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Developing Power Engineering Education and Learning for Next-generation Smart Grid Workforce

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Power Engineering Education and Learning for Next-generation Smart Grid Workforce

Introduction

The electricity grid is one of the largest and most complex machines ever made. It sends energy worth $400 billion annually through seven million miles of transmission and distribution lines in the U.S.[1]. Although the grid has been improved and upgraded over the last decades, blackouts are becoming more frequent throughout the U.S. and worldwide. This extremely large-scale complex system continuously faces new challenges that demand fundamental revolution in physical structure, management policy, and business operation [2]. To address these challenges, emerging electricity supply, delivery technologies, advanced monitoring, control, operation strategies, and regulatory policies are continuously evolving across federal, state, and regional levels. These new practices, intended to provide affordable, reliable, and sustainable electric energy to modern life and commerce, ultimately led to the "Smart" electricity grid. "Smart Grid" is an Electrical Grid with Automation, Communication, and IT systems that can monitor power flows from points of generation to points of consumption and control the power flow to match generation in real-time [3]. With the goal of providing reliable, high-quality electric power to digital societies in an environmentally friendly and sustainable way, the smart grid is regarded as an enabling engine for our economy, environment, and future [2, 4]. However, achieving the goals of Smart Grid is hampered by a growing shortage of qualified electric power and energy engineers. According to Wanda Reder, a former IEEE Power and Energy Society (PES) President, "*The current graduation rate from U.S. university electric power engineering programs is not sufficient to meet our nation's current and future needs*" [5,6]. Not to mention that the development and integration of emerging Smart Grid technologies require entirely new skill sets involving cross-disciplinary areas for meeting the industry demand [7]. Especially that according to the Department of Energy report released earlier this year, the utility industry is facing a vacuum in its middle and top management layers. "A dip in the electricity industry workforce training programs in the 1980s contributed to a current low number of workers in the electric utilities able to move into middle and upper management positions - creating a workforce gap as a large number of baby boomers retire," the report states. A December 2016 report by PA Consulting provided further evidence of the industry's problems. According to the report, a shortfall of 75,000 new workers by 2020. [8]

According to the U.S. Senate Committee on Energy and Natural Resources, 77% of energy companies find it difficult to hire qualified employees, especially since grid technology has started advancing and needs well-qualified engineers [9]. Therefore, students ought to learn about such developments [10].

To develop the skills and traits the industry seeks, academia should formulate a curriculum that best suits the graduate preparing for a career such that the industry can hire knowledgeable smart grid employees. Multiple universities have partnered on a DOE-funded project called Grid-Ready Energy Analytics Training with Data (GREAT with Data) to solve this shortage of qualified workforce. These universities mentioned above that have partnered together consist of the University of California, Riverside (UCR), University of Texas, Austin (UT), Virginia Tech (VT), Stony Brook University (SBU), and Washington State University (WSU). To meet smart grid requirements, these five universities have adapted courses for undergraduate and graduate students in different categories, including machine learning, cyber security, alternative energy resources, and many more [8]. The majority of schools that have a Master's program for power and energy systems, such as the New Jersey Institute of Technology (NJIT), have set the goal of educating the next generation of students that are entering the smart grid workforce [11]. Professional organizations such as IEEE have also developed courses to grant their users emerging smart grid technologies (IEEE 2022) [12]. These courses provide an overview of elements within microgrid designs and provide hands-on applications of power distribution models. Discuss the necessary precautions for cyber security and the microgrid's stability. A few programs and concentrations for undergraduate students, like the University of Maine or Clarkson University [13], offer a concentration in power engineering and smart grid.

This research study aims to serve the national interest of enhancing power engineering education and learning to meet the nation's urgent needs for a highly qualified next-generation Smart Grid workforce.To achieve a remarkable change in power engineering education, the research team adopted the thematic analysis approach[14] to further understand the industry stakeholders' expectations for qualified power engineering graduates in different segments of the industry and to establish a harmony that allows defining a prioritized list of learning objectives that would guide the curriculum design of ECE programs. Hence, asking them directly to understand what the industry needs is better. Faculty and administrators could use this understanding to develop a curriculum best suited to the necessities of the industry.

Therefore, to understand the industrial requirements and needs for technical and professional skills acquired by freshly graduated ECE students, the research team conducted eight interviews with smart grid industrial professionals and obtained six learning objectives.

