Education for Workforce Development

A PSERC Future Grid Initiative
Progress Report

Chanan Singh, Thrust Area Leader, Texas A&M

Raja Ayyanar, Arizona State Univ.
James Bushnell, Univ. of California, Davis
Mladen Kezunovic, Texas A&M Univ.
James Momoh, Howard Univ.
Anurag Srivastava, Washington State Univ.

PSERC Future Grid Webinar
March 5, 2013

PSERC Future Grid Initiative

- DOE-funded project entitled "The Future Grid to Enable Sustainable Energy Systems”
(see http://www.pserc.org/research/FutureGrid.aspx)

- Project Objective: Enabling higher penetrations of renewable generation and other future technologies into the grid while enhancing grid stability, reliability, and efficiency

- This webinar’s focus: accomplishments in the research area “Workforce Development.”

Backdrop

- A smart grid with heavy penetration of variable energy sources, integrated microgrids, central and distributed energy storage and distributed communication and computational technologies allowing smarter utilization of resources and consumer participation.
- Greater emphasis on reliability, resilience to physical and cyber-attacks, as well as emergence of new loads and generation operating conditions make monitoring, control and protection of electricity grid challenging.
- These factors, together with emphasis on markets, result in a higher uncertainty in the planning and operation of future energy systems.

Workforce for this Grid

- Workforce needs will happen at various levels : skilled workers, engineers, managers.
- Our concern is with the engineering workforce needed to:
  - design, construct and operate the future grid.
  - to produce innovative ideas and transformative changes to integrate clean and sustainable energy sources.
- *Relevant education of this workforce is critical to the success of the future grid*.

What We Are Doing

- We are acting as an enabling agent.
- Our objective is to develop educational material, books as well as notes, on relevant topics and on background topics required to understand these concepts, and make them available to those interested.
- This will make it possible to teach a variety of subjects as the availability of such material facilitates offering such courses.
- Through this process of collective and collaborative wisdom, cutting-edge research and insightfulness can be made accessible to practicing engineers, researchers and students.

What We Are Doing

- The issues of breadth and depth need to be balanced.
- We need to consider the current gaps in the education of the existing workforce.
- The nature of audience, whether these are school going graduates, working engineers or other energy professionals also needs to be considered.
- We need to utilize the e-learning technologies to provide an as up-to-date education as possible.
- After careful thinking, six specific tasks have been undertaken for this thrust. Some educational materials are focused on providing the breadth and the others on depth in needed areas.

What We Are Doing

- Tasks focused on covering the breadth of the topics needed:
  - PSERC Academy: A Virtual Library of Thousand Short Videos
  - Smart Grid Education (on Synchrophasors) for Students and Professionals
  - Smart Grid Energy Processing
- Tasks focused on depth:
  - Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid
  - Energy Economics and Policy: Courses, Training, and Online Gaming
  - Infrastructure Security: The Emerging Smart Grid

Comprehensive Educational Tools for Reliability Modeling and Evaluation of the Emerging Smart Grid

Chanan Singh
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Education Need and Target Audience

- As the complexity and uncertainty increase, the potential for possible failures with a significant effect on industrial complexes and society increases.
- In these circumstances maintaining the grid reliability and economy is an important objective.
- An important step in this process is to model, analyze and predict the effect of design, planning and operating decisions on the reliability of the system – before implementation.

Education Needs and Target Audience

- This task develops educational material for teaching reliability modeling and evaluation of the emerging power grid with heavy penetration of renewables and massive deployment of computer and communication technologies
- Audience: University-level instructors, Graduate students and other professionals.

Description of the Offering

- Two courses were intended to be developed, one semester long course that can be offered at the graduate level and a short course that can be offered in about six hours.
- The semester long course has been now fully developed and has been offered twice.
- PowerPoints of the short course have been almost completed but videos for explaining these power points are being developed using Camtesia.

Semester Long Course

- This course gives a solid background in probability theory, general reliability analysis methods and those used in power systems. There are nine modules.
- First 4 modules give the background of probability theory, stochastic processes and general reliability theory.
- Next 5 modules give the methodology for power systems including integration of variable sources and cyber-physical power systems.

Short Course

- The short course consists of seven modules.
- Similar to the long course but simpler and shorter.
- It will have accompanying videos for explanation.

Learning Objectives

- Use of probability, stochastic processes and other concepts in modeling for reliability prediction
- Reliability models and analysis tools for generation, transmission, protection and bulk power networks
- Analysis of reliability issues for integrating renewable energy sources into the power grid
- Integrating the cyber components in reliability modeling

Student Feedback to Date

- Semester long course has been taught in the Fall of 2012
- Feedback was excellent: The students reported:
  - Important for engineers and they expect it will help them in the future
  - Well structured.
  - Some said this was the most important material they had and they learnt something new they never saw before.
- Short course in somewhat different version was taught at ISO New England. It was attended by engineers and some Board members. Well received.

Future Plans

- Semester long course will be taught every year.
- Short course will be taught on demand.
- The short course will have accompanying videos.
- If future funding is available, videos will be developed for the semester-long course.

Accessing the Materials

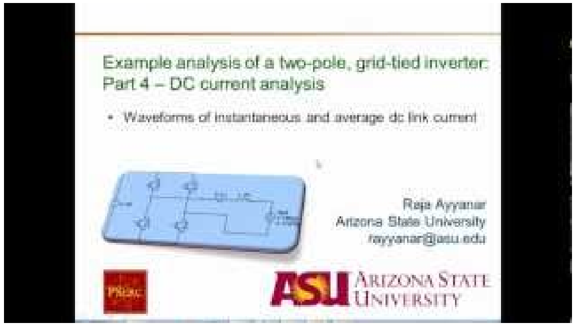
- Both courses will be made available through Texas A&M Website and linked to the PSERC website.

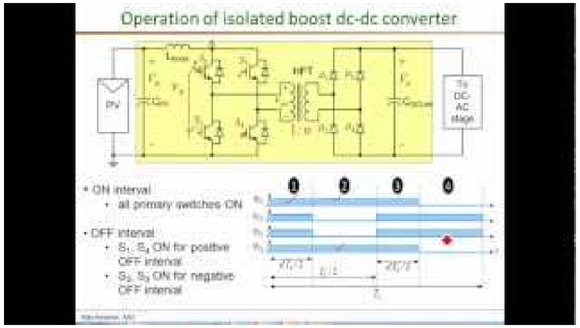
PSERC Academy: A Virtual Library of Thousands of Short Videos

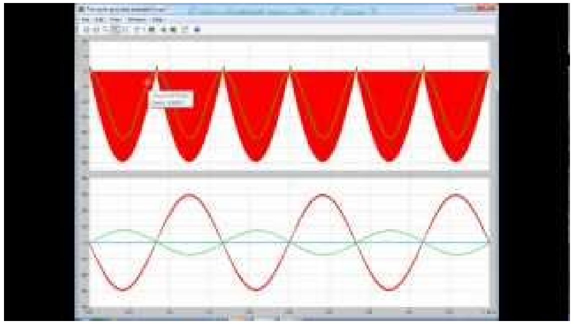
Raja Ayyanar
Arizona State University
(rayyanar@asu.edu)

