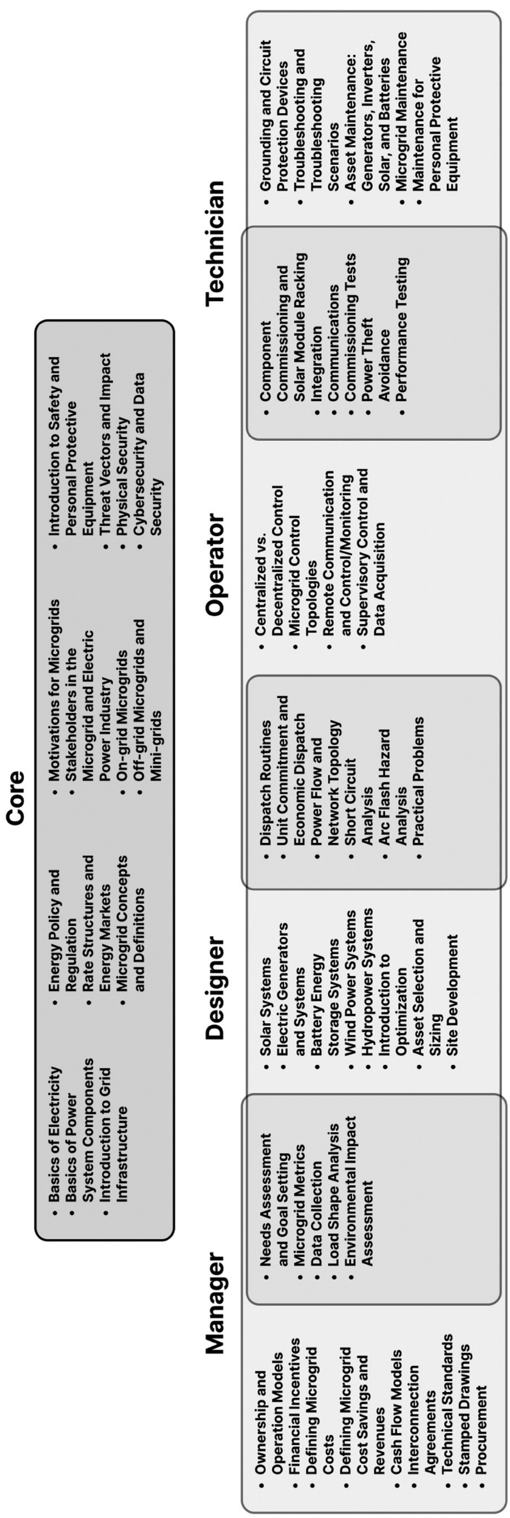

Figure 2. Training topics mapped to microgrid career specialty.

Figure 3. Hands-on practice in commissioning off-grid microgrid.

evaluation and optimization that are aligned with the creating stage of Bloom's taxonomy and can further improve the learner's connection between design and construction (Bloom et al., 1956; Kolb, 1984).

5.3. Operator

The microgrid operator includes personnel who oversee the operation of a completed microgrid system and its components. The training structure for operators reflects Knowles' emphasis on immediate relevance and application, using scenarios grounded in the operational realities learners are likely to encounter. This may include direct hands-on operation or operation through a Supervisory Control and Data Acquisition (SCADA) interface, locally or remotely. Many professionals entering the operator role have experience operating other automated systems – industrial automation, distribution networks, transmission networks, power plants, facilities, campuses, and ships – but may be inexperienced in microgrid controls, operating sequences, and transition events. A mix of SCADA operation and physical operation is valuable to train operators on the uses and limits of supervisory controls for the microgrid and primary controls at the asset level. Simulated operation is invaluable for training personnel in standard operation sequences in accordance with IEEE 2030.8 and can be completed with a generic microgrid design or digital twin of the as-built system (IEEE, 2018a). These methodologies are used to create learning cycles that progress through Kolb's stages – concrete experience, reflective observation, abstract conceptualization, and active experimentation – thereby reinforcing learning through feedback and real-time adjustments (Kolb, 1984).