The interview questions covered key smart grid components, different grid systems (such as battery, distribution, and transmission systems), climate changes, blackout events, project management, and the need for students' hands-on experience before joining the workforce, built upon an extensive literature review. Overall, industrial professionals noted a powerful need for freshly graduated students. However, they argue that students are missing critical skills in the smart grid field, such as hands-on experiences and market knowledge. This work is part of an ongoing effort of a National Science Foundation (NSF) funded study to explore a closed-loop power engineering education and learning approach for meeting the nation's urgent needs for a highly qualified Smart Grid workforce. The research question guiding this study is: ***What skills are required from the ECE graduate students to serve the SG industry better?***

Methods

To create a list of learning objectives that will be the stepping stone for an ECE curriculum to better serve the smart grid industry, the research team conducted a qualitative research study at Rowan University following the below steps. We conducted and analyzed eight interviews to help us better understand and classify the smart grid industry requirements for ECE graduates.

i. Population and Sampling

We contacted eleven industrial professionals who work in different smart grid industries. The ECE department professors of Rowan University were the gatekeepers for these contacts. As the interviewees are Rowan University's industry collaborators. Most interviewees had different roles and rank in the smart grid industry; they hold positions such as power systems engineers, analysts, business customer solutions, technical services, market leads, software engineers, and energy development engineers.

The 11 industrial professionals were contacted via email and were asked to participate in an individual interview via email requests. Eight industrial professionals responded and agreed to the interview request, and three did not respond. The eight participants belong to different industry segments with different roles, including consulting advisors specializing in smart grid market R&D, key market lead, power systems engineers, principal & trading analysts, business Customer solutions directors, senior software engineers, senior energy development engineers, and power system engineers.

ii. Instrument

We developed an interview protocol to deeply probe their perspectives towards some objectives for the smart grid industries. This initial list was based on a review of power engineering academic programs' websites, government agencies' websites, smart grid companies' websites, and journals that address the smart grid industry topics. The interview protocol was created addressing the following list of learning objectives.

1. Battery storage solutions that maximize renewable energy generation and help build a cleaner, more resilient grid [15]
2. Increase power production and distribution technologies towards renewables. [16]
3. Development of faster data processes to increase the efficiency and reliability of the smart grid [17]
4. To upgrade device capabilities to strengthen transmission and distribution systems of the smart grid [18]
5. Increase protection systems to detect or withstand cyber-attacks. [16]
6. Develop advances in measurement technology to accelerate the timing of smart grid responses to increase the system's efficiency, reliability, resiliency, and sustainability. [19]
7. Further development of blackout prevention technologies [20]

iii. Data Collection

After the study was approved by Rowan University Review Board (IRB approval # PRO-2021-487), we contacted by email and scheduled the interview appointments. We shared the interview protocol before the interview. Seven interviews were conducted via Zoom, and one was conducted in person. At least two members of the research team participated in each interview. All interviews took about 45 minutes to 1 hour. All interviews were recorded after taking the interviewee's consent. The interview was fully structured, and the interviewers followed the interview protocol to ensure that all the points were covered.

iv. Analysis

- ***Transcription:*** The eight completed interviews were then transcribed using the online platform “otter” [21]. Then the transcripts were revised by the research team to ensure transcription accuracy.
- ***Coding:*** We adopted the thematic analysis coding approach with the following six-step process [22]:

Familiarization	We started by reading the interviews and familiarizing ourselves with their details. In addition to memoing and writing early insights.
Coding	We started with one interview. We used open coding [22], which means we did not have pre-set codes but developed and modified the codes as we worked through the coding process. This process helped in creating initial ideas. Then each of the team members coded a transcript separately. We worked through each transcript, coding every text segment that seemed relevant to or specifically addressed our research question. When we finished, we compared our codes, discussed them, and modified them before moving on to the rest of the transcripts. We generated new codes and

	modified existing ones as we worked through them. Finally, we created a 16-item codebook
Generating themes	Through thematic analysis and axial coding [23], we classified the codes into multiple categories. For example, we had several codes related to smart grid components and the importance of students practicing in this field. We collated these into an initial theme called the simulation of smart grid components.
Reviewing themes	We read the data associated with each theme and considered whether the data did support it. Next, we ensured the themes worked in the context of the entire data set.
Defining and naming themes	The research team worked on identifying the essence of what each theme is about. Then we created subthemes to interpret every theme further and ensure that every subtheme interacts and relates to the main theme.
Writing up objectives	Finally, by combining the literature review, interview themes, and analysis results, a list of learning objectives was created.