Overall Objectives

- Create an online library of short (10-15 minute) videos on various topics in sustainable energy systems, smart grid and power engineering
- The vision is to eventually develop several hundreds or even thousands of such videos that will serve as a major online reference source







Workforce Need and Target Audience

- Difficulty in offering specialized university courses in the broad area of power engineering
- Need to accommodate different paces of learning among students
- Limited flexibility in traditional course delivery

- Target audience includes university students in power engineering and related fields
as well as practicing engineers

Description

- Topics cover major aspects of power engineering and sustainable energy systems in clearly defined modules complementing university courses

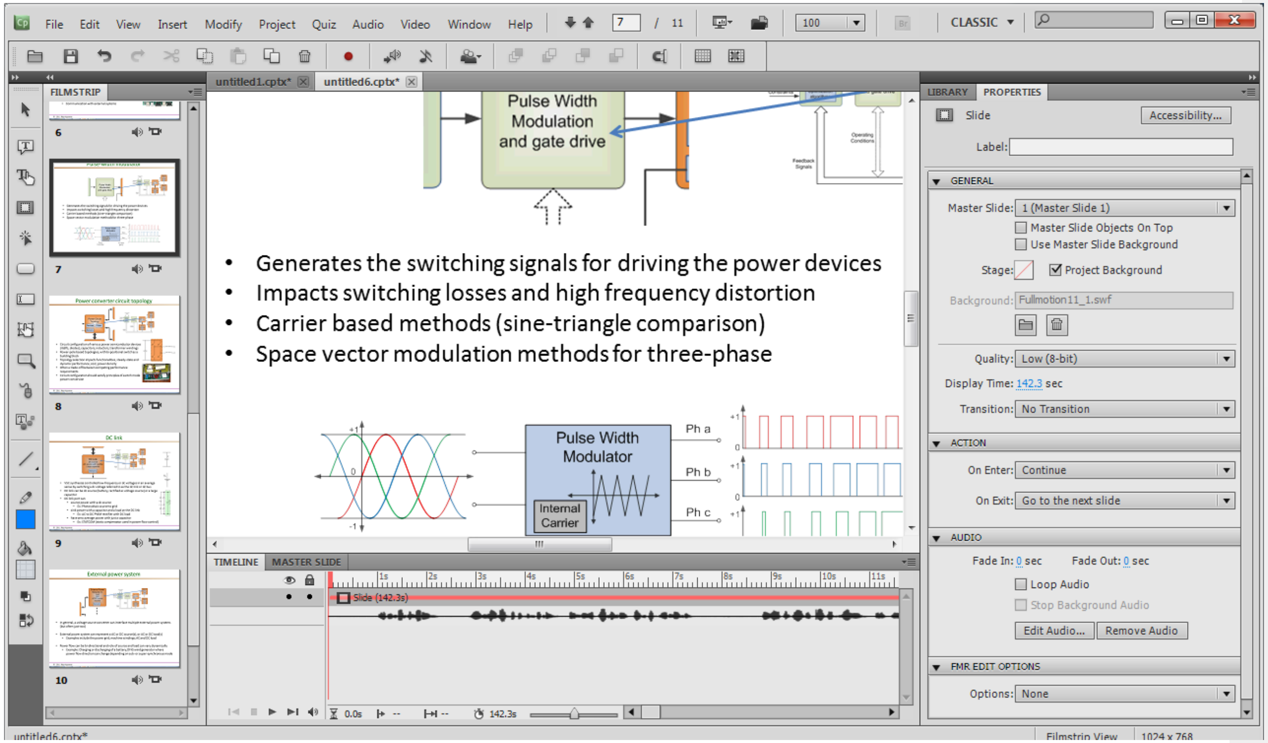
- Initial modules
  - Power electronics
  - Photovoltaics systems and grid integration
  - Grid integration of wind energy

- A wide range of delivery methods including
  - PowerPoint lectures with audio narration
  - Interactive animations, simulations, movie clips
  - Online exercises and online peer-to-peer correspondence, feedback

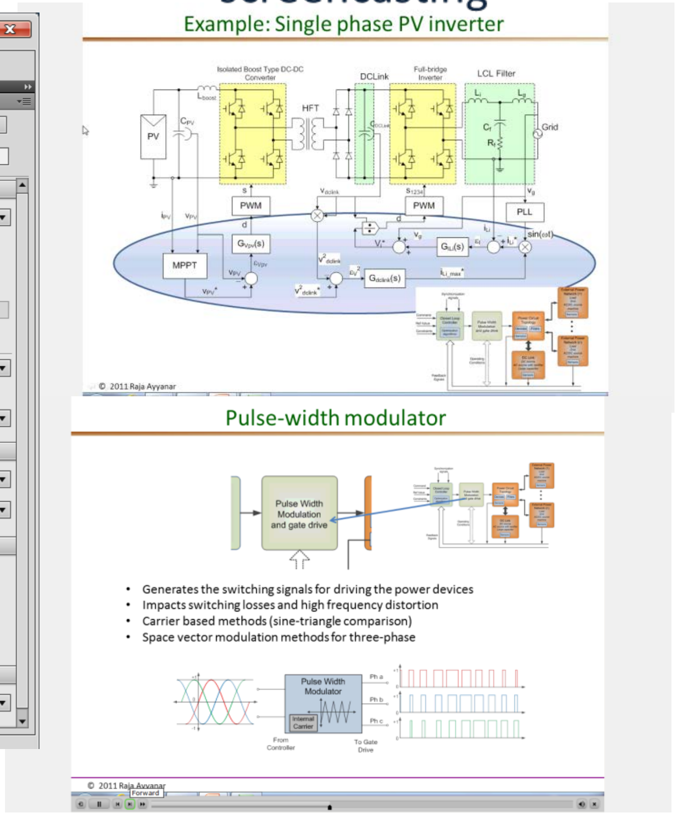
Screencast Method for Videos

- Screencast techniques using *Adobe Captivate*
- Easy to use a variety of tools including power point, simulations, animations and other programs

