Industry-University Collaboration in Workforce Development: Results from a Short Course on IEEE Standard 762

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***Abstract*—Traditional generation and operation practices are being challenged worldwide by new technologies and alternative ways to plan, design, build and manage power systems. For example, the role of large generating units in the presence of renewable energy needs to be reexamined, especially in places with good renewable resources and aggressive energy policies. This paper presents lessons learned from the preparation, coordination and delivery of a short course on reporting electric generating unit reliability, availability, and productivity. The short course addressed specific industry needs, and was arranged under the leadership of the University of Puerto Rico-Mayaguez. Besides discussing the use of IEEE Standard 762, the course also covered ways to consider variable generation in the future. Puerto Rico's current and proposed renewable energy use was the primary context for the discussion. Assessment results demonstrated that the short course achieved its objectives.**

***Index Terms*—Workforce development, industry-university collaborations, electric generating unit, renewable energy.**

I. INTRODUCTION

Since 1997 electric energy researchers from the University of Puerto Rico-Mayaguez (UPRM) have engaged in continuing education activities that have benefitted over 5,000 practicing engineers. Dozens of seminars and workshops, as well as a handful of conferences have been organized, coordinated and delivered by UPRM researchers regarding topics such as energy storage, renewable energy, energy policy and even engineering ethics. A description of the impact of some of those workforce development activities can be found in [1], [2], [3]. These continuing education contributions also include articles published in the newsletter and official magazine of the state society of professional engineers, for a sample see [4]. Furthermore, a graduate program was designed and delivered via distance learning to the Dominican Republic, resulting in 15 Dominican engineers earning a Masters degree [5]-[6]. That program was based on the needs of the Dominican electric power industry. Through these experiences the authors from UPRM have developed a practical framework for continuing education activities that have contributed to the local workforce development. This framework has been informed and expanded by best practices from engineering education research on industry-university collaborations. Some of the most influential references (for the careers of the UPRM authors) are briefly described in the following paragraphs.

Results from a Faculty survey on industrial outreach were particularly useful in the early days of industry collaborations for the two UPRM author-professors of this paper [7]. The survey, which covered 107 faculty in 19 universities, was used as a reality check for industry engagement in areas such as qualifications, interest, time and compensation. It has been proven, through personal experience of the UPRM authors of this paper, that Faculty that participate in industrial collaborations improve their practical problem-solving skills through experiences working with industry and develop further the interpersonal skills necessary for industry interaction [7]. Defining an appropriate compensation is another important area, and Faculty must ensure their services are properly valued. A key take-away from this Faculty survey

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is the need to design industry collaborations that are related to other Faculty activities such as teaching (e.g., through capstone courses) or research (e.g., knowledge transfer).

Perhaps the most influential experience in the development of UPRM's practical framework in power was the Learning Factory [8]. UPRM was a partner in this endeavor whose mission was "to integrate design, manufacturing, and business realities into the engineering curriculum." Some of the key areas that influenced the UPRM authors were the active learning facilities and activities, the strong collaborations with industry and the practice-based engineering courses among other areas. The strong emphasis on industry relations of that partnership guided many projects and initiatives, including workforce development and continuing education activities in electric power. The initial assessment strategy at UPRM for ABET EC2000 was based on the Learning Factory experience [8]. The UPRM authors of this paper, to this day, continue to use the assessment skills, and even some of the instruments, from the Learning Factory. At UPRM specialized facilities for pharmaceutical and electronic manufacturing were established and are remain operational today. One of them now is named UPRM Model Factor, and is leading important electric energy efforts such as the manufacturing of LED lighting for local applications. Another key influence from the Learning Factory were the many seminars, workshops and short courses sponsored at UPRM. Many of those capacity building activities were Guest Lectures by practicing engineers in their field of expertise [8].

