The Center for Grid Engineering Education

Identifying Training and Education Gaps in the Electric Industry
A GridEd Report

Abstract

An education and training gaps analysis report is created by GridEd with support from the U.S. Department of Energy's Solar Energy Technologies Office which summarizes the results of surveys, advisory meetings, and interviews of utility and industry partners. The report identifies gaps in training & education (T&E) materials for both new electric power engineers (new university-trained engineers) and professional training (applicable to working professional power engineers). In addition, this report provides a blueprint for types of materials believed by industry to be necessary to create a workforce of engineers suitably trained for meeting the needs for the grid of the future.

Introduction

This document has captured electric industry workforce needs and knowledge gaps in the power delivery and utilization sector necessary to support the integrated grid of the future with large amounts of distributed energy resources (DERs). In particular, GridEd sought to identify needs for training and education (T&E) as viewed from the perspective of electric utilities. Over nearly a five-year period, GridEd has assembled an electric utility advisory body composed of twenty-five (25) electric utility companies (Appendix I) and has routinely engaged them. In addition, twenty-eight (28) additional electric utility companies (Appendix II) have participated in short courses have been queried. These advising bodies have been critical to guiding the GridEd effort and identifying training and education gaps. Four (4) primary sources of engagement have been used to identify gaps:

- *Conducting annual surveys from the utility advisory body,*
- *Regular and routine webinars and in-person meetings with the advisory body,*
- *Conducting one-on-one interviews, and*
- *Surveys of short course participants.*

The annual survey asked respondents to prioritize training and education topics from a pre-determined list (see Appendix III). A questionnaire (see sample in Appendix IV) was then administered through Survey Monkey where respondents could provide feedback about the importance of each topic. Over time, these "choice derived" materials adapted as the GridEd team engaged more deeply with the electric utility advisors. Early efforts were less structured seeking self-generated ideas from utility advisors which proved to be ineffective. The learning process of engaging and soliciting thoughts, then reformulated as responses to "choices" of topics proved most effective to gather information on needs and gaps.

The GridEd approach was to develop short course modules which were nominally 12-hours in length to help address identified gaps on high prioritized topics. These courses have been delivered through in-person courses, e-learning modules, live-online and recorded training methods. At origination, it was imagined that such selected critical topics would likely include electric utility distribution systems, distributed generation technologies, smart-grid or grid modernization, utility applications of power electronics, solar resource assessment, modeling of high penetration of renewables on distribution circuits, and energy markets. Beyond these candidate course materials, early discovery revealed the need for training in the fundamentals of electric power systems.

Involvement with Electric Utilities

The electric utility industry is a key driver for the integration of DER into the electric grid. Competent and qualified electric industry professionals, including new emerging engineers as they transition from being students at various universities, in critical topic areas is paramount to the successful transition towards an integrated grid[1]. Therefore, it is imperative that the electric utility industry provide advice and guidance to the process for developing undergraduate, graduate, and professional enhancements to T&E materials for the electric industry's workforce. GridEd has been able to leverage its unique connectivity with many electric utilities through EPRI as a resource. This report shares the GridEd experience from the engagement with utilities on their needs and expectations for its next generation of power engineers.

Over the last decade, EPRI has been restructuring its R&D efforts towards the emerging technology fields best known as a broad class as DERs. This action is in response to the outlook of a future grid being driving by:

- *The recognition that the electric industry's infrastructure is aging*
- *An increasing amount of innovation from private and public investments in DER technology*
- *Broad public interest to seek electricity options that will lessen the impact on the environment that will alter the fundamental characteristics of the electric system*
- *The recognition that DERs could be a better economic and environmental choice.*

There is prevailing recognition that there is a ***gap in workforce readiness*** to address these changes. An additional pressure point is the recognition that an aging workforce will also be exiting the industry in large numbers, creating more urgency to fill these workforce needs.

GridEd started its process by creating an electric utility advisory committee comprised of subject matter experts from partnering utilities. These utility partners provided overall guidance and direction on needs of the industry as well as served as a source of adjoint funding to supplement the bulk of funds provided by DOE.

Through EPRI, the electric utility industry drives a large part of its research agenda geared towards integration of DERs. By extension, the GridEd team sought input for the structure and content of a T&E activity from electric utilities. The electric utility industry is a major employer of the power systems workforce and has prescriptive needs for meeting current and future requirements of the grid. It was only natural to seek advice on the development of training materials.

Our identification process of needs for T&E began as a ***first step*** by coordinating with seventeen (17) electric utility organizations and two (2) independent system operators as GridEd sought their support and commitment to the principles (from the original proposal). The total number of engaging utilities

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[1] *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources*. EPRI, Palo Alto, CA: 2014. 3002002733

later reached some fifty-three (53) electric utility organizations (see lists in Appendix I & Appendix II). The GridEd team used a variety of means (as cited above) to determine specifically which are the most relevant challenges that the electric industry faces with respect to the topic of training (in this case the integration of renewable and distributed energy resources) and what are the training needs according to their specific workforce demographics and the availability for sending engineers to educational programs.

As a ***second step***, the formal advisory committee was established from our participating and supporting electric utility partners. This committee provided much of the information through oversight, direction, and review of training materials. Participants on the committee also reached out to others within their companies to assist in developing perspectives on various topics. These advisors were tasked with developing or reacting to "choice" lists to formulate a comprehensive and prioritized portfolio of topics of immediate and midterm interests of the electric utility industry which helped define offerings throughout the five-year program. Electric utility advisors help to pinpoint specific training needs. They were continuously asked to evaluate results for potential training activities, and these results were channeled into the creation of course offerings.

First Steps on Identifying T&E Gaps – The 2014 Experience

The GridEd team launched its efforts to understand what position the electric utility industry had taken regarding its prescriptive needs for T&E at an EPRI Power Delivery & Utilization (PDU) Advisory Meeting in Huntington Beach, California in February 2014. The plan used the technique of engaging the advisory committee as a first step. Clearly, these prescriptive needs were not well understood as there had not been any organized effort with a documented outcome to capture a complete snapshot of T&E needs and requirements. Our early discussions were largely unstructured solicitation of information from a face to face meeting which led to some chaotic responses and made it very difficult to understand trends so that we could devise a short course program. However, it was clear that participants showed much interest in new topics like DERs, smart inverters, etc. rather than classic topics on electric power systems for a short course program.

The following summary of general findings were developed from the initial face-to-face meeting:

- Most electric utilities expect to be growing in the future
- Most electric utilities desire well rounded power engineers with technical knowledge, business savvy, and strong communication skills
- Most electric utilities are hiring undergraduates
- Most utilities wanted to expand their internship programs as a best recruiting tool
- Most utilities had broad, albeit not prescriptive, desire for T&E
- Many utilities had significant interest in T&E that involves e-learning
- Most utilities wanted universities involved in the process of identifying particular T&E needs
- Many utilities were involved in a previous DOE program around ARRA grants and they wanted to connect with those efforts which were largely abandoned as a sustaining activity.