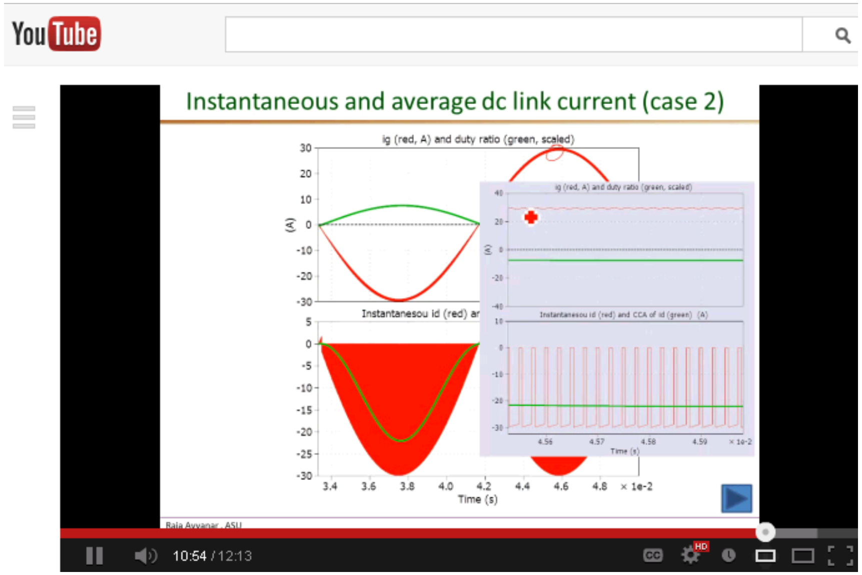
Screencast process

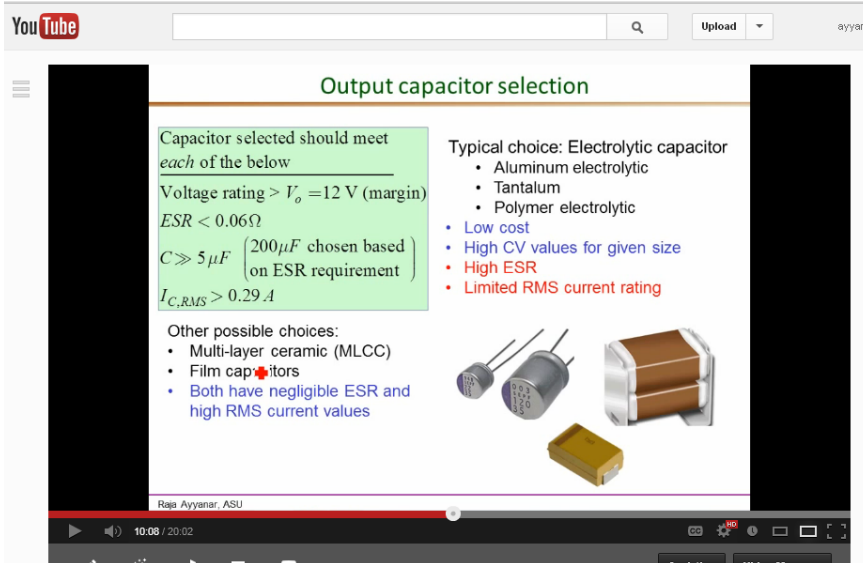


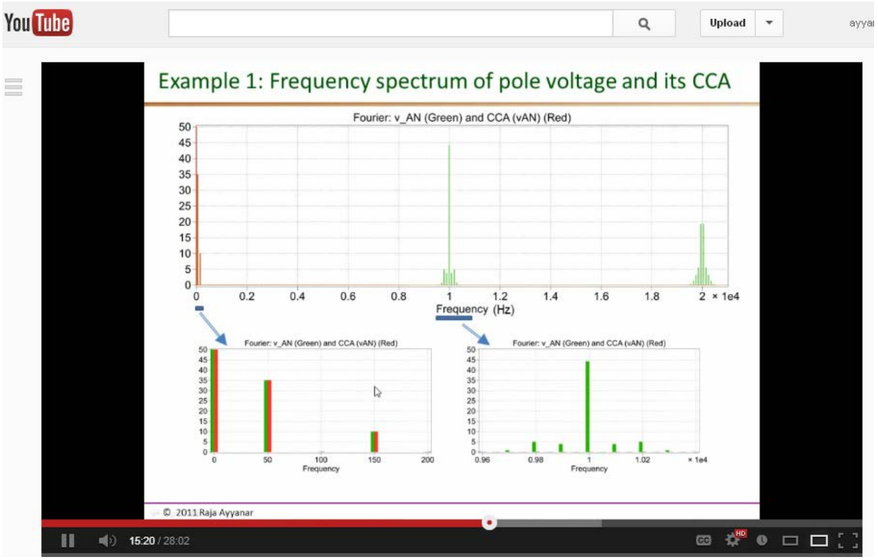
Sample outcomes of screencasting



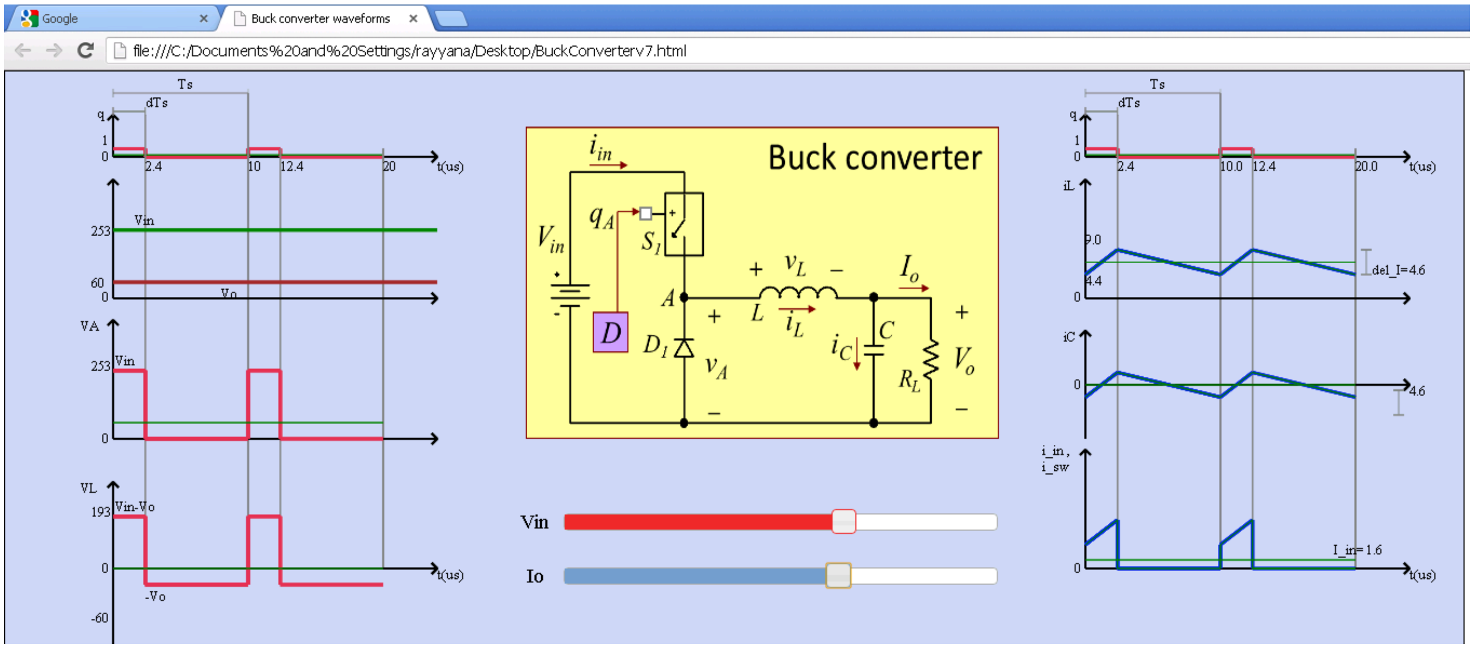
Screenshots of Sample YouTube videos

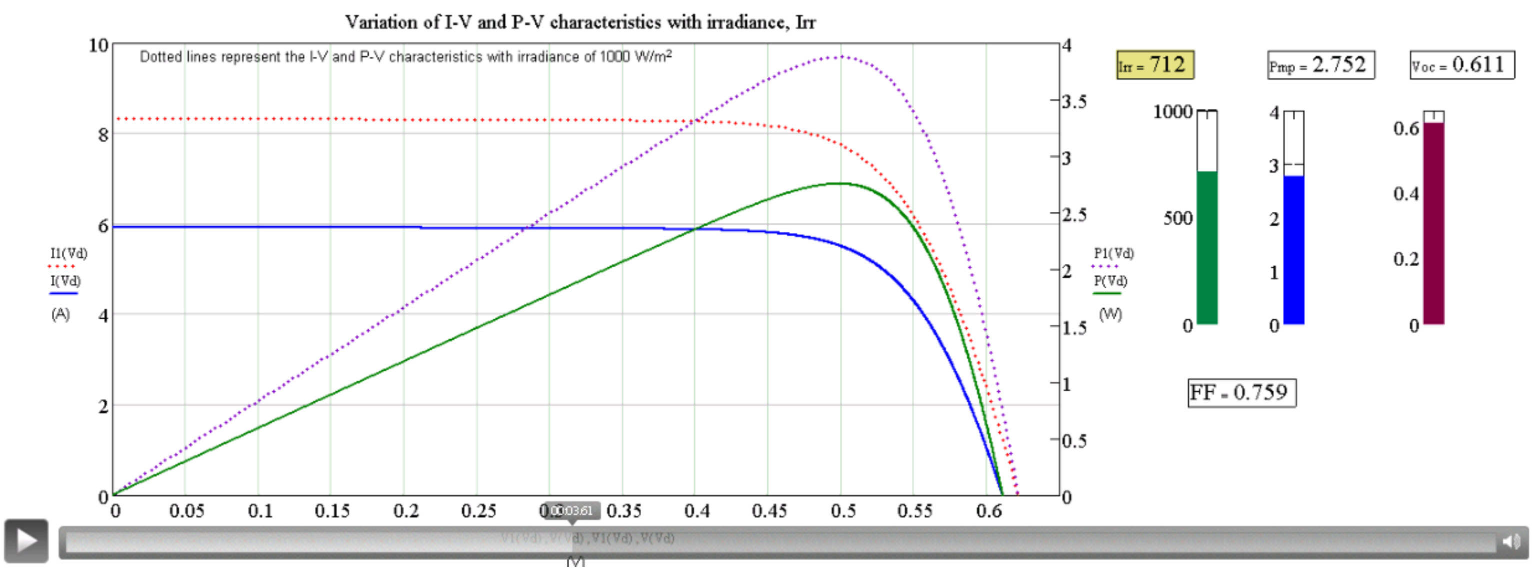






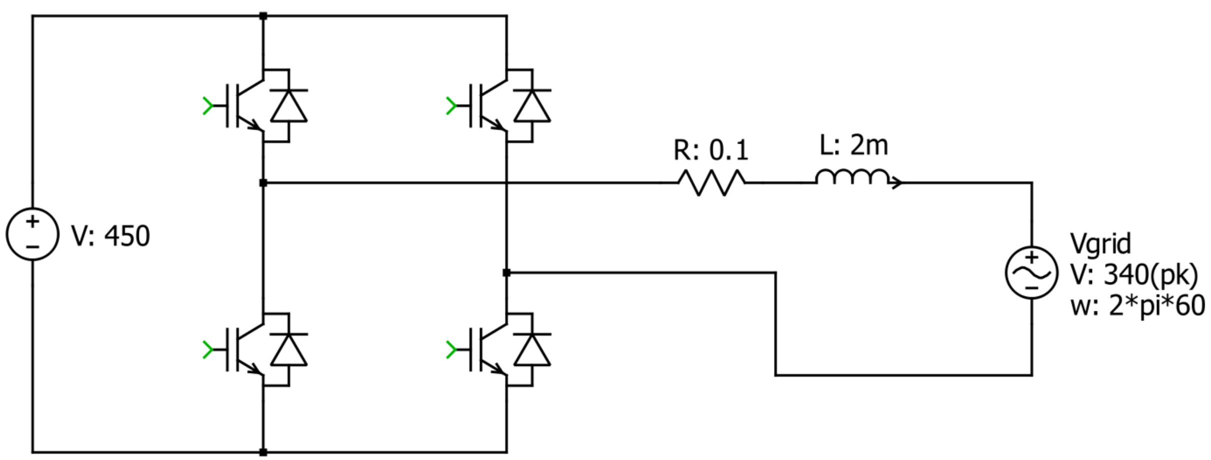
Highly User Interactive Animations





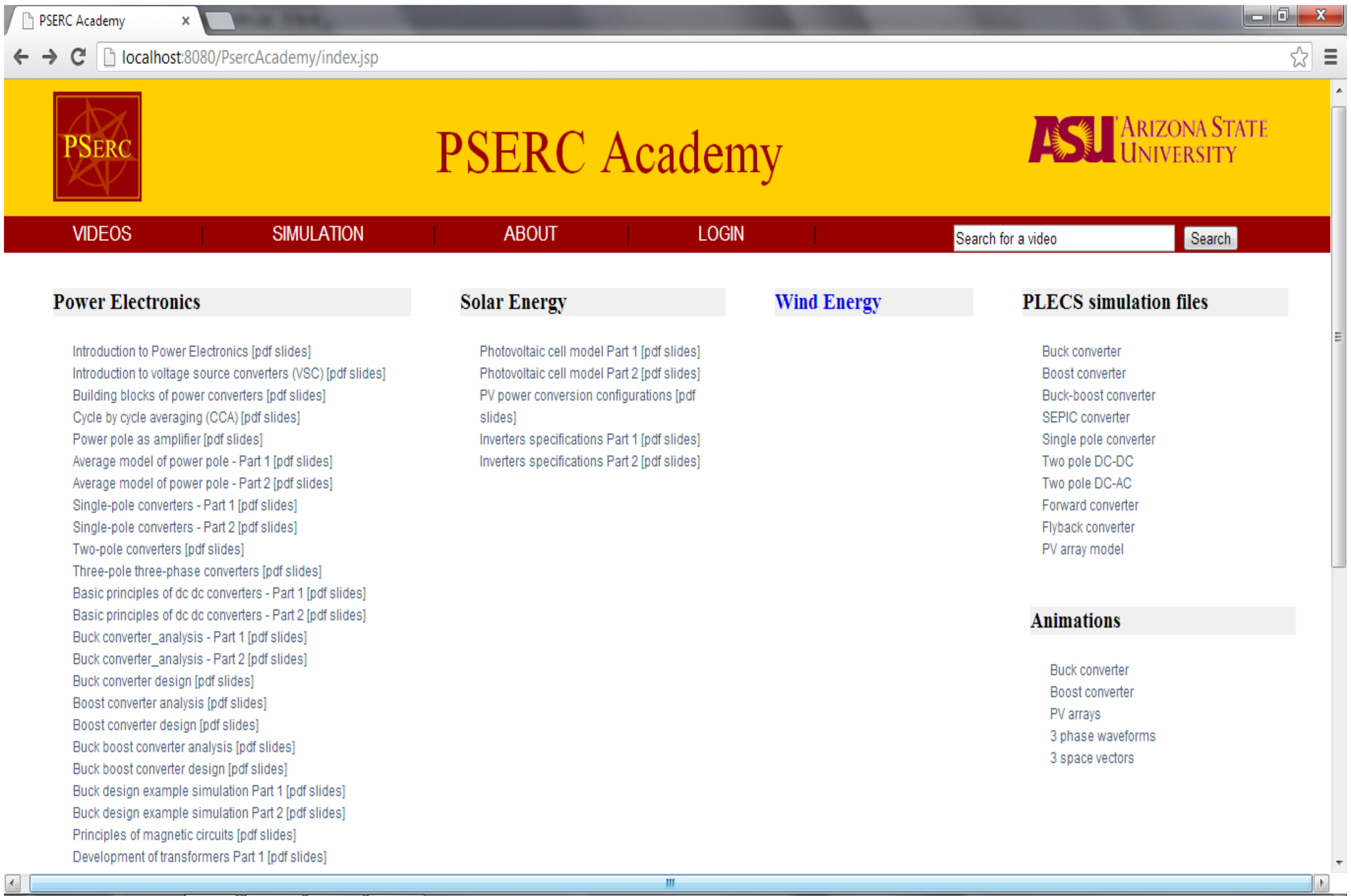
Power Electronics and Systems Simulations

- PLECS (Piecewise Linear Electrical Circuit Simulation) simulation files to be made available through the PSERC Academy website
- Working with Plexim (developers of PLECS) to offer these as ‘Demo files’ for public use with some restrictions on circuit modifications, saving changes etc.



Accessing the Materials: PsercAcademy.asu.edu