Results and Discussion

As we mentioned earlier, this study focused on creating a list of learning objectives based on the expectations of smart grid industry professionals.

Code *Book*

Below Table 1 summarizes 16 codes generated from the coding process with definitions and examples. The developed codebook addresses multiple themes, such as required hands-on experiences, technical skills, market analysis skills, understanding of environmental impacts, and smart grid systems and technologies knowledge.

TABLE 1

CODE BOOK

CODE	**Definition**	**Examples/Ideas**
Students design projects	Ideas for students to conduct smart grid project design and implement the outcome in industry.	Design Challenge, documentation, and implementation in industry, mentoring, hackathon.
Industry/Students requirements	Skills that the industry requires from engineering students when they graduate	Education advancement, hands-on experience, professional field requirements, social power, readings, diverse background, teamwork skills, leadership, and communication skills
ECE Curriculum	Upgrading the ECE department curriculum to serve better the smart grid industry	Smart Grid labs, a curriculum that includes smart grid technology, smart grid/energy minor
Obstacles/Challenges in smart grid Industry	The problems smart grid industry is currently facing	Smart grid industry needs a highly qualified smart grid workforce.
Instructional activities	Activities and hands-on experiences that could be added to classes to serve the smart grid industry	Lab activities, field tests, software, system design, social interaction, external consultations companies)
Smart grid clinics	Implementing Smart Grid clinics and hands-on experiences in senior and junior projects	Senior/Junior capstone design projects.
Smart grid environmental effect	The effect smart grid is having on the environment	Its effect on climate change
Smart grid future industry	What are the aspects that the smart grid industry is willing to improve in the future	More social power/connections/ legacy system upgrade/ modernizing grids

Financial process of smart grid project	The financial process/cash flow for a smart grid project.	Budget, financial support, investment from companies
Business mindset in smart grid Industry	The importance of a business mindset in the smart grid industry	Cost/budget, business case, marketing, market
Rowan University Competitors	Rowan University competitors in smart grid curriculum development	Arizona microgrid labs, advanced living lab, testing location
Electrical engineering core concepts/ techniques	Basic and core concepts/techniques that every electrical engineer needs to know which are directly related to the electric grid	loT, electrical theory, coding
Grid technology	Different types of technologies for the electrical grid	Traditional grid, legacy systems, Platform, application, transmission, microgrids, energy transition, bi-directional communication technology, batteries.
Partnership suggestions	Businesses or industries that universities can partner with to help students learn about industry practices	Utilities, industries, students training
Smart grid Industry Professionals	Who are the main players in this area, and what do they focus on	Consulting Houses, experts, experts perspectives.

The main objective behind this project is to engage both industry stakeholders from different segments of the power industry and academic experts to understand their expectations for qualified power engineering graduates and to establish a connection that allows defining a prioritized list of core Smart Grid technology topics to be imparted into the existing ECE curriculum. The current effort focuses on developing a list of learning objectives that summarizes the power grid industry's current needs and requirements from freshly graduated ECE students. To answer the current projects' phase research question: ***What skills are required from the ECE graduate students to serve the Smart Grid industry better?*** The research team created a list of objectives that characterize the power industry's different needs and requirements from the current undergraduate students before joining the workforce.

Objective 1: *By the end of the B.S. in ECE, students should be able to implement and manage industrial projects individually and in teams in the smart grid industry.*

In this objective, interviewees expect that students can quickly understand the whole project process, requiring they can manage the projects if needed. Specifically, knowing what should be done after every step, how to budget, how to communicate with clients and vendors, how to report their work to superior managers, and being able to present their work in front of their co-workers are regarded as critical. These aspects are sometimes addressed in class settings individually but non-necessarily as a whole, specifically those processes relevant to the smart grid industry. The power industry expects students to understand and be able to act upon all the steps when managing a project as an industrial process operation. This is a particular step in the process of management highlighted by all eight interviewees. The industrial process knowledge will help the industry advance faster, decreasing the learning period for the freshly hired engineers and making them understand the specifics of the industrial process quicker as they won't need to focus on learning how to communicate with others. This objective was addressed in all eight interviews and reflected the importance of the student's understanding of the power system process operation.