As a second part of the face-to-face meeting, the GridEd team tried to obtain a priority on short course content. The discussion was opened to the audience to seek topics and to arrive at some consensus regarding most important materials. The effort was largely a failure as no priority was established. However, the following topics did emerge:

- Power System Design, Protection and Automation
- Power System Analysis and Modeling

- Distributed Generation (DG) Technologies
- Distribution Planning with DG
- Reliability Indices and Power Quality Standards
- Power Markets and Economics
- SCADA Protocols, Point Mapping

This first face-to-face meeting was not a total failure as it set some early tone about how GridEd needed to approach electric utilities to obtain valuable information so that a quality T&E effort could be assembled. Clearly, the effort needed to be directed as a structured approach if good quality data was to be obtained. This led to a post meeting follow-up where our efforts switched to the use of a formal survey to identify priorities for T&E materials. The following plan of action was put in-place:

- GridEd will send out a survey to project advisors to address gaps in training needs.
- The GridEd team, including university partners, is to construct a "choice" list of potential training topics.
- Survey participants are to score each course in the "choice" list from highest interest to no interest
- Survey participants are to provide other information on courses of interest.
- Results will help steer early direction for short course content under the GridEd initiative
- Advisors will be surveyed annually to provide continuous feedback on appropriate T&E content

In Table 1, the results of the first survey are shown. The top-rated course – "Applications of Smart Inverter Technology" has remained as the one of the most popular offerings that the GridEd short course has provided. A course in the fundamentals of electric distribution systems has attracted attention over time. Although modelling and simulation practices did not score high in this survey, over time it has emerged as a top course when focused on "DG Interconnection on a Radial Distribution System." In later years, the survey broadened in terms of choice as well as how questions were posed.

Table 1. 2014 GridEd Short Course Prioritization Survey Results

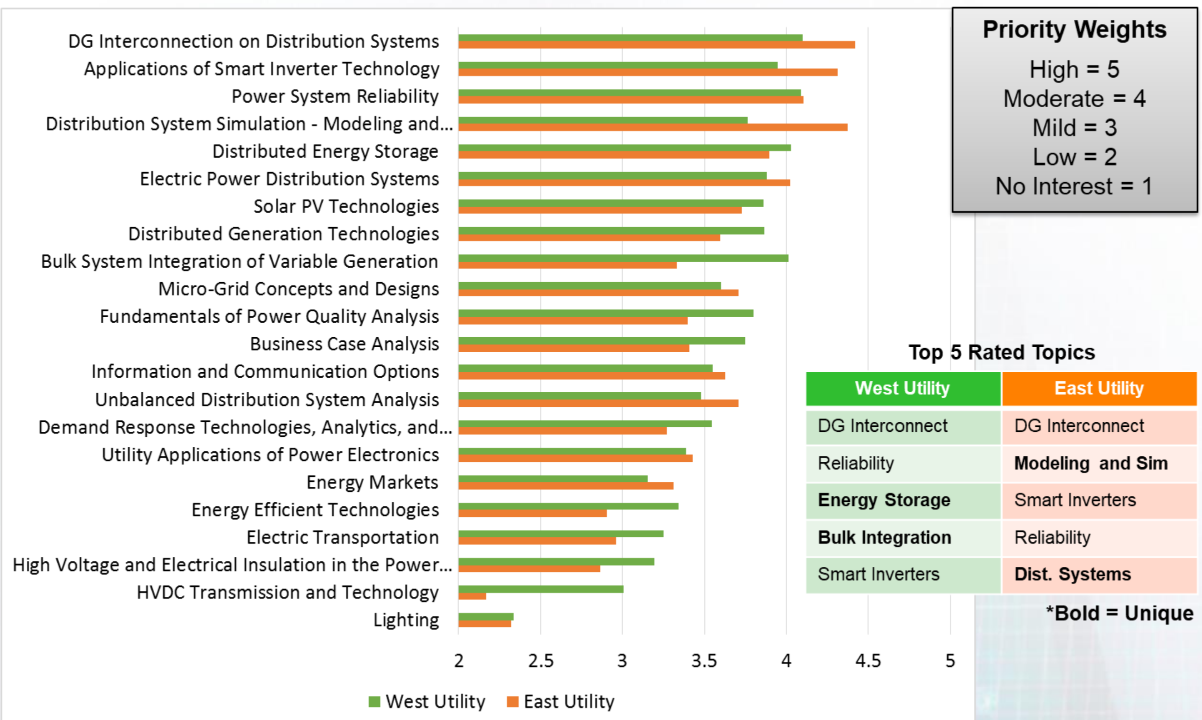
Topic Title	High Priority [5]	Moderate Priority [4]	Mild Priority [3]	Low Priority [2]	No Interest [1]	Total	Weighted Average
Aplications of Smart Inverter Technology	6	4	1	0	0	11	**4.45**
Power System Reliability	6	4	0	1	0	11	**4.36**
Electric Power Distribution Systems	6	3	1	1	0	11	**4.27**
Micro-Grid Concepts and Designs	4	4	1	2	0	11	**3.91**
Distributed Generation Technologies	3	4	2	2	0	11	**3.73**
Distributed Storage & Generation	3	4	2	2	0	11	**3.73**
Demand Response Technologies, Analytics, and Economics	3	3	4	0	1	11	**3.64**
Distribution System Simulation - Modeling and Analysis	3	4	1	3	0	11	**3.64**
Energy Efficient Technologies	2	5	3	0	1	11	**3.64**
Fundamentals of Power Quality Analysis	1	5	3	2	0	11	**3.45**
Information and Communication Options	2	4	2	3	0	11	**3.45**
Utility Applications of Power Electronics	1	3	7	0	0	11	**3.45**
Business Case Analysis	1	4	4	2	0	11	**3.36**
Unbalanced Distribution System Analysis	1	2	7	1	0	11	**3.27**
High Voltage and Electric Insulation in the Power System	2	2	3	4	0	11	**3.18**
Electric Transportation	3	1	2	3	2	11	**3.00**
Energy Markets	0	2	6	3	0	11	**2.91**
HVDC Transmission and Technology	0	3	4	2	2	11	**2.73**
Lighting	0	4	2	2	3	11	**2.64**

Extending the Survey to 2015

Survey results from 2015 were similar to results from 2014 except both east-coast and west-coast utilities were surveyed. This was the first time that GridEd was able to see clear distinction between regional preferences for training topics. A summary of findings from the survey results includes:

- DG Interconnection on Distribution Systems is consistently the highest rated topic.
- Major differences between East and West Utilities:
  - Bulk Integration of Variable Generation (West preference)
  - Distribution Simulation and Modeling (East preference)
- Major differences between utilities and universities:
  - Power System Reliability (Utility Preference)
  - DG Technologies and Demand Response (University preference)
- Top Rated Courses NOT in the GridEd Library
  - Distributed Energy Storage
  - Solar PV Technologies
  - Bulk System Integration of Variable Generation
  - Micro-Grid Concepts and Designs

As an outcome of these survey results a course on Distributed Energy Storage was developed and offered beginning in 2016.



