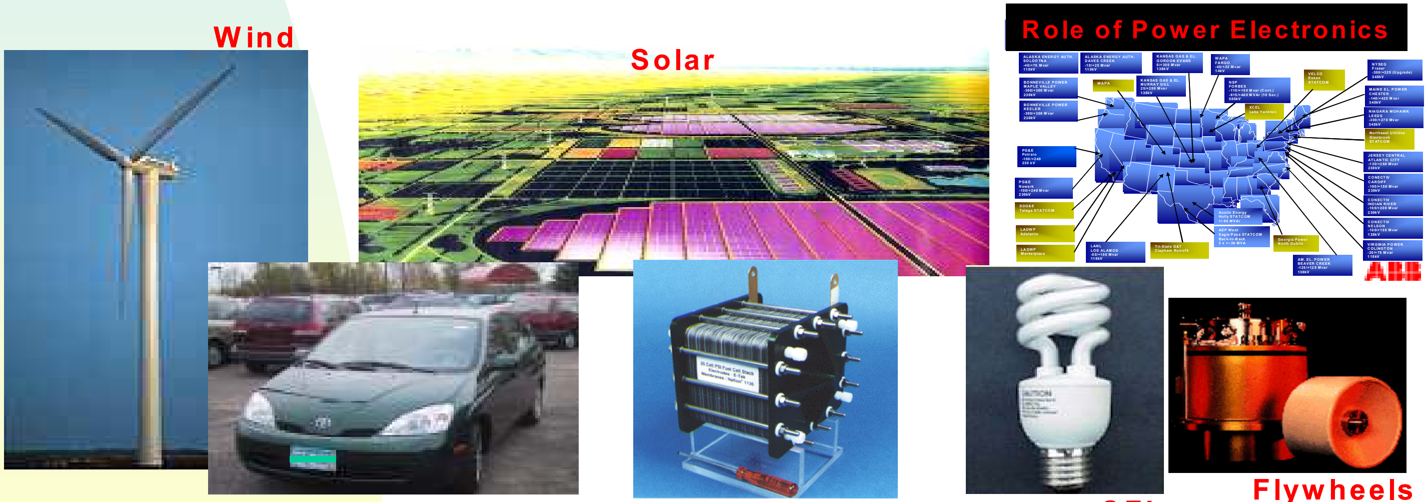
Electric Energy Systems Curriculum

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

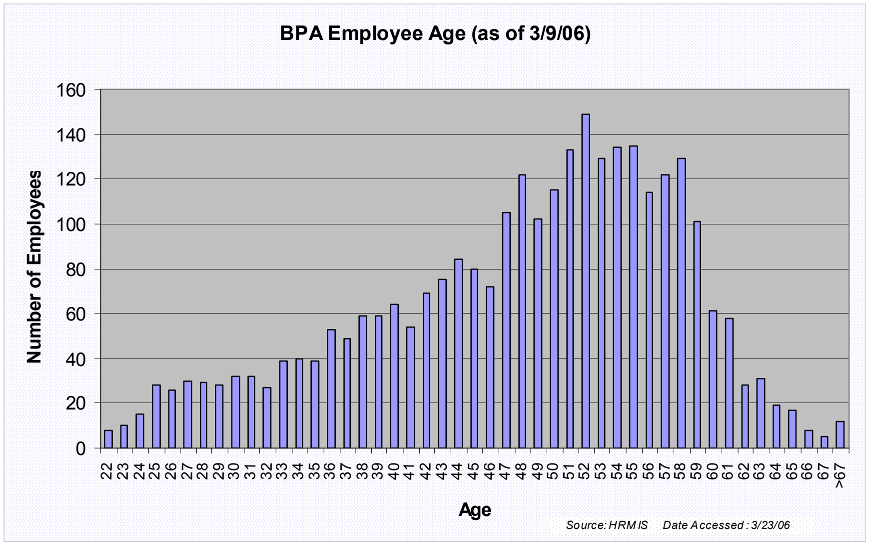
Workforce Crisis:

- **Serious shortfalls predicted**
  - **NSF-Sponsored Workshop in Arlington, Virginia Nov, 2008**

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)