A more recent reference reaffirmed some of the early knowledge used for the practical framework in this paper. The idea of an equal partnership, is still vital for successful industry-university collaborations [9]. This requires an early definition and continuous understanding of the roles and expertise of all the partners to avoid the dichotomy mentioned in a 33-year old reference (still relevant today): "The power company was really looking for a product, and the university was looking for a relationship" [10]. Another area of continued importance in any industry-university collaboration is the need for continuous knowledge sharing throughout the relationship [11]. By adapting these best practices to the local context and considering particular audiences and learning objectives, the practical framework has the following elements:

1. Meet an industry need
2. Include local context
3. Provide a "take-away" to participants
4. Expand participant's scope of work beyond the day to day

UPRM's strength in undergraduate power engineering education and workforce development has enabled its researchers to secure funding for research and teaching activities that have supported further growth and development of power education. The next section describes a key collaboration in power education and workforce development that extends beyond the frontiers of the Puerto Rican archipelago.

II. Workforce Development Platform for Electric Utilities

For over 100 years, the power system paradigm has been based on electric power generated at large installations, which is then transported to the users through transmission lines, as well as distribution lines in most instances. Nevertheless, factors such as increased equipment efficiencies, self-generation and aggressive efforts towards energy conservation have reignited the distributed paradigm that dominated in the early years of the electricity sector. The penetration of distributed energy resources requires a reliable engineering workforce to envision, design and integrate these grid-connected resources. The U.S. Department of Energy created the Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) program as a research, training and education framework to provide the current and future electric utility sector professionals with the knowledge and skills to operate the electric grid with high penetrations of distributed technologies [11]. The GEARED consortia work to bring more power systems engineers to the workforce that are able to handle increased amounts of distributed energy. The Electric Power Research Institute (EPRI) leads a GEARED consortium known as the Center for Grid Engineering Education (GridEd) which was initially called the Distributed Technology Training Eastern Consortium. Clarkson, Georgia Tech, University of North Carolina-Charlotte and University of Puerto Rico-Mayaguez (UPRM) are core partners in GridEd. EPRI, the universities and utility/system operator partners aim to combine utility and industry research to address critical energy challenges in education (Fig. 1 illustrates GRIDED's general approach).

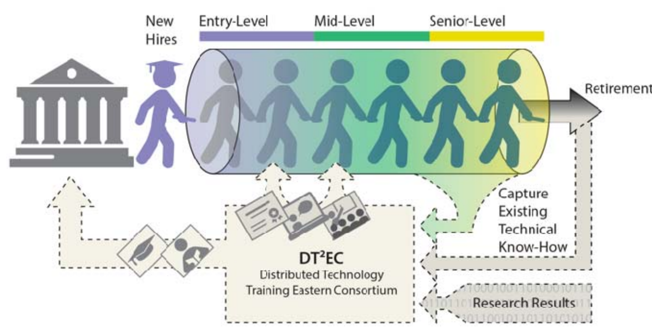

Fig. 1. Utility Industry Educational Needs

In addition to student support to train the next generation of power engineers at university partners, GridEd has activities to enhance the knowledge of current industry professionals such as short courses. These educational short courses have been developed to train practicing engineering professionals on renewable energy and the future electric grid, and also to aid engineers in attaining professional development hours needed to retain their engineering license [12]. GridEd has publicly available outreach materials promoting interest in power engineering and also disseminates its work through publications and conferences. To sustain the effort and make it sustainable, educational services such as seminars, tutorials, workshops, and short courses are offered for a fee. Fig. 2 shows the spectrum of GridEd's activities.

GridEd short courses are 1.5 to 2 days in length and are generally limited to 25 participants. To develop short course content, GridEd initiative draws from partners' research results, including university partners and participating utilities. GridEd engages industry and university partners to identify training needs and options. Some of the topics covered in continuing education activities include smart inverters, distributed energy storage, and electricity markets. The next sections focus on industry-university exchanges which resulted in a short course on *IEEE Standard 762* delivered in Puerto Rico to match the training needs of an industry partner on power plant reporting and on power plants' potential new role as renewable energy use is increased in Puerto Rico.