5.4. Technician

The microgrid technician encompasses all positions involved in integration, commissioning, maintenance, and troubleshooting of a microgrid. Results of the TNA framework evaluation of this role indicate gaps in systems integration, cybersecurity, and utility coordination, which are addressed through scaffolded, hands-on modules (Iqbal & Khan, 2011). Entering professionals often have experience working with generation assets, storage assets, inverters, and medium-voltage systems, but may not have experience with systems-level integration of all microgrid assets, communication, controls, interconnection with the utility, and the safety and performance standards needed to commission a microgrid. The hands-on nature of a technician's role requires experience with safely commissioning and troubleshooting real microgrid systems, and as such, a test bed or other physical setup that safely allows exposure and learning for a variety of microgrid configurations is invaluable to establish foundation knowledge and a complementing set of familiar circumstances the technician can draw upon during their work. Training modules are designed to support technicians in progressing from understanding to applying and analyzing according to Bloom's taxonomy, and rely heavily on experiential tasks that mirror Kolb's model of active experimentation (Kolb, 1984)

6. Best practices and implications

Experience gained through review of third-party trainings and the process for continuous improvement of the ASU trainings in Table 3 led to the development of best practices for training microgrid professionals.

6.1. Provide foundational structure for knowledge that can adapt with a developing profession

The microgrid development process provides a flexible, structured approach that encompasses all major steps and activities for microgrids from concept to construction. Grounding all trainees in a common framework, terminology, and process supports the understanding and applying levels of Bloom's taxonomy, allowing learners to build conceptual clarity before engaging in deeper problem-solving activities. This structure also reflects the gaps identified through application of the TNA framework for consistent knowledge baselines across professional roles and helped define interfaces between steps and people to improve understanding of what's expected holistically in microgrid development while also improving clarity for where each role fits in. The microgrid development process framework from Figure 1 also provides a structure that permits additions and adaptations such as microgrid technology, business models, policies, and standards continue to development.

6.2. Identify specific training content for job specializations

Training content was aligned with job specializations and followed TNA framework principles by aligning role-specific learning objectives with job tasks and organizational goals to ensure trainees acquired knowledge relevant to their roles. This alignment ensures that content is directly relevant and immediately applicable, a key element of Knowles' andragogy, and while this could be considered an obvious best practice, it is less common in emerging professions in which roles, responsibilities, and even basic terminology is still developing. This is an important barrier preventing wider microgrid adoption. The initial training needs assessment and process for continuous improvement clarified the core competencies required for different positions and mapped training content to those career specializations, as shown in Figure 2. These job categories could then also be tailored by market sector or by organization that need certain knowledge and skill sets to meet their different application cases, such as power engineering for medium voltage grid-connected systems compared to power engineering of low voltage off-grid systems.

6.3. Create generalized and specialized content

Microgrid training provided a foundational knowledge base for all trainees and specialized content tailored to specific career tracks (Raffe, 2000). Foundational knowledge helps people in emerging profession develop a common understanding of core concepts such as microgrid fundamentals, technical components, ownership models, financial models, regulatory frameworks, regulation, standards, and operations. Specialized content delves deeper into individual career specialties such as design, integration, operation, and maintenance. Designers may focus on system configuration and optimization, while operators practice with real-time monitoring and control systems including switching events, microgrid transition states, and clearing faults. The resulting training framework provides a blend of academic concepts and vocational application to prepare the learner for continuous learning in the developing profession. This modular design also respects Knowles' principle that adults learn best when they can self-direct and build on existing knowledge and experience.