Source: HRMIS Date Accessed: 3/23/06

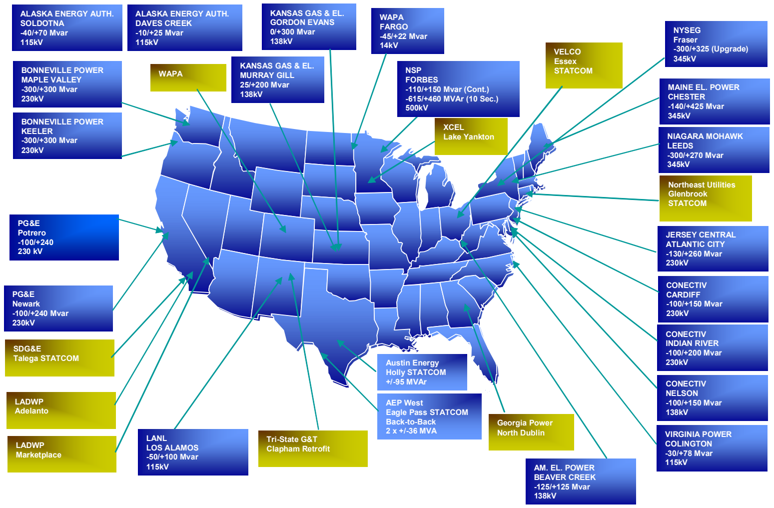
Data Source: HRMIS as of 2/9/06

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 <u>and</u> Quantity
- Faculty Resources are Limited

Is there a Faculty Hiring Freeze at your University?

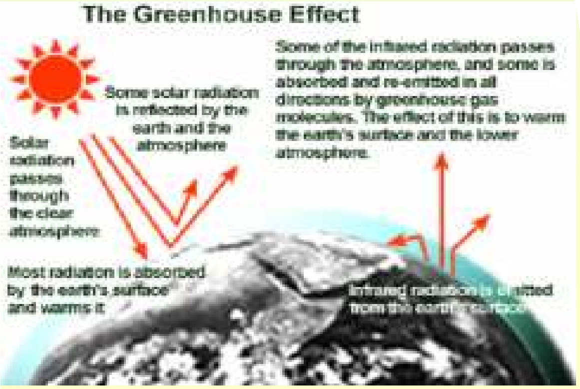
1. Yes
2. No

“ The new wind projects account for about 30% of the entire new power-producing capacity added nationally in 2007 ….”

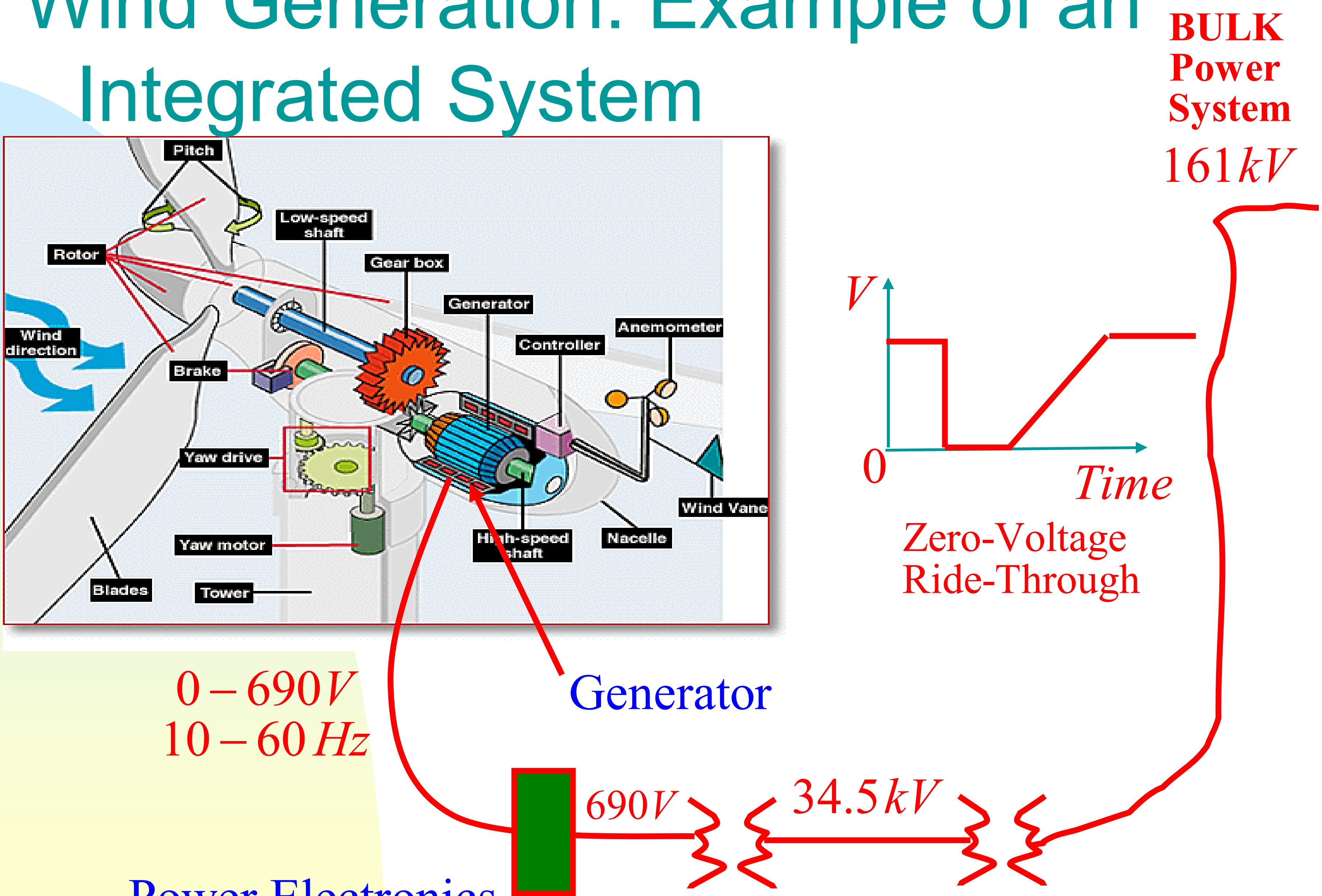
Solar is today where wind was 5-8 years ago.