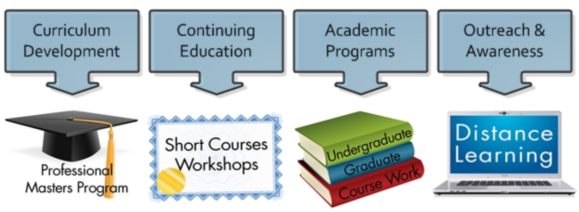

Fig. 2. GridEd's Educational Areas and Development Activities

III. Workforce Development activities at UPRM

UPRM's workforce development initiatives are aligned with GridEd's overarching goal and are structured around three main areas:

1. Outreach to high school students
2. Public outreach to communities
3. Curriculum development
4. Continuing education activities for industry

The workforce development framework presented earlier, and the leverage offered by EPRI's vast practical experience in workforce development in the utility industry have been instrumental in UPRM's fulfilment of its GridEd's tasks. Although the focus of this paper is on continuing education of practicing engineers, a brief description of the other initiatives is given next.

Community collaborations are essential to the outreach efforts at UPRM. They provide not only knowledge to participants, but active training laboratories for students and concrete examples to industry about the application of GridEd-generated knowledge to enable the transition to more sustainable energy practices focused on the use of local resources (renewable energy, efficiency and conservation). It is of utmost importance to transfer research on renewable energy and microgrids to practical guidelines and standards that can aid industry to address the challenges related to the transition to a new, more sustainable, more distributed electric energy infrastructure. Besides visits to communities in Puerto Rico, UPRM researchers have hosted seminars in campus open to the general public, high school students, the UPRM community and industry.

During 2014 UPRM organized two continuing education activities in Rincón and Caguas (Puerto Rico), as local kick-off activities of the project. Although the main audience for both activities was industry, the Rincón seminar had the participation of students from three high schools. Based on the feedback obtained on those activities through a survey, specific topics for further activities were identified [1].

One of the topics of interest from a local industry collaborator was a short course on the IEEE Standard 762.

IV. IEEE Standard 762-2006 and Renewable Energy

A key component of the work towards the short course was delineating its contents. This section summarizes part of the work completed to address the topic requested by the industry partner.

IEEE Standard 762-2006 "Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity" presents a methodology to interpret electric generating unit performance data from different systems. It also facilitates comparisons among different systems [13]. Standard 762 provides 15 energy and capacity terms, 21 time designation and dates, 25 performance indices for individual generating units, including availability, capacity and outage factors. The North American Electric Reliability Corporation (NERC) has been operating the Generating Availability Data System (GADS) since 1982. Initially, GADS was collecting data on base-loaded units only (fossil-steam and nuclear) with a few cycling and peaking units mixed in. In 2002, the IEEE Risk, Reliability and Probability Applications Subcommittee formed a working group at the request of NERC to revise IEEE Standard 762 to address non-base load generation unit performance indices. Originally written in 1987, that standard needed revisions to meet the needs of industry [14]. There were four key changes in IEEE 762 and GADS: demand-based indices, un-weighted (time- based) and weighted (capacity) indices, non-generating indices and outside plant management control (OMC). The revision work also considered concepts such as commercial availability and market power monitoring. However, these topics did not make it into the final version of the revised standard.

Standard 762 defines reliability, availability and productivity indices to report traditional dispatchable power plant performance but assumes energy is available without limitation [15]. NERC also works trying to keep compatibility between IEEE 762 and the International Union of Producers and Distributors of Electric Energy (UNIPEDE) definitions and terminology. The major difference between standards is that IEEE's is time-based and UNIPEDE's is energy-based. Neither defines measures of performance specifically for non-baseload generating units [16]. On the other hand, performance metrics for PV plants must take into account the fact that the energy varies both diurnally and randomly and this variation is the main determinant of plant availability. The solar resource at a given location is dependent on the weather and the time period examined. A method was proposed to address this by combining the "daily clearness index" with a "daily variability index", defined by Sandia National Laboratories. Using this combined index, the variability in irradiance can be qualitatively categorized using five categories of variability conditions: high variability, moderate variability, mild variability, clear and overcast days [15].