6.4. Develop stackable learning blocks to promote skills progression

Microgrid training programs can be structured into beginner, intermediate, and advanced levels to cater to the diverse knowledge prerequisites and career aspirations of potential trainees. This practice is rooted in the Bloom's Taxonomy framework by providing a structured progression of learning from novice to expert. The introductory level establishes a foundational understanding for newcomers in the microgrid development process, stakeholders and their roles, microgrid technologies, and an overview of established industry standards. The intermediate level introduces progressively more intricate topics such as system integration, economic analysis frameworks, and regulatory compliance considerations. This level is ideally suited for professionals possessing a baseline understanding who are now seeking to expand their knowledge and skills within the same career specialty. The advanced level caters to professionals seeking to stay updated on new and emerging microgrid topics, and apply that knowledge to projects. A person may be advanced in one career specialization (e.g. designer) and be at the beginner or intermediate level for other specializations. Delineating these distinct learning tiers allows training programs to cater to participants with varying base knowledge, empowering them to acquire the requisite skillsets at any stage of their professional development. Stackable learning blocks also promote options for learners to engage different phases of the microgrid development process without having to start at the beginning (Carberry et al., 2014).

6.5. Promote collaborative learning communities through peer learning and cohorts

Peer learning and cohort-based training models play a vital role in enhancing knowledge and skills development for emerging professions in which information, successes, and challenges are being developed in real-time around the world. Peer learning is an excellent approach to facilitate sharing such information that is not available in any single repository (Polkowski et al., 2020). Such collaborative engagement exposes trainees to unique perspectives and knowledge they may not otherwise have access to in their own organization. Peer learning activities leverage Kolb's reflective observation phase, where learners compare their experiences with others and form generalizations. They also align with Knowles' focus on social relevance and intrinsic motivation in adult education. Additionally, peer learning activities that improve students' critical thinking, learning autonomy, collaborative nature, and communication skills can be easily added to core concepts (Stigmar, 2016). Networking is also common in such settings and provides an opportunity to understand how the job market is developing and changing.

6.6. Enhance impact through semi-tailored training content

Limited standardization in microgrid professions has led to a myriad of titles and roles in the industry, and while efforts such as those described in this paper seek to improve standardization, there will still exist user groups that prefer semi-tailored training content for their target market and employees. This approach provides the same base of foundational knowledge, with adaptations in case studies, technical requirements, permitting, financial models, regulations, and more. For example, designing microgrids for resilience of US federal buildings and energy access for off-grid mining sites share common technical principles but needs differ in application and engineering. Modular course design is used to create semi-tailored content based on participants' learning objectives. These structures permit customization based on the specific background and needs of individual trainees. This semi-tailored content approach enhances training programs' impact and relevance in the microgrid sector. This practice is rooted in social constructivism and centers the training around the needs of the learners first, ensuring the content delivered will meet those needs.

6.7. Provide optional continuing education units

CEUs are necessary to maintain professional licenses for certain occupations, and while the microgrid industry does not have professional licenses, there are a number of related and relevant licenses such as electrician, grid operator, and generator technician and that require regular accrual of CEUs to maintain (IEEE, 2024). Universities and other organizations can offer optional CEUs for working professionals to meet their licensing needs while also advancing microgrid knowledge. Offering CEUs acknowledges the ongoing professional development needs of adult learners and aligns with Knowles' principle of motivation through relevance and external certification. It also supports the TNA approach by ensuring training is linked to industry-recognized requirements. Offering CEUs also highlights those training organizations that keep knowledge up-to-date to benefit professionals who are working to adapt to the changing microgrid profession.

6.8. Provide flexible delivery formats to increase access

Training programs that offer online, in-person, and hybrid models provide learners with options to overcome logistical constraints. These formats also accommodate the self-direction emphasized in andragogy and allow learners to engage content at their own pace and skill level. Virtual self-paced or real-time training became necessary during the COVID-19 pandemic (Che Ahmat et al., 2021). Remote and online learning has remained commonplace for the microgrid profession as workloads are high and in-person training sessions are less common (relative to other trades and professions). Virtual delivery formats can include live webinars, self-paced modules, virtual labs, interactive simulations, and collaborative 'ranges' or 'test beds' where multiple people work on a project or challenge in real-time. In-person training, while acknowledging travel needs, offers significant advantages with hands-on experience with equipment and direct interaction with instructors and peers. In-person experiential learning is particularly effective for practical skills development that requires physical manipulation of equipment, commissioning, and testing of both power systems and cyberphysical layers. Hybrid models combine the strengths of both online and in-person training, reinforcing Kolb's active experimentation and concrete experience stages of learning, offering a balanced approach that promotes concept development through remote participation and skills development through in-person hands-on practice (Development and Learning in Organizations, 2018). This format ensures that learners receive comprehensive training that is both flexible and effective.