Objective 2: *By the end of the B.S. in ECE, students should acquire hands-on capability and experience to work in teams and design smart grid solutions.*

Interviewees claimed that the ultimate focus of schools is on theories rather than hands-on experiences and design projects. Therefore, students lack hands-on capability when joining the workforce. Students need to know how to integrate the whole system together, besides experiencing that in school before joining the workforce. They think most training and basic skills must be covered in undergraduate courses instead of requiring the industry's time and effort.

Objective 3: *By the end of the B.S. in ECE, students should be able to acquire solid software programming/applications capability for the smart grid industry.*

Interviewees stated the importance of having solid software programming capability when joining the smart grid industry. Not all ECE students should have these skills, but students interested in working in the smart grid industry must know the basics of coding and programming.

Objective 4: *By the end of the B.S. in ECE, students should be able to develop mathematical modeling/simulation for critical smart grid components and systems.*

The industry expects students who join the smart grid workforce to have sufficient knowledge of all the smart grid systems, including their major/critical components, besides being able to analyze and know how to create multiple systems in the smart grid industry. Examples of these systems are battery systems, distribution systems, transmission systems, renewable energy systems, control systems, operating systems, utility operation systems, and resource management systems. Developing students' skills in understanding and being able to analyze the smart grid components will strongly support the rapid solution deployment in the smart grid industry. As we mentioned earlier, the smart grid industry is rapidly growing, and students lack the basic knowledge and understanding of this industry and will not catch this rapid development. The industry needs candidates aware of the process to help them save time and effort and easily build up their knowledge for a more advanced industry.

Objective 5: *By the end of the B.S. in ECE, students should develop cyber security skills and understand how to protect the system from cyber attacks in smart grid industries.*

Industry professionals think cyber security skills are essential as the industry needs candidates to create a defense line against potential threats and data leaks. Students might be taking courses covering this skill, but the industry still thinks it's insufficient and that students need more hands-on training to cover this gap during their undergraduate school.

Objective 6: *By the end of the B.S. in ECE, students should be able to describe the smart grid business model.*

The industry expects students to be able to describe the smart grid financial model besides understanding its cash flow and expenses. As they think that understanding how the smart grid business model works will help the students further understand how the process is running and how decisions are made. As decisions are not only dependent on the components' technicalities but also on how their prices affect the system. They also need students to understand how to deal with different stakeholders, as it's one of the major steps in the business model. Particularly understanding the stakeholders' demands and knowing how to comply with product reliability and sustainability. The industry needs students to be able to analyze the smart grid market and how it is affected by climate change and different environmental scenarios. The industry thinks that students having market and environmental knowledge will help them better deal with market situations that require understanding the market history and analyzing different solutions.

Conclusion and Implications

The proposed learning objectives are a response to the nation's urgent need to educate the next-generation smart grid workforce, which otherwise could obstruct the nation's smart grid mission, and our economy, environment, and future will be compromised. To further understand the power industry requirements from freshly graduated students, a qualitative study based on the thematic analysis coding approach was conducted. The research team interviewed eight industrial professionals from eight different power industry segments, taking different roles. The study generated a code book that contains 16 codes with definitions and examples. In addition, six learning objectives are derived from identifying the power grid industry needs and requirements of freshly graduated students. The learning objectives constitute the initial step for a wide survey to prioritize the importance of the resulting list of objectives from both academic professionals and industrial professionals, which will help us refine the B.S. in ECE curriculum that supports the smart grid industry. We expect our current efforts will strongly support the power industry's needs and the nation's "Smart Grid" mission.

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Appendix 1

Interview Protocol

- Opening Questions
    1. Is there a demand for a qualified workforce (smart grid/electric power)?
    2. Can you tell me more about Your company's core business in smart grids, and
        a. What about the company's future directions/plans combined with the business?
        b. Are there any specific devices/projects you or your company are working on/ advancing to increase smart grid efficiency and reliability?
    3. Do the new engineering hires at your company typically have the skills they need to begin the work in innovating products?

The team researched the smart grid and found key objectives. These objectives were found using government, industry, academic articles, and other interviews. The team took the knowledge from these sources and created the topics that we found to be important to the innovation of the smart grid.

Technical Skills Section

- To upgrade device capabilities to strengthen the transmission and distribution systems of the smart grid.

    Device capabilities are strength, efficiency, cost, and others.
    We believe it is always important to keep integrating new technologies into the smart grid to keep advancing forward. Some devices that can always be improved on are.
        - Smart Generators
        - Source transfer devices
        - Smart meters
        - Distributions and control centers/devices
        - Smart Sensors

    - From your experience, is this objective important
        - Why

- How is your company currently trying to innovate so the devices of the smart grid are more reliable and efficient for the consumer?
    - What are the fundamental skills/techniques you think a practicing power engineer would need to help advance smart grid devices?