West Utility	East Utility
DG Interconnect	DG Interconnect
Reliability	**Modeling and Sim**
Energy Storage	Smart Inverters
Bulk Integration	Reliability
Smart Inverters	**Dist. Systems**

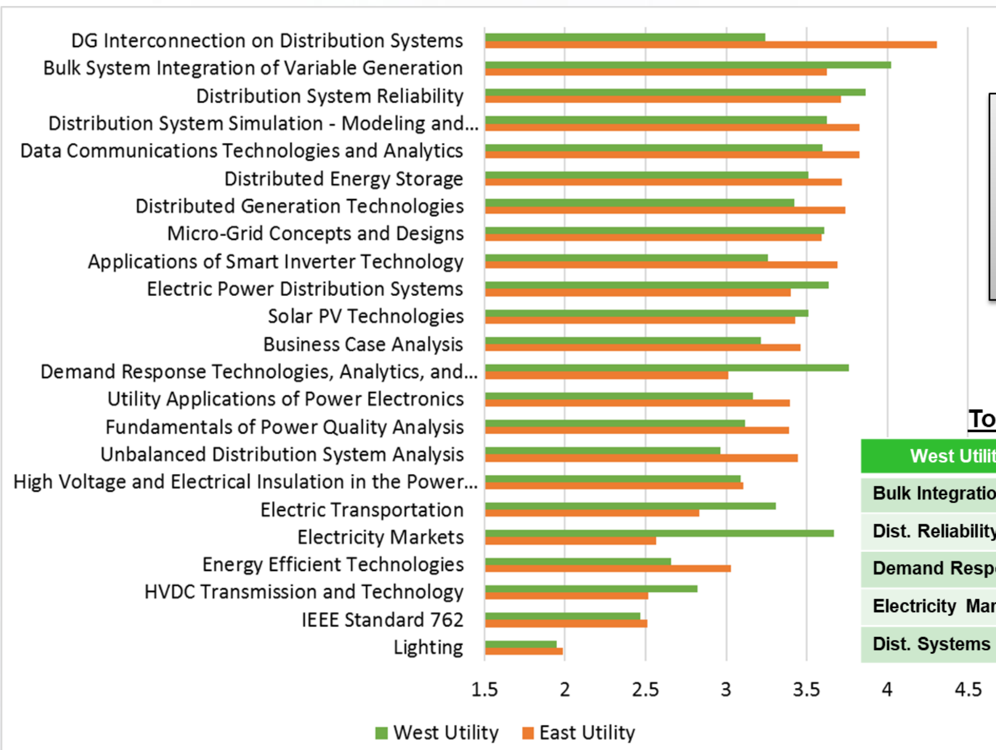
Figure 1. 2015 GridEd Short Course Prioritization Survey Results

Extending the Survey to 2016

The 2016 survey results had some very different results from 2015. Though DG Interconnection on Distribution Systems continued to be the highest overall priority, there were drastic differences between east coast and west coast utilities. In fact, east and west utilities did not share a single course topic in the top 5 prioritized topics. The summary of takeaways from the 2016 survey include:

- Less agreement between prioritization of course topics between east and west coast utilities compared to 2015 survey results.
- Major differences between East and West Utilities:
  - DG Interconnection on Distribution; (East preference)
  - Demand Response; Electricity Markets (West preference)
- Major differences between utilities and universities:
  - Distribution systems; Microgrids; EE Technologies (University preference)
  - Data Communications Technologies & Applications (Utility preference)
- Top Rated Courses NOT in the GridEd Library Pipeline
  - Bulk System Integration of Variable Generation
  - Data Communications Technologies & Applications
  - Micro-Grid Concepts and Designs

As an outcome of these survey results, a course on Bulk System Integration of Variable Generation was developed and offered in 2017.



Priority Weights

High = 5
Moderate = 4
Mild = 3
Low = 2
No Interest = 1

Top Five Topics

West Utility	East Utility
Bulk Integration	DG Interconnect
Dist. Reliability	Modeling and Sim
Demand Response	Data Com.
Electricity Markets	DG Technologies
Dist. Systems	Energy Storage

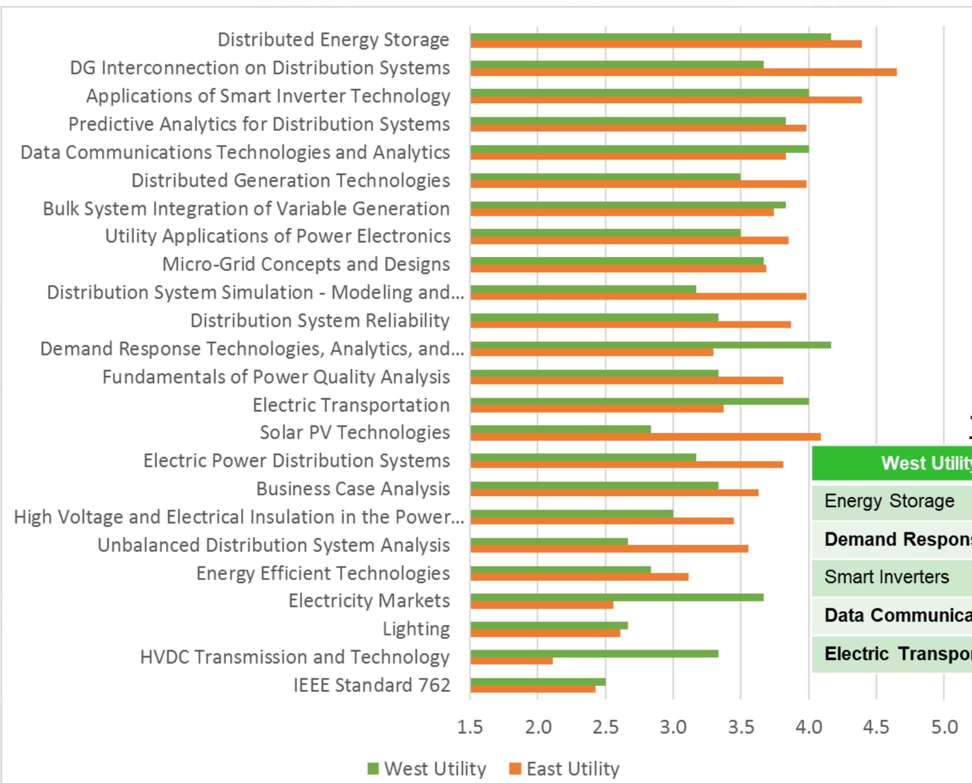
Figure 2. 2016 GridEd Short Course Prioritization Survey Results

