Electric Energy Systems Curriculum

With Emphasis on
- Renewables
- Smart Delivery
- Efficient End-Use

ONR-NSF-EPRI-AEP Workshop
Corvallis, OR July 21-25, 2009
Group Effort:

- Ned Mohan
- Bill Robbins
- Bruce Wollenberg
- Paul Imbertson
- Tom Posbergh
- Dr. Narain G. Hingorani (Project Consultant)
- Students

www.ece.umn.edu/groups/power
Past Sponsors:
Lab Development Grants:
• NSF CCLI-EMD
• NASA
• ONR

Initial Dissemination Grant: NSF CCLI-ND
Present ONR Dissemination Grant:
Program Officer: Terry Ericsen
(1.23 Million Dollars over 5 years)

Supported by:

• NSF
• EPRI
• AEP
Outline:

- Problem
- Approach and Results
- Available Resources
- Dissemination Goals
- Brief Description of the Courses
Workforce Crisis:

- Serious shortfalls predicted


BPA Workforce:  Source: Clark Gellings, EPRI

- 2,944 employees
- Median age is 50
- 21% eligible to retire by 12/07
- 42% eligible to retire by 12/11

BPA Employee Age (as of 3/9/06)

Data Source: HRMIS as of 2/9/06
Crisis in Undergraduate Education in Power Engineering

- Courses have not kept pace with Industrial Practices

HVDC Projects in North America

Role of FACTS – SVC & STATCOM
We can all agree....

- Goal: Increase Quality and Quantity
- Faculty Resources are Limited
Is there a Faculty Hiring Freeze at your University?

1. Yes
2. No
“The new wind projects account for about 30% of the entire new power-producing capacity added nationally in 2007 ....”

Solar is today where wind was 5-8 years ago.
Young People are Concerned about the Environment - We can tap into their enthusiasm to make a difference and provide them a career path.
Wind Generation: Example of an Integrated System

BULK Power System
161 kV

Zero-Voltage Ride-Through

Time

Generator

690 V
34.5 kV

60 Hz

Power Electronics Converters

0 – 690 V
10 – 60 Hz
Our Integrated Curriculum – Only 3 Courses

Complementary Courses:
- Analog/Digital Control
- DSPs, FPGAs
- Programming Languages
- Heat Transfer
- Thermo

Students are Broadly Trained; They can work in any field of EE.
Increasing Student Enrollments –

2008-2009 Enrollments:
Power Systems: 90
Power Electronics: 118
Electric Drives: 124
Resources:

**Power Electronics:**

**Electric Drives:**

**Power Systems:**

**Software Lab:**
MATLAB/Simulink
PowerWorld
PSCAD-EMTDC
2008 Annual Workshop
Napa, CA Feb 7-9, 2008

2009 Annual Workshop
Napa, CA Feb 13-15, 2009
(Nearly 150 participants; 35 ECE Dept Heads)

2010 Annual Workshop
Tucson, AZ Feb 4-6, 2010
Weeklong Summer Training Workshops:
(sponsored by ONR-NSF-EPRI-AEP)

- Oregon State University
- July 4-6, 2010
- In collaboration with Prof. Ted Brekken of OSU
Goal of ONR/NSF Grants

Supported by EPRI & AEP:

Affect Curricular Change in at least 175 Schools Nationwide

– Adapted so far in various combinations at > 100 schools

Parallel International Effort
Next Step: Online Course Modules

- Certificates for Practicing Engineers
- Use in Courses at other Universities (ABET: 432)
- Graduate Courses and Certificates

Center for Innovation – Electric Energy Systems (CI-EESE)

- Midwest ISO
- New York ISO
- ISO - New England
- Air Force Research Lab
- Hamilton Sundstrand
- Ulteig Engineers
- UMCEE Members

Benefit to Members: Courses are free to all their employees
Membership Fee: 10,000 $/year
Characteristics of Online Courses:

- Modular
- Tightly-Coupled to our Textbooks
- CEUs/PDH
- Low Cost: $70/Module
Pedagogy-

Motivation:

- Students are actively engaged

Procedure:

- Pre-class: watch a 20-minute module and answer a brief online quiz
- During-class: discuss and solve real-world, design-oriented, somewhat open-ended problems in small groups
- Post-class: homework problems on individual basis
Course in Power Electronics

Enables Power Exchange between:

- DC ⇔ DC
- DC ⇔ AC
- AC ⇔ Variable Frequency AC
Example:

Cross Sound Cable HVDC Light Project

Schematic Single Line Diagram

- United Illuminating
- ABB supply
- 345 kV
- 346 MVA
- ±150 kV
- 330 MW
- 200 kV
- New Haven
- 25th 41st 21st
- 61 32 10 Mvar
- Shoreham
- 21st 41st 25th
- 10 32 61 Mvar
- Long Island Power Authority
- 138 kV
A Common Topology: Voltage-Link Converters

Switching Power-Pole: Building-block of converters
- Synthesis by Pulse-Width Modulation
- Bidirectional Power Flow

\[ q_A = \text{1 or 0} \]
Average Representation of the Switching Power-Pole:

Feedback Controller Design assisted by PSpice:
Converters for DC and AC Motor Drives:
Topics Covered in this Course:

- Switch-Mode Converters
  - Buck, Boost, Buck-Boost
  - Flyback, Forward, Full-Bridge
  - DC and AC Motor Drives
  - Power-Factor-Correction Circuits
- Feedback Control
- Thyristor Converters

Textbook:
- Presentation Slides
- Solutions Manual
Course on Electric Drives

Teaching Machines as a subcomponent of Drive Systems

- Harnessing of Wind Energy
- Electric and Hybrid-Electric Vehicles
Course Objectives:
- Analyze
- Control
- System Design (not machine design)

Two Common Principles:

\[ f_{em} = B i \ell \]

\[ e = B \ell u \]
Use of Space Vectors:

Similar to use of Phasors:
Physics-based Analysis:

\[
dT_{em}(\xi) = r \hat{B}_r \cos \xi \cdot \ell \hat{I}_s \cdot \frac{N_s}{2} \cos \xi \cdot d\xi
\]

\[
T_{em} = 2 \times \int_{\xi=-\pi/2}^{\xi=\pi/2} dT_{em}(\xi) = 2 \frac{N_s}{2} r \ell \hat{B}_r \hat{I}_s \int_{-\pi/2}^{\pi/2} \cos^2 \xi \cdot d\xi = (\pi \frac{N_s}{2} r \ell \hat{B}_r \hat{I}_s)
\]
Topics:

- Designing for the Mechanical Load
- DC Motor Drives
- Permanent Magnet AC Drives
- Induction Motor Drives: Steady State and V/f Control
- Stepper and Switched-Reluctance Drives
- Feedback Control
- Power Quality Considerations

Textbook:

- Presentation Slides
- Solutions Manual
First Course on Power Systems

Generator

Step up Transformer

Transmission line

Feeder

Load

13.8 kV
Balanced Coverage of Topics

- Changing Landscape and Resources
- Apparatus in Generation & Delivery of Power
- Analysis and Operation
- Fault Protection

Textbook:
- Presentation Slides
- Solutions Manual
**Price Derivation at Locations A & B**

- The LMP at B is $20/MWh. An increment of load at B can be met at lowest bid cost by dispatching the generator at B at a price of $20.
- The LMP at A is $40/MWh. An increment of load at A can be met at lowest bid cost by dispatching the generator at A at a price of $40. Incremental generation at B cannot serve load at A, because part of it would flow on the line from B to C, violating the limit on this line.
Wind and demand correlation.

Balancing market prices, April 22, 2009, \$/MWh

- North Zone Price
- South Zone Price
- West Zone Price
- Houston Zone Price