6.9. Implement interactive simulations and hands-on learning

Interactive simulations and hands-on content are critical components of effective training programs that emphasize skill building to complement knowledge growth. Simulations and hands-on labs are designed to move learners through Kolb's entire experiential learning cycle and to meet higher-order objectives such as analyzing, evaluating, and creating within Bloom's taxonomy. They also respond to adult learners' preference for practical, problem-based tasks that closely mirror their professional responsibilities. Experiential learning opportunities help participants apply theoretical knowledge to real scenarios. Further, such scenarios can be designed to enhance troubleshooting expertise and help the learner develop approaches to identify problems and create new solutions that do not lock them into scripted approaches to problem solving that may not always work. Simulations of systems and physical equipment offer practical experience that is indispensable for mastering technical skills in integration and operation. Training programs should incorporate activities such as equipment installation, safety checks, troubleshooting, and performance testing to ensure trainees gain confidence and competence in their roles. Some examples are shown in Figure 3, Figure 4 and Figure 5 for off-grid and on-grid microgrids, respectively.

6.10. Develop Mobile hands-on training platforms

Mobile training platforms offer hands-on, experiential learning for dispersed populations, enabling access to training without the need to travel to centralized facilities. These mobile platforms extend experiential learning opportunities to distributed learners, providing concrete experience in contextually relevant environments. They also allow for just-in-time training tailored to TNA framework skill gap findings for specific geographical regions or occupational sectors. Mobile training platforms can be small briefcase-sized kits containing hands-on content, trucks and trailers, or full shipping containers with portable laboratories. Some examples are shown in Figures 6 and 7, with Figure 6 including a WiFi router hacking activity to demonstrate cybersecurity risks that can be shipped in standard mail, and Figure 6 including a mobile 10 kW microgrid for training microgrid integration, operation, maintenance, and troubleshooting, respectively. This practice also supports LPP theory by increasing hands-on training access.

7. Discussion

This article introduced a microgrid development process as a framework with foundational knowledge to address needs of the rapidly growing profession. This seven-step framework includes goal setting, preliminary system design, power engineering, business model development, permitting and procurement, deployment and commissioning, and operation and monitoring. This framework improves communication and coordination among professionals, and helps define each job specialization and collaboration requirements for overall project success.

The microgrid development process was complemented with a Training Needs Analysis (TNA) based needs assessment to characterize the current state of training needed in the microgrid sector, with key roles identified to bring greater clarity to professional specializations and their associated responsibilities. Training content rooted in legitimate peripheral participation and fundamental constructivist andragogy was then introduced for selected specializations including managers, designers, operators, and technicians, with examples and best practices drawn from more than 100 training courses and programs delivered to over 3000 individuals at Arizona State University and with partnering organizations. Training for managers focuses on project coordination and understanding workflow interfaces, designers receive in-depth technical training in various engineering disciplines, operators gain hands-on experience with microgrid systems and SCADA interfaces, and technicians focus on integration, commissioning, maintenance, and troubleshooting of microgrid components. Comprehensive ‘boot camp’ training programs also gave any audience a general exposure to all aspects of microgrid development from original concept to final construction and commissioning.

These trainings and best practices are informed by widely accepted learning models, including the TNA framework, Knowles’ theory of andragogy, Kolb’s experiential learning cycle, and Bloom’s taxonomy of cognitive learning. Together, these models are

Figure 4. Hands-on practice for grid integration tests of microgrid.