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

$0-690V$
$10-60\,Hz$

Generator

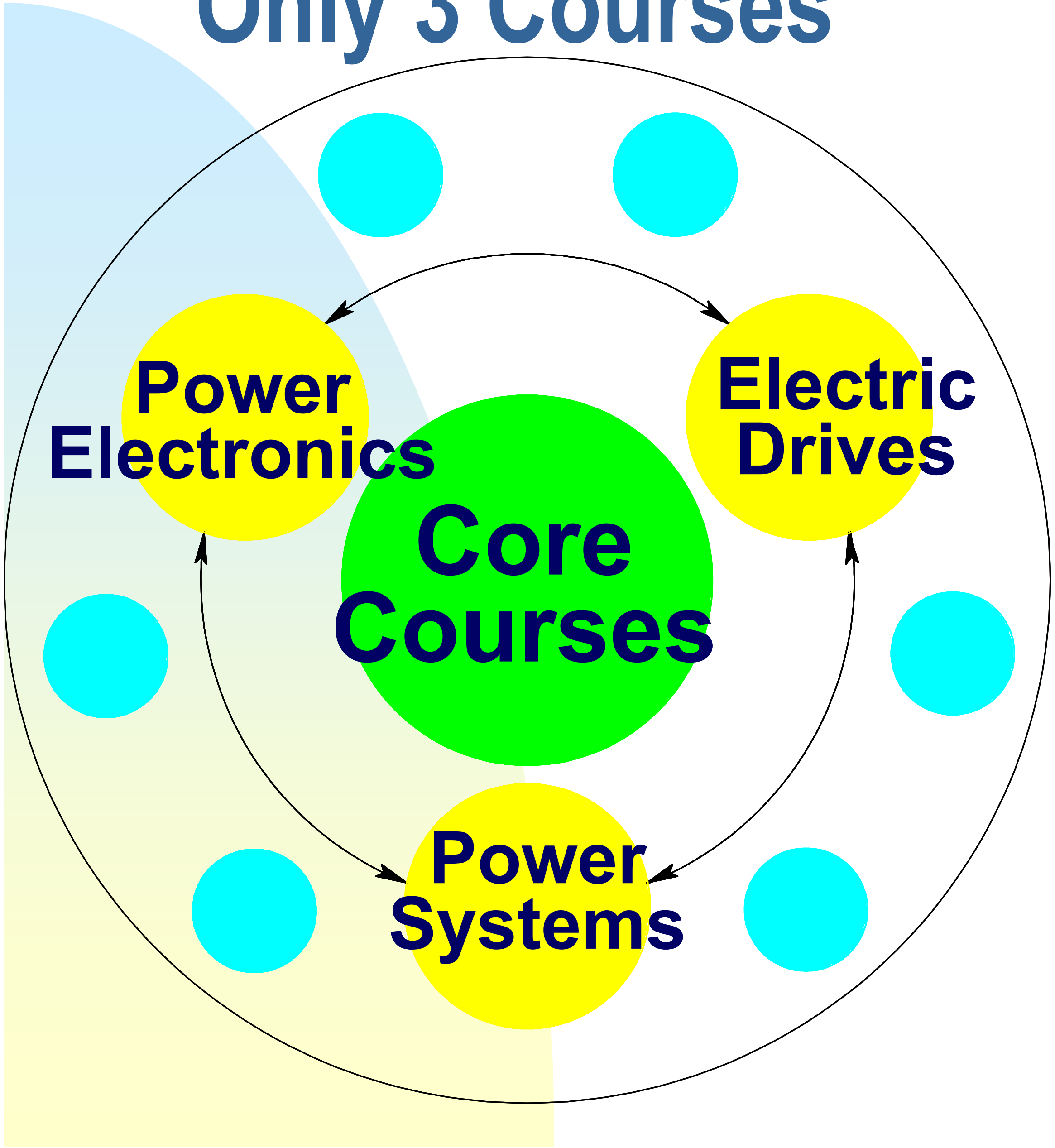
$690V$

$34.5kV$

$60\,Hz$

Power Electronics Converters

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 :