In 2007, NERC created the Integration of Variable Generation Task Force (IVGTF) to address issues related to variable generation from a fleet operation and flexibility perspective. The IVGTF also provides analysis of technical considerations, specific actions, practices and requirements, including enhancements to existing or the development of new reliability standards for integrating large amounts of variable resources into the bulk power system [16]. Controllability is one of the main issues with parameters such as start-up time, cycling ranges, rates and minimums. NERC has recommended two dependability metrics for variable generation: effective load carrying capacity (ELCC) and loss of load expectation (LOLE). Alternatively, industry-proposed PV plant variables include: energy production and solar resources factors (over a specified time period of interest) and solar plant energy performance based on either inverter (ac) or array (dc) ratings. The annual capacity factor for solar PV plants ranges from about 12 to 24%. It depends on many elements, including location, weather, array tracking, balance of plant efficiencies and inverter size [15].

A different way to look at energy performance specific to PV plants is to normalize performance based on local sunlight conditions. The concept of PV plant daytime energy performance factor can be used to compare performance with other plants. Energy performance factor is defined as a ratio of a daytime production factor and a sun factor. This factor is dimensionless and typical values may range from 0.6 to 1.0. Daytime production factor is the total daytime energy produced divided by the plant rated capacity times daytime hours. The plant rated capacity can be in terms of the inverter or the array. Sun factor is the daytime insolation normalized to a value representing clear sky irradiance (1,000 W/m^2) times the daytime hours.

As more state policies support renewable energy and distributed energy technologies, a reexamination of the role of large power plants will be necessary. A key challenge that needs to be addressed is the training of future engineers, as well as the retraining of current engineers so that they can cope with the changing industry environment while maintaining the reliability and security of power systems.

V. SHORT COURSE COORDINATION AND DELIVERY

Ecoeléctrica is an independent power producer in Puerto Rico that generates electric power using natural gas. It was established under PURPA in 2000, and it cogenerates drinking water via desalinization. It also has the only LNG receiving port in the Island. The electric power generated by Ecoeléctrica is sold to the Puerto Rico Electric Power Authority (PREPA) a state-owned company and the only electric utility in the Island. Ecoeléctrica's management approached UPRM researchers in 2014 asking for help in arranging an activity to have its personnel trained on the reporting guidelines of IEEE Standard 762. Since power plant performance standards and operation procedures need to be adapted for variables, Ecoeléctrica was also interested on the impact of an increased use of renewable energy. This is particularly true in areas like Puerto Rico where variable wind and solar generation are expected to become a relatively large part of the electric generation mix as mandated by local laws.

During 2015 UPRM researchers negotiated the expectations and desired outcomes with Ecoeléctrica, and led the short course development within GridEd. A graduate student, and author of this paper, was tasked to study the IEEE 762 in detail and search for relevant literature based on the input received from EcoEléctrica. Resources from EPRI and UPRM were identified to be part of the short course instructors. UPRM researchers consulted with industry contacts to identify a presenter on IEEE 762 standard that was a "practitioner". This meant a person who worked at conducting the measurements and gathering the data required to calculate the reliability, availability and productivity indices of electric generation units, as defined in the IEEE 762. Mr. Schneider was identified as a potential presenter, as he is the Chair of the Working Group in charge of revising IEEE Standard 762 to incorporate terms for variable energy resources. The group of presenters was completed with Agustin Irizarry (UPRM) and Tom Key (EPRI), and the outline of the course was finalized.

The first day would include the following topics:

- Overview of the electric power situation and challenges in Puerto Rico's Power System Operations. Overview and Characteristics of Wind and Solar.
- IEEE 762 overview. Unit states, time designations and unit states.
- Capacity terms, energy terms, performance indexes of an individual unit.
- Unweighted (time-based) calculations for group performance indexes.
- Capacity-weighted calculations for group performance indexes.
- Review of Day 1

The second day's topics were:

- Specific situations in Puerto Rico with renewable generation.
- Discussion panel (all presenters)
- Future directions for extending performance standards to renewable generation
- Course assessment
- Ecoeléctrica plant tour

After the usual date and terms logistics, the short course was presented at Ecoeléctrica on June 21 and 22, 2016. Twenty-one engineers participated in the short course, including Ecoeléctrica personnel, PREPA employees, one AES engineer (the other IPP in Puerto Rico), and three private consultants.