Figure 5. Mobile cybersecurity training kit.

underpinned by the principles of Legitimate Peripheral Participation (LPP) and social constructivism, which emphasize the importance of learning through social interaction, shared practice, and progressive engagement in real-world tasks. By integrating these theoretical foundations, the training content and best practices described here are positioned to effectively build both individual competencies and collaborative capacities,

Figure 6. Mobile microgrid training platform.

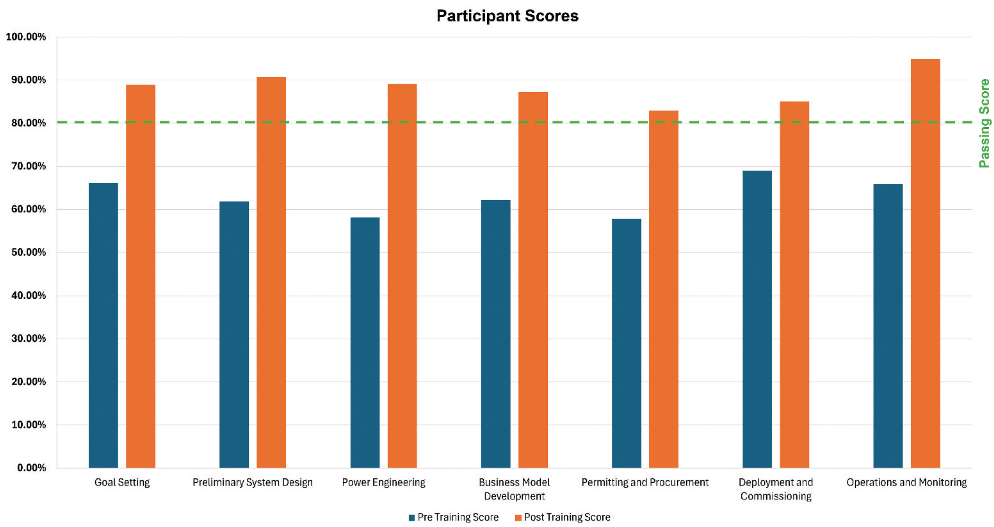

Figure 7. Participant scores from pre test and post test knowledge assessment.

ultimately contributing to the success and sustained expansion of the evolving microgrid workforce.

A knowledge assessment was given both before and after the training to measure attainment by individual learners and to evaluate the effectiveness of the overall training program. Participants were also invited to provide narrative feedback on their training experience; an example of such feedback is presented in Table A4. This feedback enables a direct comparison between participants' perceived performance and their actual performance on the knowledge assessment. Discrepancies between perceived and actual outcomes may highlight further opportunities for instructional improvement, ensuring that participants do not leave the training with misconceptions.

8. Conclusion

The collected work provided a training framework, content, and delivery methods to help address workforce requirements needed to meet the rapidly growing demand for microgrids.

Individual learner attainment and training program evaluations were completed through a combination of quantitative and narrative responses leading to the curation of ten best practices for adult learning in microgrid training: (1) Provide foundational knowledge structure that can adapt with the increasing pace of change in microgrid technology, business models, and policy; (2) Map training content to specific job specializations to ensure trainees gain relevant knowledge and skills; (3) Programs should provide generalized foundational content for everyone to have the same or similar framework for thinking about microgrid development, and then provide specialized content tailored to different career tracks; (4) Deliver training in beginner, intermediate, and advanced levels and use stackable credentials to help accommodate diverse knowledge prerequisites and career aspirations; (5) Implement peer learning and collaboration to enhance knowledge transfer across the rapidly changing sector and distributed knowledge base; (6) Semi-tailored training content improves relevance by addressing specific market needs and case study examples; (7) Optional CEUs support certain professional specializations to maintain relevant licenses; (8) Flexible delivery formats, including online, in-person, and hybrid models, increase accessibility and effectiveness; (9) Interactive simulations and hands-on learning are crucial for mastering skills for operators and technicians, respectively; (10) Mobile hands-on training platforms enhance distributed learning environments.

Notes

1. Training is real-time, and all participants and instructors are in person.
2. Content is given in real time but portions of the training are delivered in person and other portions are delivered through a virtual platform.
3. Training is not real-time and is delivered through a virtual platform.
4. Training is real-time and is delivered through a virtual platform.