Extending the Survey to 2017

In the 2017, the survey results saw a few changes when compared with 2016. Emerging predictive analytics technology for distribution systems was first introduced into the survey and received the 4th

highest prioritization. This course carries the popular topic of analyzing "Big Data." Energy storage also moved to the highest overall rated course topic. Other observations from the survey results include:

- Some agreement between prioritization of course topics between east and west coast utilities rankings, but still strong differences.
- Major differences between East and West Utilities rankings:
  - DG Interconnection; Solar PV Technologies (East preference)
  - Demand Response; Electric Transportation (West preference)
- Major differences between utilities and universities rankings:
  - Modeling and Simulation; Microgrids; DG Technologies (University preference)
  - Energy Storage; Smart Inverters, Predictive Analytics (Utility preference)
- Top Rated Courses NOT in the GridEd Library Pipeline
  - Micro-Grid Concepts and Designs
  - Demand Response Technologies, Analytics, and Economics
  - Electric Transportation



Priority Weights

High = 5
Moderate = 4
Mild = 3
Low = 2
No Interest = 1

Top Five Topics

West Utility	East Utility
Energy Storage	**DG Interconnect**
Demand Response	Energy Storage
Smart Inverters	Smart Inverters
Data Communication	**Solar PV Tech**
Electric Transportation	**Predictive Analytics**

Figure 3. 2017 GridEd Short Course Prioritization Survey Results

Short Course Library

Over the span of 4 years, GridEd has developed a library of fourteen (14) course topics and thirteen (13) of these courses have been offered with attendance as shown in Figure 4. Course topics that consistently received the highest ratings also have had the most number of participants, including DG Interconnection on Distribution Systems, Applications of Smart Inverter Technology, and Energy Storage

Technology and Applications. There are however other courses, such as business case analysis in the electric utility industry, that have received average prioritization scores but have had higher demand than some of the other courses that received higher prioritization.

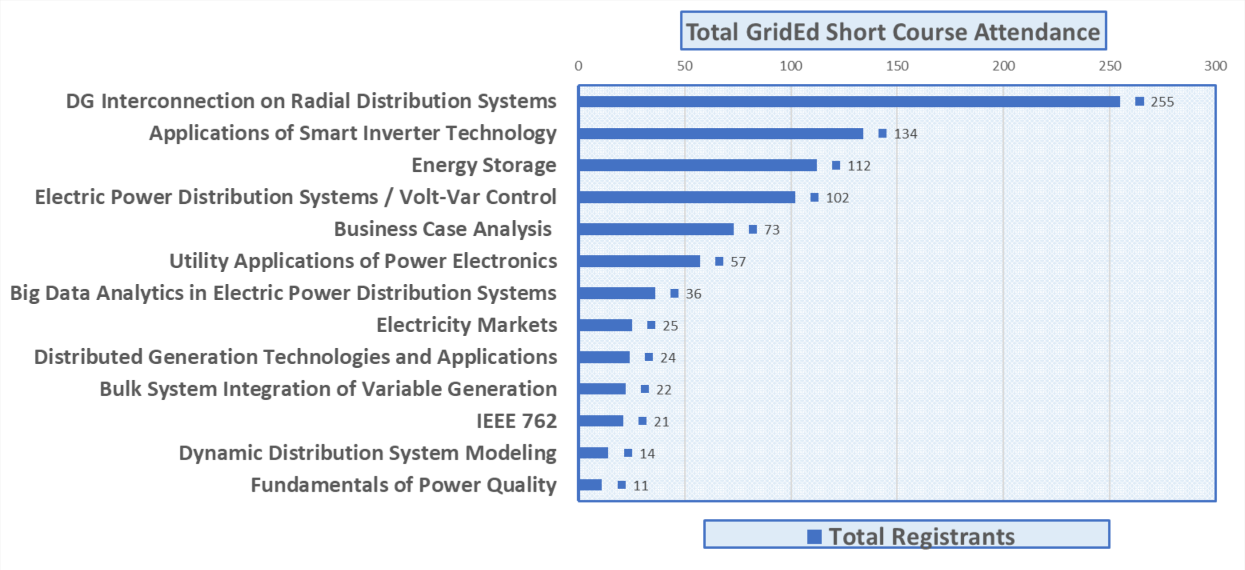


Figure 4. GridEd Short Course and Workshop Offerings (2014-August 2018)
Notes: 891 total participants, 39 short courses, and 2 workshops.

<u>Development of the Basic Course in Electric Power Systems</u>

Although a core course in basic electric power systems was not a part of the GridEd proposal nor was it in the original plan, GridEd learned early that electric utilities were very interested in having access to such T&E materials. The primary driver was related to the hiring of new college engineers where little or no college preparation was provided in electric power systems. A statement from an IEEE PES PEEC Survey from 2015 indicates the data behind what had been discussed at many GridEd advisory meetings and webcasts, that many graduates didn't have a background in power.

"About 70% of Canadian universities have mandatory courses in power engineering for all engineering students while 46% of US universities have mandatory courses for all students. The percentage of universities requiring a power course in the electrical engineering undergraduate curriculum decreased from an all-time high of about 80% in 1994 to about 65% in 2001-02 to about 59% in 2005-06. Almost all universities have undergraduate elective courses in power engineering. Those universities that do not offer elective courses do offer mandatory courses. Mandatory course for all students in a special track, minor, or certificate are offered at 30% of the Canadian universities and 43% of the US universities."[2]

Utilities are having to invest heavily in bringing new hires up to standards in the electric industry before they could school them in the principles and practices of a particular utility. These results pointed to a need for an Electric Power Systems "101" course that taught fundamentals of being a power engineer for students that did not get this education in the university environment. This led to the formation of a

[2] *Electric Power Engineering Education Resources: 2015-16 US and Canadian University Survey Results*. Report from the Power and Energy Education Committee of the IEEE Power & Energy Society. November 2017.

two-semester course equivalent (about 85 lectures), known as the "Basic Course" (see syllabus in Appendix V) that addressed most aspects of fundamental power system analysis.

The development of the Basic Course was assigned to the four Partner[3] universities (Georgia Tech, Clarkson, UPRM, & UNCC) in the east of the GridEd team. The four project leads debated course content for several months before mutually agreeing on a course syllabus. It was decided that material would be recorded as an e-learning experience made available as a public deliverable at no cost to the public at large including the electric industry.

Two utilities and two individuals within those utilities have had a major impact on decisions related to the basic power system course. Both utilities, Duke Energy and FirstEnergy, are active members in GridEd and each had a profound impact on developing the basic power system course. Steve Whisenant (Duke Energy) and Rodney Phillips (FirstEnergy) have been true pioneers in recognizing the deficiency in T&E in power systems engineers and each have made moves to correct the problems.

Steve Whisenant has been tasked by Duke Energy to advance relations with universities in the southeast. Whisenant has a history of university relations and developing T&E programs that relate specifically to the content of the Basic Course. A few years ago, he was developing a similar course inside Duke Energy. It did not quite come to fruition. Later, he was tasked to the formulate CAPER as previously highlighted in this report. Today, Whisenant has taken the Basic Course and he is developing a two-week special course on the principles of basic power systems using GridEd's Basic Course and offering it as a part of the Center for Advanced Power Engineering Research (CAPER)[4].