- Dedicated website under construction with search and interactive features with the video links (YouTube), lecture material, simulations and animations



Plans for Future Use

- PsercAcademy.asu.edu expected to go live by end of March with initial modules on power electronics and PV systems
- Obtain feedback from the PSERC community and beyond, and refine the style and contents of videos and other material
- Seek funding for sustaining this initiative
- Seek partners for developing videos on other aspects of sustainable energy systems

Smart Grid Education for Students and Professionals

Research Team:

Mladen Kezunovic, Texas A&M Univ.

Sakis Meliopoulos, Georgia Tech

Alex Sprintson, Texas A&M Univ

Mani Venkatasubramanian, Washington State Univ.

Vijay Vittal, Arizona State Univ.

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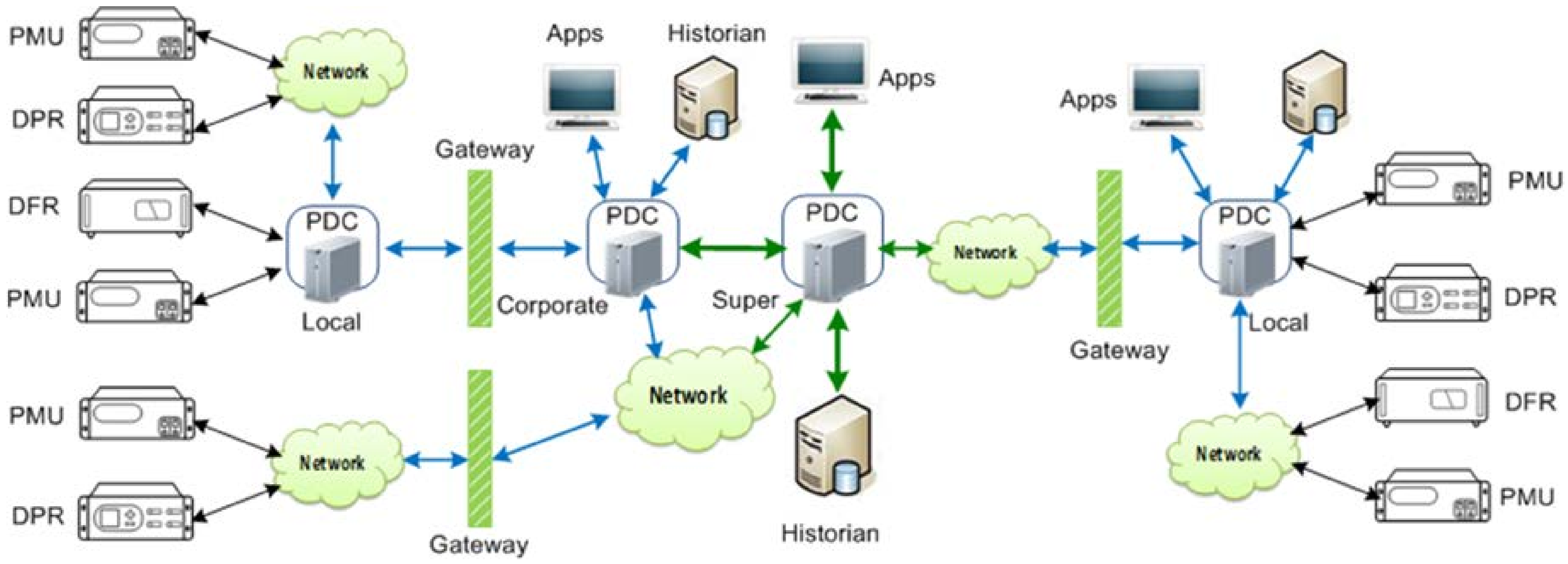
Background: Growing Adoption of Synchrophasor Technologies



Task Description

- Write a book on PMU applications and produce supplemental materials for course use
- Target audience: professionals and students
- Commercial Availability: Early 2014
- Objectives
  - Promote a better understanding of synchrophasor technology in the academic and engineering communities
  - Shed light on what it takes to implement the technology
  - Stimulate research, more elaborate engineering solutions, and more strategic approaches to wide-scale adoption

Book Contents

- Synchrophasor Fundamentals (Meliopoulos)
- Monitoring Applications (Venkatasubramanian)
- Stability Assessment and Control (Vittal)
- Protection and Fault Analysis Applications (Kezunovic)
- Energy Management Applications (Meliopoulos)
- Synchrophasor Communication (Sprintson)
- Standardization and Interoperability (Kezunovic)
- Future Directions (all)