The last activity of the first day was a hands-on exercise to determine the IEEE 762 standard's indices. This exercise was intended to give participants the chance to handle the data required and the necessary equations to calculate the indices. All participants received an electronic copy of an Excel© worksheet. The worksheet had a reduced data set of power generating units for the class exercise. The exercise assumed one year of operations. A sample population of 6 generating units was included in the worksheet, with information such as location (region), unit capacity (MW), seasonal derating and outage levels (p.u.). Tables I and II show how the worksheet would automatically summarize that information from the sample unit population. The data can be changed based on actual power units from the participant's employer.

Table I. Maximum Net Capacity

Type	Region			Grand Total
	M	T	V	
Combined Cycle-2			770	770
Hydro		30		30
Nuclear			380	380
Steam Gas			45	45
Wind	2.5			2.5
Grand Total	**2.5**	**30**	**1195**	**1227.5**

Table II. Dependable Capacity

Type	Region			Grand Total
	M	T	V	
Combined Cycle-2			770	770
Hydro		27		27
Nuclear			340	340
Steam Gas			45	45
Wind	2.5			2.5
Grand Total	2.5	27	1155	1184.5

The worksheet had all the equations and steps required to obtain the indices. Table III shows some of the processes programmed in the worksheet. Table IV shows some of the resulting unit performance indices from the sample population (the numbers with format 8.X show the section of the Standard where each index is defined and explained). Participants were also asked to change some of the parameters, and study the effect on the indices.

Table III. Functions of the Tool to Calculate Performance Indices

Worksheet Tab	Description
Heat Rates and Fuels	Used to calculate incremental costs
Maintenance Summary	Maintenance date for each unit
Forced Outages	Count, forced outage hours and MWh for each unit
Available Periods	Periods when each unit was not on planned or forced outage, retired or not yet in service.
Unit Performance Totals	Used to calculate unit demand
Scaled Load	Hourly load profile
Pooling	Unweighted average performance
Weighting	Weighted average performance

At the end of the first day participants were asked to email organizers their main questions and doubts. The organizers met that night, for a debriefing of the day's work and discuss the questions received. The results of that discussion were used to guide the Discussion Panel in Day 2.

Table IV. Performance Indexes for Each of the Six Units in the Example

Unit	Planned Outage Factor (8.1)	Forced Outage Factor (8.3)	Availability Factor (8.6)	Service Factor (8.7)
Steam Gas	2.30%	2.85%	94.85%	0.72%
Combined Cycle #1	5.74%	0.55%	90.77%	89.40%
Combined Cycle #2	6.27%	2.73%	90.86%	10.22%
Wind	1.91%	3.72%	94.36%	94.35%
Hydro	3.83%	4.47%	91.70%	91.69%
Nuclear	9.56%	3.95%	86.49%	0.40%

VI. Assessment Results

An assessment form was distributed to short course participants at the end of day two. The two main questions related to how well each of the main objectives of the short course were addressed:

- Main objective: To understand how IEEE 762 performance indices are used for conventional generation and means to cover variable generation in the future.
- Secondary objective: To present NERC work on fleet control standards and the Integration of Variable Generation Taskforce (IVGT).

For the first question, 88% of participants answered that the short course largely or fully covered the use of IEEE 762 indices. For the second question, 82% of participants said the short course largely or fully presented NERC work and the IVGT. Furthermore, for both objectives an additional 11% of participants described the short course's coverage of the objectives as acceptable or adequate. Such large percentages of approval (over 90% for each objective) reflect the success of the short course in meeting its goals.

Table V shows that at least 76% of participants thought the topics were covered either effectively or exceptionally. In most of the topics that percentage was 82%. Perhaps the most useful information from the assessment process was that obtained from open questions. The first open question was "The short course was an introduction to IEEE 762. With this in mind, do you feel prepared to use the standard?" Thirteen participants answered in the affirmative. Some of the comments were:

- Yes, definitions are clear.
- Yes, a useful guideline for evaluate energy reporting.
- Yes. The concepts explained in the course, will help me to use the standard.
- Yes, the terms and calculations were well explained.