Rodney Philips conducted an independent study inside FirstEnergy on the preparedness of 67 new graduate electrical engineers spanning a three-year period hired into the company. That study[5] was presented at the IEEE PES meeting in Chicago in July 2017. Key findings were that most of these engineers had not taken a course in power systems. In particular, there was a fundamental absence of the core theories of electric power such as the per unit system, load flow, short circuit analysis, symmetrical components, etc. These deficiencies have caused FirstEnergy to explore new training programs to erase these deficiencies in new staff.

Other Emerging Gaps: The Human Resource (HR) Committee

In pursuit of understanding T&E needs through industry engagement, the GridEd team identified another gap that relates to T&E. Electric utilities have been struggling to recruit qualified electric power engineers for some time. Often, they have chosen good electrical engineers and trained them in electric power systems. That recruiting process has become difficult as well. Further, retention of engineering staff has become progressively more difficult. Most electric utility Human Resources (HR) departments have recognized that T&E is a likely key to both recruiting and retaining engineers. Today's engineer is seeking professional growth in a world where company mobility is a growing trend. This recognition for developing and sustaining a workforce led GridEd to establish an HR Committee. The purpose of the committee is to examine workforce development needs for electric power engineers for the electric

[3] Partner universities are receiving federal funds through the DOE GEARED project.
[4] http://caper-usa.com/
[5] Reforming the Power Engineering Educational Curriculum amid the Industry Transformation, Rodney L, Phillips, Director, Transmission Operations, FirstEnergy Corp, 2017 IEEE PES Meeting, Chicago.

utility industry. A separate report will be issued on this topic. However, it is recognized here that the need for the HR Committee emerged from the "Gap Analysis" effort with electric utilities.

Lesson's Learned from the Gap Analysis

The key thesis of the GEARED initiative was the development of university curriculum that embraced solar and other renewable technologies as well as the merging DER field. As a part of that effort, it became clear that the deficiencies in university systems ran much deeper -- none any greater than the failure to produce "ready to go" electric power engineers. The awareness is now well documented. Multiple movements are underway to correct the situation. However, engineering certification processes are potential barriers to improvement in power engineering training as in Accreditation Board for Engineering and Technology, Inc **(**ABET) where they are making modifications difficult to achieve as engineering curriculum requirements are continuing to decrease hours for achieving a degree. Adding more course structure without removing some existing materials is a difficult at best. Electric utilities now have the deficiencies in full focus and they are expected to step forward to help solve the problem.

There were trends in T&E priorities that were observed in the repeated surveys over the five years of the project. The priority list kept changing as new topics emerged as new issues were emerging to the electric industry.   There was consistency around how DERs would impact the distribution system, however, the speed of change did accelerate. In general, most of the urgency focused on distribution impacts of new technology more than anything else.

The following items recognize some specific "lessons learned" from this experience:

- Unearthing T&E needs from electric utilities requires a structured process to obtain good, high quality information through using a "choice" process.
- A formal T&E activity area is still emerging in the power delivery and utilization sector of the electric utility industry, albeit pockets of T&E are prevalent across facets of the industry.
- The role that T&E will assume in the HR processes of recruiting and retaining engineering workforce is growing as professional growth and development are linked to it.
- Course content needs to be directed at emerging technology areas, however supporting courses need to be included to help understand how legacy processes are impacted by new technologies.

Appendices

Appendix I
GridEd Electric Utility Advisors

GridEd-East	GridEd-West
Arkansas Electric Cooperative Corporation	Arizona Public Service
CPS Energy	Bonneville Power Administration
Central Hudson	Pacific Gas and Electric
Consolidated Edison, Inc.	Portland General Electric
DTE Energy	Salt River Project
Duke Energy	Snohomish County Public Utilities
EcoElectrica	Southern California Edison
Entergy	Tri-State Generation and Transmission
FirstEnergy	Western Area Power Authority
Louisville Gas & Electric and Kentucky Utilities	Xcel Energy
Lincoln Electric System	
National Grid	
New York Power Authority	
Southern Company	
Tennessee Valley Authority	

Appendix II
Short Course Participants from Electric Utilities

Alliant Energy	Missouri River Energy Services
Ameren	North Carolina Electric Membership Corp.
American Electric Power	Pacificorp
Avista Corporation	PowerSouth Energy Cooperative
CenterPoint Energy	PPL Electric Utilities
Dakota Electric	PSE&G
Energy United	Public Service Co. of New Mexico
Eversource	Puget Sound Energy
Exelon Corporation	Sacramento Municipal Utility District
Fortis Alberta	Seattle City Light
Four County Electrical Membership Corp.	Sunflower Electric Power Corporation
Gas Natural Fenosa	The Potomac Edison Company
Hawaiian Electric	The United Illuminating Company
Korea Electric Power Corp.	Tokyo Electric Power Company Holdings, Inc.

Appendix III
GridEd Short Course Options - 2017

1. **Applications of Smart Inverter Technology** -- This course investigates the core theory, modeling and analysis behind smart inverter technology, and its application on the power system. Students will learn relevant characteristics of inverter operation, including topologies,

modulation, maximum power point tracking, grounding, and protection. From the foundational understanding, "smart" functionality will be discussed including control of real and reactive power and low-voltage ride-through. Advanced methods of control such as frequency-Watt and Volt-VAr control will also be covered. The course will then expand to cover the impacts of these techniques on distribution system behavior and PV hosting capacity. Theory-based discussions will be supplemented with simulation, experimental results, and relevant case studies. Recent developments in codes and standards, including UL1741 and IEEE1547 will also be included.