Example Topics

- **Kezunovic**: Fault location, wide area disturbance detection, testing and certification of synchrophasor technology
- **Meliopoulos**: EMS applications, dynamic state estimation and SE based protection
- **Sprintson**: GPS signal communication, PMU-PDC communication, QoS requirements and testing
- **Venkatasubramanian**: detection of angle, voltage and small signal instability
- **Vittal**: DT for on-line transient stability assessment, control for islanding

Future Work (new team)

- Big Data
  - Streaming PMU Data
  - Automated revenue metering (ARM)
  - Condition-based and electrical measurements
  - Weather, Lightning, GIS data
  - Market Data
- There is a wealth of information in these datasets.
- Methods for managing, processing and visualizing such data may create material for a new book

Energy Economics and Policy: Courses and Training

James Bushnell
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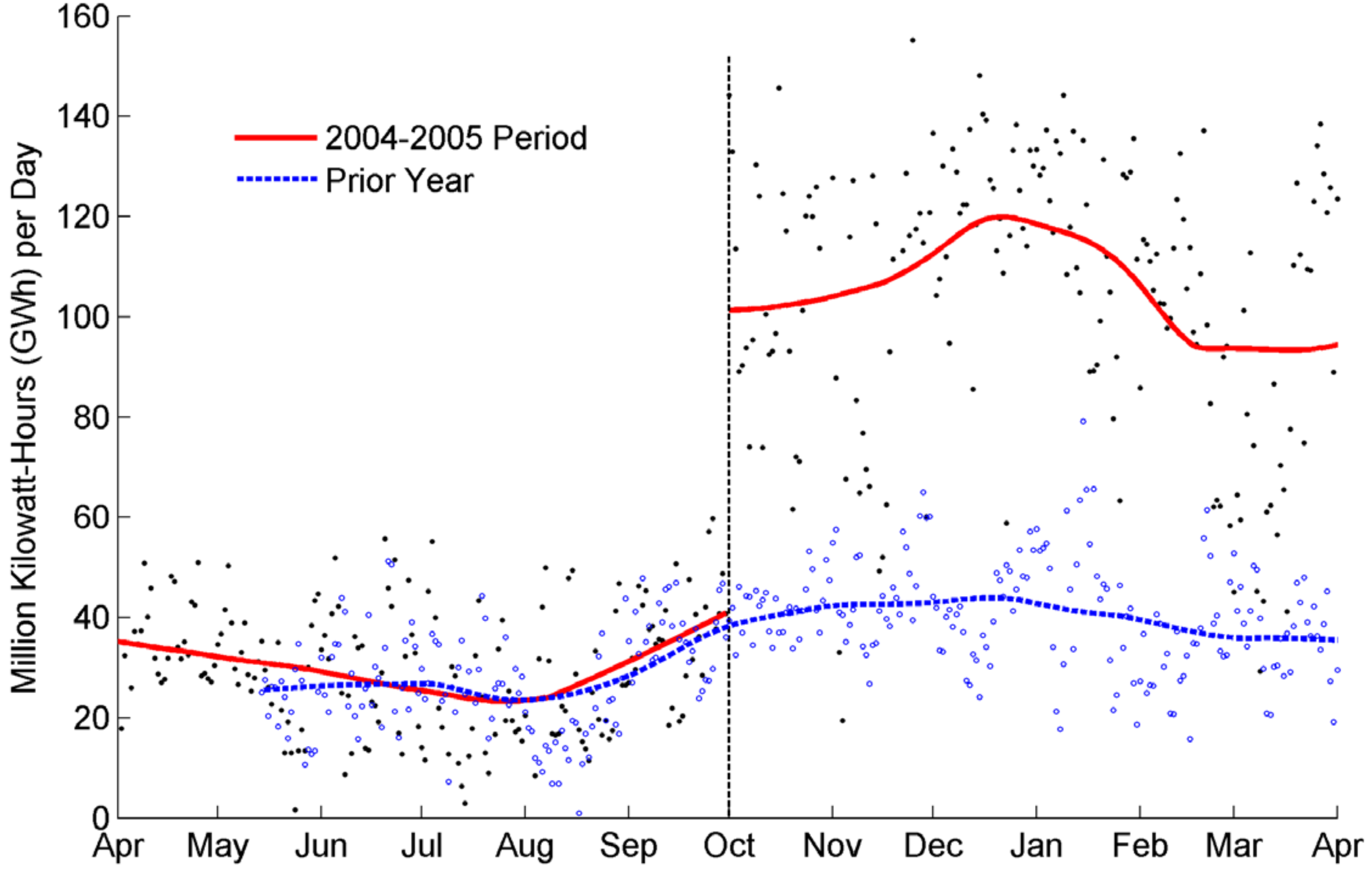
Motivation: Economics Matters

Impact of PJM Expansion on Day-Ahead Net Exports:
Midwest → East



Source: Mansur and White, 2012

What does energy economics have to do with smart grids?

- The effectiveness of new technology depends upon *if* and *how* it is used.
- In electricity, adoption and use depends upon
  - Regulatory environment
  - Market structure and organization
  - Consumer behavior
  - Incentives!

Objectives

- Instruct future energy industry professionals and researchers on the economics of energy markets.
- Convey real-world experience blending advance micro-economic concepts and energy-industry case-studies and simulations.
- Expand and refine interactive learning tools such as the Electricity Strategy Game.
- Provide exposure to the leading economic research on the organization, regulation, and operation of energy markets

Multiple Target Audiences

- Masters-level course aimed at graduate students in economics, engineering, sciences and public policy offered through Haas School of Business at Univ. of California, Berkeley
- Research-level (PhD) material offered through Department of Economics at Univ. of California, Davis
- Practitioner-level material already offered through short courses at ISOs and Univ. of Cal. campuses
  - Attended by staff from utilities, ISOs, state regulatory commissions and other regulatory agencies

Course Topics

- Regulating Natural Monopolies
  - Incentives, productivity, consumer prices
- Regulatory retail pricing
  - Dynamic pricing, non-linear tariffs, consumer behavior
- Market Structure and Competition
  - Oligopoly, vertical integration, transportation
- Environmental Regulations and Energy Markets
  - Cap-and-trade, Clean Air Act, alternative energy policy