Table V. Results for Specific Short Course Objectives

Please rate *how well each of the topics was covered*	Scales		
	Reasonably	**Effectively**	**Exceptionally**
IEEE 762 overview; unit states, time designations and unit states	4	7	6
Capacity terms, energy terms, performance indexes of an individual unit.	3	8	6
Unweighted (time-based) calculations for group performance indexes	3	10	4
Capacity-weighted calculations for group performance indexes	3	10	4
Future directions for extending performance standards to renewable generation	3	8	6
Overview of the electric power situation in PR and challenges with renewable generation	0	9	8

The second open question as "Will the short course be useful in your job? How?" Some of the answers were:

- Yes, during monthly report data collection several parameters are now better understood
- Yes, I'm a performance engineer.
- Yes, will help better understand various internal topics.
- Yes. Primary for the generation personnel.

The third open question asked about recommendations for improvement of the course.

- More hands-on practice with the IEEE 762 reporting.
- Use local data.
- Allow for full 2 days to cover topics in depth.
- Excel (spreadsheet) should be shared beforehand.

The fourth open question asked what the participants liked the most about the short course.

- PV and system challenge.
- The expertise of the instructors was very good.
- The discussion of the integration of DG in distribution system.
- Open discussions.
- The interaction was good.
- Course dynamic and flexibility to actively interact with the audience.
- The integration of the renewable energy to conventional grid.
- Openness and environment. Great to learn and make questions.

Assessment results will be used to improve the short course, both its contents and delivery.

In terms of objective assessment of participant learning, the questions sent by participants via email and the questions asked during the short course provided ample opportunity to clarify participants' doubts. Participants' understanding was verified through their use of the worksheet (one of the authors walked around the room verifying use of the worksheet). A sample of six participants were informally interviewed by one of the authors, regarding their knowledge of the Standard. The questions were based on the short course's objectives, and all six participants gave correct answers, confirming their understanding of the subject matter. Table VI presents how the practical framework of industry-university collaborations was applied in this case.

Table VI. Summary of Framework Elements in the Short Course

Framework	**Short Course**
Meet an industry need	Based on data from a 2014 survey on industry needs and the direct request of an industry representative
Include local context	The application of the standard was taught considering the local power system conditions (e.g., island issues, particular challenges of renewable integration)
Provide a "take-away" to participants	Participants received an electronic worksheet that could be adapted and used to address other data sets
Expand participant's scope of work beyond the day to day	A key message was the need for large power plants to assume a new supporting role in the path to an increased use of renewable sources.

Addressing specific industry needs, and following a practical framework in the design, preparation, coordination and delivery of a continuing education activity are presented as the two main recommendations of this paper. Other lessons learned that can serve as guidelines are presented next. The interaction between the university and industry occurred at two levels. The first was the local company approaching university professors with a request for continuing education. The second was the link to industry available through GridEd which allowed the university professors access to a wider range of human resources and knowledge to address the request of the local industry collaborator. The integration of a graduate student to the design of the short course gave the group an alternative perspective that was helpful in identifying topics outside the day to day operations. The inclusion of an industry practitioner in the group of instructors was invaluable for the expertise he brought and the tools (practical knowledge and worksheet) he was able to share with participants. The constant interaction with participants, and close monitoring of their reactions and doubts (orally, via email, in informal interactions during breaks) was also a key factor in the success of the short course.

VII. Conclusions

It is well-known that the electric power sector is transitioning from a dominance of central power plants to a more hybrid network that will see a more active role for users, distributed resources, storage and renewable energy. Faced with this transition, it is of utmost importance to have a workforce knowledgeable not only on traditional power systems but also on new technologies and analysis perspectives. The role of large electric power generating units needs to change to better support the new realities and challenges facing the power industry. This paper presented an industry-university collaboration which yielded a short course on IEEE standard 762, and the considerations needed to revise the standard to accommodate the challenges of renewable energy use in the power grid. The course achieved its goals, and is an example of the type of collaboration that will be needed to successfully transform the power industry. It also provides guidelines that might be followed in other industry-university collaborations.

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