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Appendix A

Table A1. Summary of microgrid courses reviewed.

Course Title	Provider	Course Format	Course Topics T1	T2	T3	T4	T5	T6	T7	T8
Microgrid Certification Training (Tonex Training, 2023)	Tonex	Hybrid						✓	✓	
Microgrid Fundamentals Online Training Program (AEE Education [AEE], 2023)	Association of Energy Engineers	Live Virtual	✓							
PVOL303: Solar Training – Advanced PV Multimode and Microgrid Design (Battery-based) (Solar Energy International, 2023a)	Solar Energy International	In-person	✓	✓					✓	
PVOL303: Solar Training – Advanced PV Multimode and Microgrid Design (Battery-based) – Online (Solar Energy International, 2023b)	Solar Energy International	Live Virtual	✓	✓					✓	
Microgrid Design; Economic Optimization and Simulation (UC San Diego Division of Extended Studies [UC], 2023)	UC San Diego	Asynchronous Virtual		✓						✓
Microgrid Design and Implementation (NABCEP, 2023)	Heatspring	Asynchronous Virtual	✓	✓	✓	✓	✓			✓
Energy Storage and Microgrid Training and Certification (ESAMTAC) (ESAMTAC, 2023a)	PennState College of Engineering	None Specified					✓	✓		
Energy Storage and Microgrid Training and Certification (ESAMTAC) (ESAMTAC, 2023b)	ESAMTAC	Asynchronous Virtual					✓	✓	✓	
Microgrids – Understanding and Developing Effective Deployments (EnergyEdge, 2023)	Petroedge	Live Virtual	✓		✓	✓			✓	
Designing and Implementing Microgrids (Clean Energy Academy, 2023)	Clean Energy Academy	Asynchronous Virtual	✓	✓		✓	✓			
Smartgrid; Microgrid and Energy Storage (Udemy, 2023)	Udemy	Asynchronous Virtual	✓						✓	
Foundations of HOMER (HOMER Energy [HOMER], 2023)	HOMER Energy	Live Virtual			✓					✓
Introduction to HOMER (HOMER, 2023)	HOMER Energy	Live Virtual			✓					✓
Microgrid Training Overview (Admin, 2023e)	Eno Wireless	Hybrid	✓				✓	✓		
Microgrid Certification Training (Admin, 2023a)	Eno Wireless	Hybrid	✓					✓	✓	
Microgrid Systems Engineering Training (Admin, 2023c)	Eno Wireless	Hybrid	✓				✓	✓		
Microgrid Training Workshop (Admin, 2023b)	Eno Wireless	Hybrid	✓					✓	✓	
Smart Grid Training (Admin, 2023d)	Eno Wireless	Hybrid	✓			✓	✓			
Solar Energy: Integration of Photovoltaic Systems in Microgrids (edX, 2023b)	EdX; DelftX and Delft University of Technology	Asynchronous Virtual	✓					✓		
Renewable Energy: Sustainable Electricity Supply with Microgrids (FutureLearn, 2023)	Futurelearn; University of Leeds	Asynchronous Virtual	✓		✓		✓			
Foundations of Microgrids (edX, 2023a)	EdX; AlaskaX; University of Alaska Fairbanks	Asynchronous Virtual	✓		✓		✓	✓	✓	
Schneider Electric Microgrid Learning Series (Schneider Electric, 2023)	Schneider	Live Virtual	✓		✓	✓			✓	
Microgrid Essentials (Red Vector, 2023)	Vector Solutions (RedVector)	Asynchronous Virtual	✓							
Fundamentals of Microgrids (Brown, 2023)	EUCI	Live Virtual	✓			✓		✓		
Implementing Microgrids in the Federal Sector Series (2023)	Federal Energy Management Program	Live Virtual	✓		✓		✓			
Electrical, Smart Grid and Micro Grid Technologies Certificate (Santa Fe Community College, 2023)	Santa Fe Community College	Hybrid	✓		✓			✓	✓	

Table A2. Summary of LEAPS microgrid courses reviewed.