Electricity Strategy Game

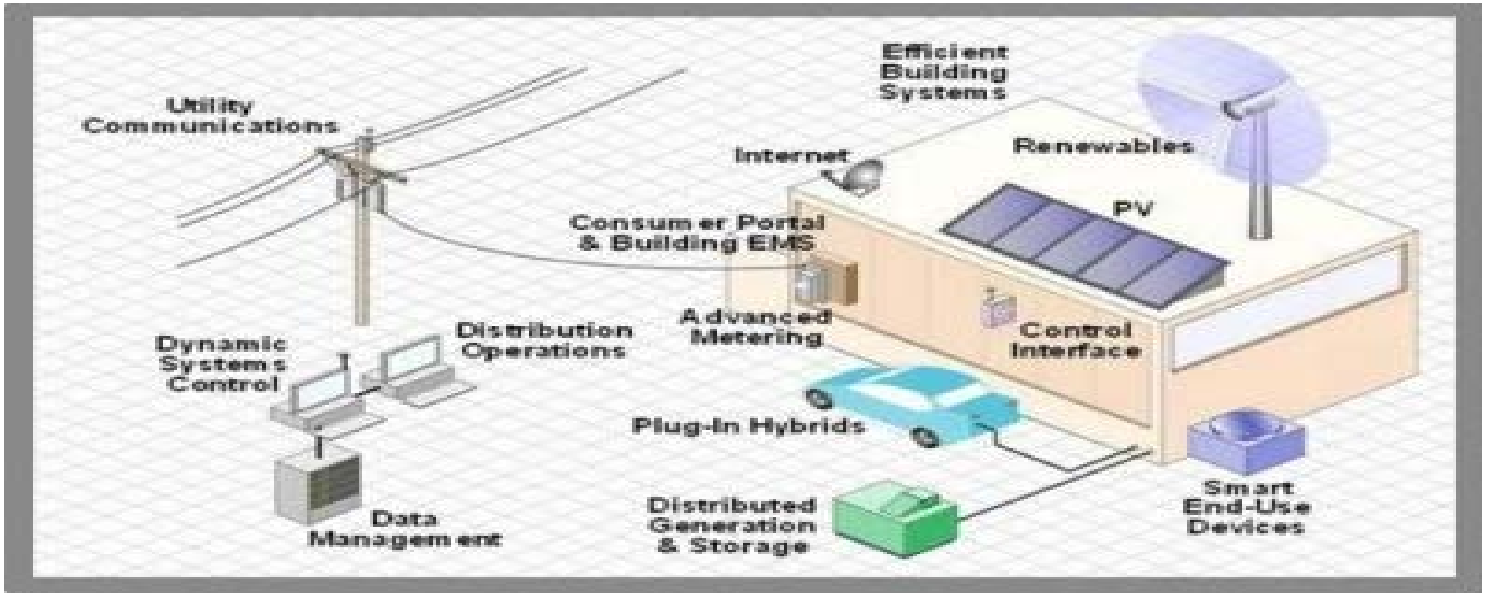
- Teams evaluate and purchase generation portfolios
- Portfolios are bid into daily spot markets
- Teams experience impact of varying market design elements
  - Auction design, transmission congestion, forward contracts
- Versions now in use at UC Berkeley, Stanford, Michigan, MIT, Yale, Dartmouth and others.

Electricity Strategy Game: Web-Based Interface

Accessing the Materials

- Course Materials
  - Syllabi, extensive reading lists, lecture materials, thought questions, exams
- Materials will be made available online for access by instructors at accredited non-profit institutions.
- Electricity Strategy Game
  - Software and documentation for running the game
  - Web-based bidding interface and results
  - Access to https://esg.haas.berkeley.edu/ is available upon request)

Energy Processing for Smart Grid



James Momoh
Howard University
(jmomoh@howard.edu)

Education Need and Target Audience

- Objective: Develop a university course on energy processing for the smart grid.
- Need: The overall need is to re-energize the interest in power system engineering. Educational material is needed for teaching renewable energy, storage facility, energy processing, measurement techniques, and smart grid technologies/systems.
- Audience: This university course is for undergraduates and first year graduate students in the field of power engineering.
- Status: The course is currently being taught with the new materials.

Learning Objectives

To develop competency in problem solving, design, analysis of technical challenges in the development of technologies for deployment of energy processing and smart grid network. The course covers the following topics:

1. Fundamentals of Energy Conversion Principles
2. Tracking and Evaluation of the Renewable Energy Resources
3. Storage Techniques/ Options
4. Fundamentals of Smart Grid
5. Energy System Controls
6. Real Time Measurement for Smart Grid
7. Communication , Protocol, Standards, Security, and Protection of Smart Grid Devices

Description of Energy Processing for Smart Grid Course

1. Fundamentals of Energy Conversion Principles

Content

•Three Phase Power
•Load Types
•Magnetic circuits
•Transformers
•Classical Machines
•AC/DC Machines
•Converters & Inverters
(Modeling and Characteristics)

Student Assessment

Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also do research paper on emerging trend related to the module's contents.

Module Duration

•2 weeks

Reference

•Text books
•Published papers

2. Tracking and Evaluation of Renewable Energy Resources

Content

•Renewable energy resources including solar, wind, hydro, biomass, etc
•Modeling
•Characteristics Evaluations in terms of: efficiency, reliability, cost, interconnectivity, etc

Student Assessment

•Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also do research paper on emerging trend related to the module's contents.

Module Duration

•3-6 weeks

Reference

•Text books
•Published papers

Description of Energy Processing for Smart Grid Course

3. Storage Techniques/ Options

Content

Study of various storage techniques including batteries, pump hydro, flywheel, etc.

•Study includes areas such as

1. Energy storage characteristics
2. Efficiency
3. Cost
4. Reliability
5. Environmental impact

Student Assessment

•Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also do research paper on emerging trends related to the module's contents.

Module Duration

•2 weeks

Reference

•Text books
•Research papers
•Published papers

4. Fundamentals of Smart Grid

Content

•Overview of Smart Grid concepts, fundamentals, and design
•Types of devices
•Advancements
•Measurement tools
•Matrix of performance
•Security Issues
•Communication requirements

Student Assessment

•Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also perform experiments and do research papers on emerging trend related to the module's contents.

Module Duration

•3 weeks

Reference

•Text books
•Published papers

Description of Energy Processing for Smart Grid Course

5. Energy System Controls

Content
•Local & Wide area control
•Smart Grid performance Matrix
(Voltage & frequency load control)
•Real time control
(Phase Measurement Unit-PMU)
•State Estimations
•Devices

Student Assessment
•Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also do research paper on emerging trends related to the module's contents.

Module Duration
•3-6 weeks

Reference
•Text books
•Published papers
•Advanced Books in Power Systems, Stability, and Control

6. Real Time Measurement for Smart Grid

Content
•Concepts and Applications of Phasor Measurement Unit, Smart Meters, Instrumentals, Protection devices, and Intelligent Electronic Devices-IEDs.

- **Communications**
  Remote Terminal Unit-RTU, SCADA, Energy Management Systems-EMS, Distribution Management System-DMS
- **Advancements**
  Modern Substations, Distribution Automation

Student Assessment
Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also do research paper on emerging trends related to the module's contents.

Module Duration
•3-6 weeks

Description of Energy Processing for Smart Grid Course

7. Communication , Protocol, Standards, Security, and Protection of Smart Grid Devices

Content

- Data Encryption and Decryption
- Protection
- Computation Analysis
- Communication controls
- Security Options

Student Participation

Students will be assigned homework and tested on their knowledge based on the content of the module. Students will also perform experiments and do research papers on emerging trend related to the module's contents.