2. **Bulk System Integration of Variable Generation** – This course identifies the challenges and benefits of integrating uncertain variable generation into the bulk electric system. Topics include considerations for grid planners and operators including voltage support and frequency stability, determining operating reserve and flexibility requirements, solar forecasting technologies and methods, as well as various metrics being used for bulk system integration.
3. **Business Case Analysis** -- This course introduces participants to financial and economic principles and practices electric utilities employ to plan and operate power systems. Instructors will lay out a framework for understanding how utilities acquire capital to build assets and manage expenses – the utility cost function. How are investment requirements and operating costs determined and financed? How does that effect the revenue to be collected through rates? What mechanisms can be used to recover costs through rates? What are the implications of customer-side investments in power generation assets? It extends that perspective to consider how those investment decisions are influenced by factors that utilities do not control, market and sector externalities that reflect social interests. Participants can expect to gain a new perspective on how their job influences company decision-making company, and how they can collaborate with others to inform and includes company decision making.
4. **Data Communications Technologies and Analytics** – The use of communication systems and data transfer is a rapidly changing field in electric utility industry. This course will focus first on the fundamental communication technology options such as WiFi, powerline carrier, radio, among other technology choices. System interface designs based on platform approaches will also be explored. Modern metering methods and products will be examined as the needs for metering technique, end-use metering, and other practices are evolving. Other advanced automation practices such as including distributed energy resources (DER), advanced metering Interface (AMI), the OpenADR protocol and other demand response (DR) protocols will be considered. Data formats and structures will be evaluated to determine suitability and best practices will be provided. Size and frequency of information packets will be examined.
5. **Demand Response Technologies, Analytics, and Economic** -- Despite its well-documented and demonstrated benefits to society, utilities, and consumers -- demand response (DR) remains a critically underused resource. One of the key barriers to greater participation is the cost to utilities of installing equipment in buildings and homes to enable demand response strategies. Practical solutions for these problems will be explored. This course will focus on the fundamentals of DR for effective control of air conditioners, water heaters, pool pumps, appliances, lighting, and other large end uses that contribute to peak demand. Further, advanced automated DR research has developed a suite of open source applications that make it possible for users to learn and evaluate the new OpenADR 2.0 specification. Other topics in DR will be entertained as well, e.g., its impact on load shape and energy use profiles that influence distribution system design.
6. **DG Interconnection on Distribution Systems** -- This course provides computational examples that cover key issues that arise when distributed generation is added to radial distribution systems. Key topics include Voltage rise/drop; Voltage regulation; Fault performance and protection; Grounding and Temporary Overvoltage. This course includes material on Smart

Inverter capability and adaptive time overcurrent protection in addition to the traditional methods for identifying DG penetration level limitations. It includes three design case studies as well as a series of on-line quizzes. The case studies will be based on the open source software Open DSS. An OpenDSS tutorial will be provided as part of this course and no previous experience with this software is needed.

7. **Distributed Energy Storage** -- This course focuses on distributed energy storage technologies and applications. The operation and applications of energy storage and battery technologies for utility applications will be explored. The course content spans not only how these technologies work but also the history of their development and use and the benefits that distributed energy storage can bring to generation requirements; transmission and distribution systems; microgrids; and off-grid applications. Students will also learn about the policy, cost, and technical challenges facing the wider use of electricity storage and what can be done to address those challenges.
8. **Distributed Generation Technologies** – A survey of distributed technologies including characterizing the solar resource, photovoltaics materials & electric characteristics, photovoltaics systems, CSP solar, wind power systems, fuel cells, and distributed fossil generation systems. The economics of these systems will be evaluated.
9. **Distribution System Reliability** -- The course will focus on distribution reliability. Typical reliability indices are considered distribution capacity planning, loss of load expectation, expected energy not supplied, other reliability indices, computational methods of those indices and introduction to commercial reliability software. In addition, causes of interruptions will be considered. Rious modeling and analysis methods is explored. The course closes out by examining several case studies.
10. **Distribution System Simulation - Modeling and Analysis** -- This course is directed at modeling with OpenDSS including advanced techniques for analyzing many modern distribution system problems that require time-varying simulations. In particular, emphasis is placed on modeling integrated grid technologies with time-varying characteristics that have potentially disruptive impacts on load profiles, voltage profiles, reliability, and efficiency. Further, problem sessions are included where the class will work through real-world problems in the subject area. EPRI's open-source and freely-available OpenDSS program, which was designed for dynamic distribution system modeling, will be used for the examples. Also, the course provides background on the OpenDSS software tool and illustrates the tool with example cases.
11. **Electric Power Distributions Systems** -- This course focuses on the designs, performance criteria, equipment characteristics, and operational practices associated with electric power distribution systems. Students will learn about proven designs and concepts, while also receiving training on the latest trends and emerging power distribution technologies. The topics covered include: distribution system layouts, substation configurations, feeder configurations, distribution transformers, grounding, voltage regulation, capacitor applications, system overcurrent protection, lightning surge protection, power quality, reliability, automation, distribution planning and distributed generation interconnection issues. The course also covers relevant standards pertinent to system design including ANSI C84.1, IEEE 519, IEEE 1410, IEEE 1366, IEEE 1547 and many others.
12. **Electric Transportation** – This course develops the fundamentals of various electric transportation products and systems for moving people and materials. The properties of electric transport vehicles as in passenger cars, trucks, lift trucks, utility vehicles, vans, and commercial and industrial vehicles will be characterized. Attention will also be directed at infrastructure requirements for charging vehicles with both conventional and fast charge

options.   Finally, utility impacts of all types of electric vehicles will be considered as well possible innovative electric rate structures for charging electric vehicles.

13. **Energy Efficient Technologies** -- Evolving new energy efficient technologies have very different load shapes than classic end-use devices for residential, commercial and industrial applications. Developing appropriate load profiles for conducting electric distribution system analyses is a primary objective of this course. Use of advanced meter and non-intrusive load monitoring technologies to disaggregate end-use loads to support load model development is also advanced. New lighting technologies, advanced motor drives, and other end-use devices will be characterized from a load modeling perspective.
14. **Electricity Markets** – This course teaches the fundamental principles which govern electricity market operation and pricing dynamics. Course participants will learn about the electrical power system infrastructure and reliability operation, and the locational marginal cost based pricing mechanism underlying the wholesale electricity market design. Additional topics include market settlement, the capacity and Financial Transmission Right (FTR) markets, and management of generation portfolios by the load serving entities. Impacts from integrating intermittent renewable generation, energy storage and demand-side resources will also be discussed. An online electricity market simulator that allows course participants to play realistic market clearing scenarios while acting as market participants.
15. **Fundamentals of Power Quality Analysis** -- As the power system becomes more complex in both generation and load aspects, analyzing and solving Power Quality issues can be daunting to the utility and their customers.   In this course, we examine the common power quality issues experienced both on the grid and at the end-use customer. The course will include topics such as harmonics, flicker, wiring, grounding, voltage balance, voltage swells, and voltage sags. The emphasis of the course will be to determine the nature of the power quality issue and what paths should be taken to analyze and solve the power quality issue.
16. **High Voltage and Electrical Insulation in the Power System** – The course covers the fundamentals for the occurrence of impulses in the power system due to lightning and switching operations, transmission line equations and the response of the system to transients, the role of electrical insulation, breakdown mechanisms of insulators, detection of insulation degradation, and insulation coordination and protection methods.
17. **HVDC Transmission and Technology** – This course serves as an introduction to HVDC systems. The course will focus on the system aspects and benefits of HVDC. The VSC-HVDC networks will be reviewed with Classic HVDC. Other considerations include planning methods with HVDC. HVDC systems will be modelled to allow for dynamic assessment performance. Case studies and applications examples will be considered. Special circumstances like Commissioning and operational issues of HVDC links will be considered. The course will close by examining present and future trends for HVDC technology and systems.
18. **IEEE Standard 762** – Power plant performance standards and operation procedures developed for conventional dispatchable generation need to be adapted for variable wind and solar. This is particularly true in areas where variable wind and solar generation are expected to become a relatively large part of the electric generation mix. Performance indices have been established in IEEE Standard 762 and provide definitions for use in reporting both unit and groups of plants. These include time-based and capacity-weighted indexes. This course will address how the indices are used for conventional generation and explore ways and means to cover variable generation in the future. Also covered in this course will be the recent work on NERC Fleet control standards and the Integration of Variable Generation Task Force (IVGTF). The IVGTF has directly addressed a way to consider variable plant output relative to fleet operation and flexibility. Issues of resource adequacy and reserves as well as the fleet's ability to support