		Course Topics							
Course Title	Course Format	T1	T2	T3	T4	T5	T6	T7	T8
Microgrid Design for Resilience	Live Virtual	✓	✓	✓	✓	✓			✓
Microgrid Online Design Course	Asynchronous Virtual	✓	✓	✓					
STEM Microgrid Integration and Testing Training	In-person	✓	✓	✓		✓	✓	✓	
STEM Microgrid Maintenance and Troubleshooting Training	In-person	✓	✓	✓		✓	✓	✓	
Testing and Evaluating Microgrids Training	In-person	✓	✓	✓		✓	✓	✓	
Microgrid Boot Camp	In-person	✓	✓	✓	✓	✓	✓	✓	✓
Advanced Energy System Boot Camp	Hybrid	✓	✓	✓	✓	✓	✓	✓	✓
Ho'ahu Energy Cooperative Molokai Microgrid Training	Hybrid	✓	✓		✓	✓	✓	✓	✓

Table A3. Definition of reviewed courses covering topics.

#	Topic
T1	Microgrid concepts, configurations, and definitions
T2	Challenges to microgrid implementation
T3	Microgrid design considerations
T4	Business models
T5	Integration and implementation
T6	Microgrid control and operation
T7	Component-specific topics (solar, wind, energy storage)
T8	Software-specific topics

Table A4. ASU course participant feedback.

Course Title	Participant Feedback
STEM Microgrid Integration and Testing Training	The Microgrid course from LEAPS allowed me to engage a topic – energy transitions – from a new perspective. I came away from the course more informed and grateful for the opportunity.
STEM Microgrid Integration and Testing Training	This microgrid course deepened my passion for engineering and sustainability, I cannot wait to take what I have learned and apply it after I receive my degree.
STEM Microgrid Maintenance and Troubleshooting	This microgrid presentation/training provided insight into new topics for me that pertain to my major field.
STEM Microgrid Maintenance and Troubleshooting	Learned the operation of a conventional microgrid by isolating each part of the system. Git the exposure to observe the faults and short circuits which improved my practical skills. Overall, it benefited me to learn the core of the grid.
Microgrid Bootcamp	This course gave me significant exposure to the field in such a short period of time, I learned a lot and was pleased with my experience.
Microgrid Bootcamp	An amazing opportunity to see and learn how microgrids can be utilized in a wide array of governmental, industrial, and home applications.
Advanced Energy System Bootcamp	As a beginner in greener energies and micro grid, I was in doing baby steps all over again. But the more I understood the goal from this program and how quickly you understood it, the more confident and prepared I felt to take on this new challenge that our world needs.
Advanced Energy System Bootcamp	Wonderful and informative from no knowledge to being confident in explaining microgrid and its importance to the green thinking that will help our drive to soften the carbon imprint with renewables.
Advanced Energy System Bootcamp	This Fellowship program not only provided me with educational knowledge on Microgrids, but with tools to use for real life application as well. For anyone looking to get an introduction to Microgrids this course is well-rounded and lead by an all-star team.
Ho'ahu Energy Cooperative Molokai Microgrid Training	It was so great working with the ASU team and learning from their lecturers and guest speakers and applying their experience to what we face here on Molokai.
Ho'ahu Energy Cooperative Molokai Microgrid Training	The micro grid training was great because it gave me a bigger picture of why micro grids are so important and how so many people rely on electricity and most people don't understand everything that is involved in providing it. The trip to ASU was amazing and something I will always remember. I was able to make new friends and the food was great. The instructors and guest speakers were well prepared and very professional. I really appreciated the way that they took time to answer our questions and if they didn't have the answers immediately, they made sure that they would find it for you. GREAT JOB GUYS:)
Ho'ahu Energy Cooperative Molokai Microgrid Training	Energized! And appreciative of the ASU team and their unblinking support of our island's efforts to bring this knowledge back home.