Module Duration

- 3-6 weeks

Reference

- Text books, research papers, and published papers

Featured Text books

1)Title

Electric Power Distribution, Automation, Protection And Control

Author

James A. Momoh

Year Published

2008

2)Title

Smart Grid-Fundamentals of Design and Analysis

Author

James A. Momoh

Year Published

2012

Fundamentals of Energy Systems Course

- There was a need at Howard Univ. to redesign an introductory course for juniors.
- This course was developed from a subset of the materials from the proposed Energy Processing for Smart Grid course.
- The course has been approved by Howard and juniors are taking it this semester.
- The following slides describe the course.

Description of Fundamentals of Energy Systems Course

- Introduction to Power Systems, Single phase and three phase circuit analysis
- Understand magnetic circuit analysis, magnetic properties of materials, transformer theory and applications.
- Review basic primary energy sources and applications to central power generation
- Understand the fundamentals and applications of solar and wind energy technologies I
- Introduction to Power Electronics Converters (Inverters and Converters]
- Understand the principles of operation and design of three phase AC machines
- Understand the principles of operation and design of induction and DC Machines.
- Review of Smart Grid Fundamentals
- Understand the fundamentals of Transmission model and power flow analysis
- Understand the Use of PSpice and MATLAB in energy conversion performance analysis and power flow packages

Description of Fundamentals of Energy Systems Course

Laboratory

- Measurement Techniques tools such as watt meters, Smart Meters Lab for power networks
- Introduction to the power simulation tools such as PSpics, MATlab and other power flow tools.
- Experiment on different renewable energy resources and different load types
- Machine dynamics and control for AC, DC and induction machines and transformers
- Introduction to power electronics converters
- Smart grid design experiment

Student Feedback to Date

- Students now appreciate current trends in the provision of energy, especially as related to the integration of renewable energy and storage facilities into the power network.

- Students have also come to appreciate the interdisciplinary component of the development of the future energy system.

- Finally, students appreciate more the knowledge gained from previous classes that they have taken because they are able to see the direct application of that knowledge to power network development.

Future Plans

- A portion of this course has been approved to be taught to juniors ECE student at Howard University via a new course called “Fundamentals of Energy Systems” which will replace the currently taught energy conversion course.

- The energy processing and smart grid course developed can be taken as elective by senior and graduate studies with no background in smart grid and energy studies.

Accessing the Materials

Lecture notes will be collated into a book that will be published and available for purchase from bookstores. An online e-book version will also be available upon request.

Current references in support of the course are spooled from:

- Text books e.g

  1)Title

  Electric Power Distribution, Automation, Protection And Control

  Author: **James A. Momoh**

  Year Published:**2008**

  2)Title

  Smart Grid-Fundamentals of Design and Analysis

  Author: **James A. Momoh**

  Year Published:2012
- Published papers

The completed course material syllabus will be available to other schools via the internet.

Design and Development of a New Smart Grid Course at Washington State University:

'Critical infrastructure security: the emerging smart grid'

Anurag Srivastava, Carl Hauser, and Dave Bakken

Washington State University (asrivast@eecs.wsu.edu)

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Education Need and Target Audience

- Need: The increasing convergence of power, communications, and information network is creating a need for new multi-disciplinary skill sets for the power industry employee. Furthermore, an aging and retiring workforce adds to this challenging problem.

- Audience: Students and university-level instructors

Course Description

- Designed a course with multi-disciplinary content integrating topics from data communication, computing, control, cyber-security and power systems that are relevant to secure operations of smart grids.
- Designed a course to target audience of senior undergraduate and graduate engineering and computer science students (CS/EE, UG/G).
- Designed a course that could be offered to online distance engineering students or engineers from industry as well as in the conventional classroom setting.

Course Description

- Designed course materials to be easily adopted by instructors at other schools.
- Designed course evaluations that allow us to assess course outcomes and improve the content
- Team Taught by Anurag Srivastava – power systems aspects (6 lectures), Carl Hauser – computer networking (6), Dave Bakken – computation and distributed systems (6), Min Sik Kim – cyber security basics (6), Joint: cases (4)
- Take-home group mid-term, final exam, and final project, 2 individual quizzes, 4 home works
- Text book: Book chapters and online references

Learning Objectives

At the end of this course, student will:

1) Understand the basic principles of smart grid components and operation
2) Understand the principles of communication networks, data management, distributed computing and cyber security
3) Be able to critically analyze the interdependencies of related infrastructure in the smart grid needed to sense, communicate, compute and control in secure way
4) Be able to apply the interdisciplinary principles that you have learned in building secure smart grid infrastructure

Student Feedback to Date

Offered as ‘Critical infrastructure security: the emerging smart grid’

Spring 2012

- Pullman Campus:- CptS: UG 7 G 1, EE: UG 4 G 11
- Tri-Cities Campus:- CptS: UG 4 G 2, EE: U 0 G 0 (Class scheduling problem)
- Online: 24

Spring 2013

- Pullman Campus:- CptS: UG 2 G 3, EE: UG 2 G 15
- Tri-Cities Campus:- CptS: UG 0 G 0, EE: U 0 G 4

Student Feedback to Date

- Evaluations from 15 of 27 students
- Overall rating
  - 33% excellent
  - 40% good
  - 13% neutral
  - 13% poor or very poor
- Course was well organized
  - 47% strongly agree
  - 47% agree
  - 7% neutral
- I believe I learned in the class
  - 80% very often
  - 7% sometime
  - 13% few times

Student Feedback to Date

Student Feedback

- Too much information per session; cut down and emphasize the basics
- Too many professors – hard to know what is expected
- Group work on exams (not project) was “unpleasant”
- Spend more time on real-world applications

Faculty Feedback

- It was a very challenging class to design and teach
- Many were bored and others terrified at any given time
- Lectures hard to design to reach both EE/CptS students
- Final projects were actually pretty good and interesting, except in a few cases

Future Plans

- Try to integrate details about networking/power/computing/security topics around a few case studies that each involve at least two of the topics
  - E.g., Talk about AMI and its smart grid role and couple it with a detailed discussion of IP/UDP, symm. key encryption
  - E.g., Talk about monitoring and control, discuss SCADA, DNP3, and its encapsulation in IP/TCP
- We need our own notes rather than selecting chapters from topic-specific textbooks.
- Background reading list – "you should be familiar with this"

Accessing the Materials

- Course material will be available in Summer 2013 (improved one in 2014)
- More information available at:
  - Srivastava, Anurag K.; Carl Hauser, David Bakken, and Min Sik Kim. *Design and Development of a New Smart Grid Course at Washington State University.* IEEE PES General Meeting, San Diego, CA, July 2012.
  - Srivastava, Anurag K.; Carl Hauser, and David Bakken, "*Study Buddies*", IEEE Power and Energy Society Magazine, vol. 11, issue 1, pp. 39-43, Jan. 2013
- Online offering for certificate (this may change to online degree program in the long term). It will be available through the WSU global campus.

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