system frequency (CPS1) and planning targets for loss of load expectation (LOLE). This course covers the principles of IEEE Standard 762, "IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability and Productivity" (2006 version, reaffirmed 2011). It also explores how plant performance standards need to be adopted for variable wind and solar. The standard provides a methodology for the interpretation of electric generating unit performance data from various systems and it facilitates comparisons among different systems. It also standardizes terminology and indexes for reporting electric generating unit reliability, availability, and productivity performance measures. This standard is intended to aid the electric power industry in reporting and evaluating electric generating unit reliability, availability, and productivity while recognizing the power industry's needs, including marketplace competition. The course includes unit states, time destinations, energy states, performance indices, calculations of indices, and how the standard can be extended from conventional power plants to non-dispatchable solar and wind powered generation.

19. **Lighting** -- This course is designed to provide the attendee with an understanding of lighting and lighting control technologies, an understanding of the true operational nature of lighting technologies, knowledge related to the impact of lighting on grid and end use conditions, an understanding of current trends within lighting, and a grasp on the future of lighting at the grid and end use levels. Though lighting sources are evolving and changing, even innovative technologies have reached a point where their core efficiency improvements are largely incremental not disruptive. Unfortunately, these technologies are still not widely deployed in most applications, so their impact is yet to be seen fully on the utility grid. This fact, paired with modern lighting's ability to be easily controlled, remotely manipulated, and to deliver new and unique functionality, results in a very dynamic marketspace. Additionally, the evolution of lighting technologies, has resulted in lighting discussions now regularly involving a range of factors like harmonics, dimming, efficacy (lumens per watt), lumen output, color rendering index (CRI), correlated color temperature (CCT), and spectrum output. These factors vary widely product to product, and also do not easily allow direct comparisons between technologies. Lighting controls are now beginning to be mandated in certain applications and territories. Embedded lighting controls are beginning to be included in some fixtures as well. Combined these, and other, trends within the lighting control industry offer large savings potential, but their actual savings varies application to application. In fact, controls may not always offer sufficient payback to warrant their use. Additionally, pairing natural light with electric lighting is now a common need, and one which has a range of impacts. Due to these and other factors, the nature and performance of lighting in the future will impact the grid, programs, end use applications, and consumers differently than it does today.
20. **Micro-Grid Concepts and Designs** – The use of microgrids to improve end-use reliability, increase energy efficiency, and provide resiliency in the event of grid outages, has recently become a popular theme for several business areas. The principles and practices of microgrids will be examined and evaluated. In particular, consideration will be given to renewable energy generation and its role in the microgrid. The principles of load/generation balance will be explored. The value proposition for applications to military bases, eager to increase local reliability and decrease reliance on local grids especially with an emphasis on the use of renewable energy sources such as photovoltaic (PV) panels and small wind turbines, moderated by energy storage and fossil distributed generation devices such as microturbines and fuel cells. Agent-based modeling methods will be considered for evaluating performance. Various microgrid control strategies will be designed and evaluated. Also, the role of microgrids supporting system resiliency efforts will be analyzed.

21. **Predictive Analytics for Electric Power Distribution Systems** – This course focuses on applications of predictive analytics on smart electric power distribution systems and the use of Large Scale (Big) Data Analytical methods and their application to electric distribution system analysis and design. The basics of big data analytics and the electric power distribution system will be introduced. Four data-driven applications in electric power distribution systems will be studied closely.
22. **Solar PV Technologies** – This course covers the basics of solar geometry, principles of solar radiation conversion to electric power, materials and electrical characteristics, types of PV systems (residential – autonomous and grid-connected, utility scale, concentrated PV, tracking, fixed tilt, etc.), inverter topologies, technology performance differences, instrumentation & monitoring considerations, operation & maintenance needs, and PV system modeling tools. The economics of PV systems will also be evaluated.
23. **Unbalanced Distribution System Analysis** -- This course creates the analytical frameworks necessary to analyze unbalanced electrical power networks beginning with distribution sub-system fundamentals followed by topography for lines and load modeling, in consideration for overhead and underground systems, the principles of unbalanced operation, physical reasons for unbalance, and unbalanced analysis tools and methods for steady state and faulted systems
24. **Utility Applications of Power Electronics** – The fundamentals of power semiconductor devices and types are presented. In addition, building blocks for power electronic circuits are developed. The course flows by examining fundamental properties of various power electronic devices that are used in electric power systems. This includes such systems as grid tied power electronic converters, stationary energy storage interface, uninterruptible power supplies, power factor correction, active rectifiers, flexible AC transmission systems, and high voltage DC transmission.

Appendix IV
GridEd Short Course Prioritization Survey - 2017

Organizational Information

This survey is intended to help GridEd (http://grided.epri.com) prioritize topics for future short courses aimed at educating power engineers to plan, design, operate and maintain the electric grid of the future. Your input is very important and will help inform the strategic direction of our efforts. The following information is requested to help summarize results by organization and job level.

*** 1. Which organization are you affiliated with?**

*** 2. Which of the following best describes your current job level?**

- ○ Owner/Executive/C-Level
- ○ Senior Management

- Middle Management
- Intermediate
- Entry Level
- Professor
- Graduate Student
- Undergraduate Student
- Other (please specify)

Next

Prioritize Course Topics

Course descriptions can be found in the PDF sent via email titled "GridEd Short Course Options - 2017". If you do not have the course descriptions, please email Amy Feser (afeser@epri.com).

3. Evaluate the importance of each course topic.

	High Priority	Moderate Priority	Mild Priority	Low Priority	No Interest
Utility Applications of Power Electronics					
Demand Response Technologies, Analytics, and Economics					
Lighting					
Solar PV Technologies					
Distribution System Simulation - Modeling and Analysis					
IEEE Standard 762					
Distributed Generation Technologies					
Bulk System Integration of Variable Generation					

	High Priority	Moderate Priority	Mild Priority	Low Priority	No Interest
DG Interconnection on Distribution Systems	○	○	○	○	○
Electric Power Distribution Systems	○	○	○	○	○
Business Case Analysis	○	○	○	○	○
Data Communications Technologies and Analytics	○	○	○	○	○
Distributed Energy Storage	○	○	○	○	○
Unbalanced Distribution System Analysis	○	○	○	○	○
Distribution System Reliability	○	○	○	○	○
Applications of Smart Inverter Technology	○	○	○	○	○
Fundamentals of Power Quality Analysis	○	○	○	○	○
HVDC Transmission and Technology	○	○	○	○	○
Micro-Grid Concepts and Designs	○	○	○	○	○
High Voltage and Electrical Insulation in the Power System	○	○	○	○	○
Predictive Analytics for Distribution Systems	○	○	○	○	○
Electricity Markets	○	○	○	○	○
Electric Transportation	○	○	○	○	○
Energy Efficient Technologies	○	○	○	○	○

Please provide any additional comments to help us prioritize these courses.