- Increase power production and distribution technologies towards renewables.

    - What are the most promising and widely used renewable energy sources, and why?
    - Does your company work on renewable energy sources? If yes, why is this being pursued?
    - Are any fundamental skills needed to help push renewable energy that a junior engineer would need?
    - What is the main problem that makes renewable energy challenging?
    - What innovation is your company working on to make a renewable energy source good enough to power a grid?
        - Battery capacity
        - Overall generation of power
        - The lack of wanting to change

- It is increasing protection systems to withstand or detect forged/hacked components.

    - What level of cybersecurity were you aware of during your time in the industry, are you aware of any developments in your area of expertise?
    - Did you encounter any cybersecurity-related issues, and what skills were used to mitigate the issue?
        - For example: Did you ever experience an issue with a leak in private customer information, such as account information, address, etc... due to a lack of cybersecurity during your time in the industry? If so, what were they? How were they resolved
    - In your experience, are there any environmental impacts on the grid that still haven't been solved
        - From a smart grid perspective, what should have been done in the Texas incident?
        - If yes, what is the reason they have not been resolved?

- Regarding Battery storage solutions that maximize renewable energy generation and help build a cleaner, more resilient grid
    - Initial thoughts on if it is an important topic for the smart grid
    - Fundamental skills that are needed to jump into battery storage.

        - Does your company look for specific skills when hiring to work on projects?
            - If yes, what are these skills that are needed?
    - **Do the Junior or entry-level engineers usually have the required skills**
        - What are these skills, or what is needed? **Like the above question
    - What are the key advancements the industry is trying to pursue to increase battery storage capacity
    - Is there a challenge or hurdle that needs to be solved for advancement to occur.

- <u>Development of faster data processes to increase the efficiency and reliability of the smart grid.</u>
    - Initial thoughts on if it is an important topic for the smart grid
        - **This topic is based on getting data sent back to some device and having it fix the problem independently and compute the fix based on the provided data.**
    - Are there any devices or processes you or your company currently working on?

    - What are the main skills you use to increase data processing efficiency
        - Do junior engineers start with the required knowledge
            - What are these skills, and what is needed for the industry standards?
            - Is your company looking for specific skills in this area, or do you look for specific skills in a new hire?
- <u>**Develop advances in measurement technology to accelerate the timing of smart grid responses** to increase the system's efficiency, reliability, resiliency, and sustainability.</u>
        - These measurement technologies are things like smart meters and smart sensors. To help predict the best course of action for the task at hand.
    - Initial thoughts on if it is an important topic for the smart grid
    - **Has your company ever worked on or designed better-functioning measurement technologies**

- Are there any current <u>Further development in blackout prevention technologies.</u> ?
    - Initial thoughts on if it is an important topic for the smart grid
    - This is a broad topic, but it relates more to have enough power to power the entire grid since there could be days when little power is created.
    - **Are there certain protocols for blackouts? If so, what happens, and what skill is needed to complete this**?

Professional Skills Section

- **Students should be able to manage industrial projects individually and in teams**
  - What are you expecting from freshly hired engineers regarding managing their projects?
  - Are there certain requirements for management skills?
  - Would providing a course that teaches project management students increase their hiring chances?
  - How important and influential would you rate professional skills in the SG industry?
- **Students should acquire hands-on capability and experience to work in teams and design microgrids / smart grid**
  - Can students design Microgrids from scratch? Will it require advanced levels, or can undergraduate students achieve this project?
  - What activities would you recommend to be added to the ECE curriculum to enhance their learning and hands-on experiences?
  - Consider collaborations between you and schools to find ways to develop students' skills. Do you have ideas?

- **Students should be able to analyze the SG market**
  - How can students enhance their ability to analyze the SG market?
  - Do they have to/ would it be better to know the SG market before joining the industry?
  - How could this knowledge affect their hiring chances?
  - How could you help our students understand and analyze the SG market?

- **Ending**
  - What other comments do you want to give us that you believe we have not covered.
  - Are there other skills needed to be an engineer pursuing the smart grid?
  - Is there anyone else you could recommend for us to interview?

- Thank you for your time
- We would like your input about what we found in this set of interviews. We will be sending a survey to your email soon.