Appendix V
Course Syllabus for the Basic Course

1. General Information:
This course is provided as introductory course in electric power systems via GridEd as a part of curriculum development under its U.S. DOE grant from its SunShot Initiative known as Grid Engineering for Accelerated Renewable Energy Deployment (GEARED).

2. Course Description:
Course Title: Basic Power Systems I and II

Course Materials: Video recording of class lectures, instructor's notes (power point presentations), problem sets

3. Purpose:
A two semester course series whose purpose is to provide the fundamentals of electric power systems analysis. In part I we present the primary components of an electric power system (generation, transmission, electricity demand) and their interaction. We develop and present models that allow analysis of single phase and three phase power systems under steady state operation. In part II we present the power flow problem and its solution for three phase power systems. We perform analysis of electric power systems under faulted conditions and introduce fundamental power system dynamics and stability analysis. State-of-the-art industry practice on power systems operations will frame our discussion.

4. Course Goals:
After completing the course sequence, the student should have the tools and practice to analyze and understand balanced single and three-phase power systems under normal and faulted conditions. This college-grade course will prepare engineering students and practicing engineers in the fundamentals of electric power system analysis.

5. Prerequisites:
For Part I students are expected to have an engineering background including college calculus II, differential equations, an electromagnetics course, and circuit analysis (Laplace, Fourier transforms, network equations). For Part II students must complete Part I, or equivalent.

6. Instructional Strategy:
There are two instructional pathways:

Free Open-Access Instructional Materials: A sequence of recorded modular lectures, by multiple lecturers, following the syllabus of this course. Lecture videos, power point presentations, appropriate problem sets and solutions will be provided for free download on the GridEd websites. Reference textbook materials will be identified and are to be purchased separately by the student. The material is intended as a self-taught effort and students are expected to invest, studying on their own, at least the same amount of time invested listening to the recorded classes. The materials are created under Creative Commons Copyright and any person or organization may use these materials for their own purposes.

Fee based guidance through instructional material: Organizations seeking qualified instructional support to help guide participants through the material may approach GridEd to schedule appropriate instructional support. *(This does not limit any organization from providing their own instructional support for students working through this material.)*

7. Textbook and other references:

Textbook: Glover, J.D., Overbye T.J and Sarma, M.S. (2016) Power System Analysis and Design. Sixth Edition. Cengage Learning, Stamford, CT, USA.
Saadat, H. (2010) Power System Analysis. Third Edition. PSA Publishing.
Grainger and Stevenson, Jr. (1994) Power System Analysis. Boston, Maryland: McGraw Hill.

Course Outline and Schedule:

Video tag	Lecture topics	Required reading	Instructor
A1	Energy, apparent, real and reactive power, power factor, Review of phasors	Notes and Chapter 2	S. Meliopoulos/ R. Harley
A2	Single-phase circuit analysis Efficiency and regulation	Notes and Chapter 2	S. Meliopoulos/ R. Harley
A3	Per unit Per unit single phase analysis	Notes and Chapter 2	S. Meliopoulos/ R. Harley
A4	The ideal transformer The practical transformer	Notes and Chapter 2	S. Meliopoulos/ R. Harley
B1	Balanced three-phase circuit analysis, Balanced wye-connected sources; abc and acb sequence, Balanced wye-connected loads, Balanced delta-connected loads, Phasor diagrams	Section 2.5	B. Chowdury
B2	Single-phase equivalent circuits for solving balanced 3-phase circuits, Power in Balanced Three-Phase Circuits	Section 2.5	B. Chowdury
B3	Illustrative examples	Class notes	B. Chowdury
B4	The Ideal Transformer, Equivalent Circuits for Practical Transformers	Section 3.1 and 3.2	B. Chowdury
B5	The Per-Unit System	Section 3.3	B. Chowdury
B6	Three-Phase Transformer Connections	Section 3.4	B. Chowdury
B7	Phase Shift in delta-wye and wye-delta connections	Section 3.4	B. Chowdury
B8	Per-Unit Equivalent Circuits of Balanced Three-Phase Two-Winding Transformers.	Section 3.5	B. Chowdury
B9	Solving problems with three-phase transformers Efficiency and regulation	Class notes	B. Chowdury
B10	Three-Winding Transformers Autotransformers, Transformers with Off-Nominal Turns Ratios, Illustrative examples	Sections 3.6 – 3.8, Class notes	B. Chowdury
C1	Review of Phasors, balanced three phase, per unit analysis and transformers		P. McGrath
C2	Admittance Matrix formulation, direct solution to linear equations, Gaussian elimination. Power flow analysis, iterative solutions to nonlinear algebraic equations	Chapter 6	J. Li
C3	Power flow solution by newton Raphson, control of power flow, sparsity techniques, fast decoupled power flow Load flow network calculations,	Chapter 6	L. Wu
C4	Power flow case studies	Chapter 6	T. Ortmeyer
C5	Three phase short circuits at generator terminals, balance faults on the system, Z matrix, Cb and fuse ratings	Chapter 7	T. Ortmeyer
D1	Definition of symmetrical components	Section 8.1	A. Irizarry

D2	Sequence networks of impedance loads	Section 8.2	A. Irizarry
D3	Sequence networks of series impedances	Sections 8.3, 8.4	A. Irizarry
D4	Sequence networks of rotating machines	Section 8.5	A. Irizarry
D5	Per-unit sequence models of two and three-phase two winding transformers	Sections 8.6-8.8	A. Irizarry
D6	Unsymmetrical faults - system representation	Section 9.1	A. Irizarry
D7	Unsymmetrical faults - single line-to-ground fault	Section 9.2	A. Irizarry
D8	Unsymmetrical faults - line-to-line fault	Section 9.3	A. Irizarry
D9	Unsymmetrical faults - two lines-to-ground fault	Section 9.4	A. Irizarry
D10	Unsymmetrical faults – sequence bus impedance matrices	Section 9.5	A. Irizarry
D11	Definition of Transient Stability	Case Study	A. Irizarry
D12	The swing equation	Section 11.1	A. Irizarry
D13	Simple synchronous machine model and power angle equation	Section 11.2	A. Irizarry
D14	Equal area criterion	Section 11.3	A. Irizarry
D15	Numerical solution to the swing equation	Section 11.4	A. Irizarry
D16	Multi machine system analysis using the classical model	Section 11.5	A. Irizarry
D17	Real time dynamic security assessment	Class notes	A. Irizarry
	Exams		