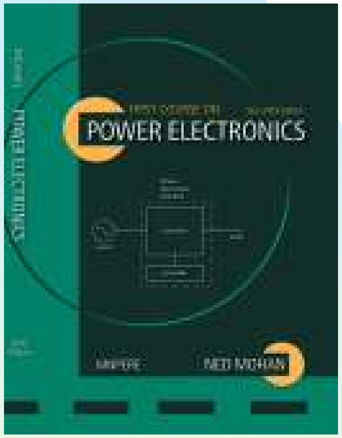
Power Systems: 90

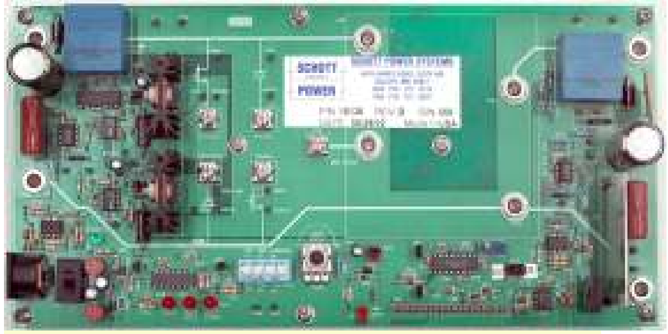
Power Electronics: 118

Electric Drives: 124

Resources:

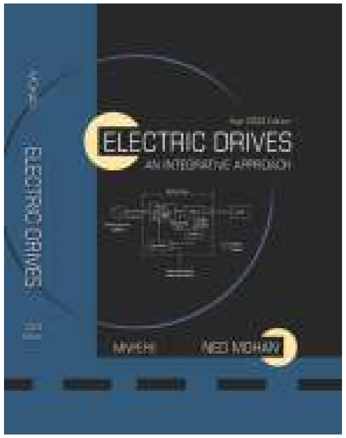
Power Electronics:



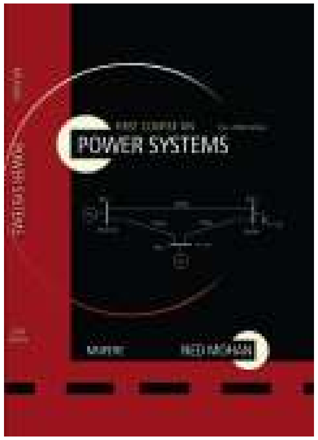


PSpice Lab:

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

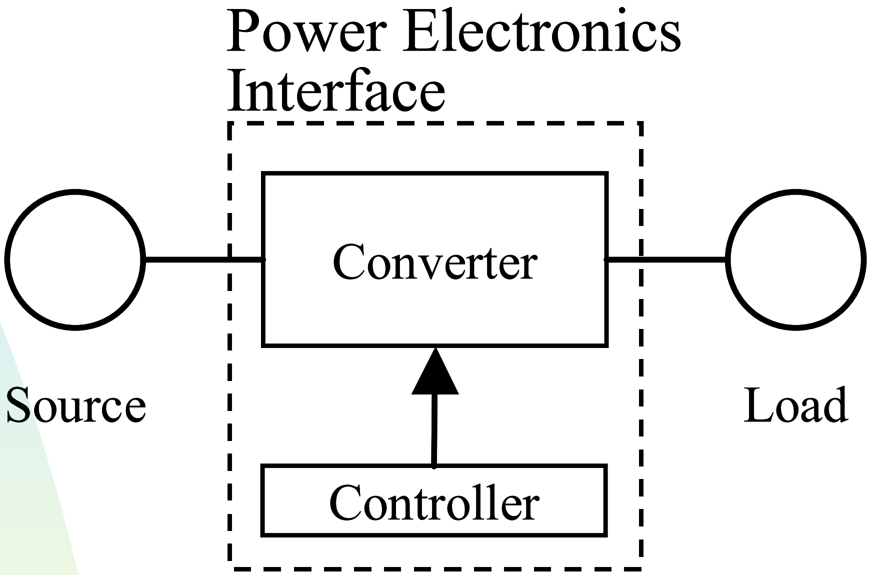
Characteristics of Online Courses:

- 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



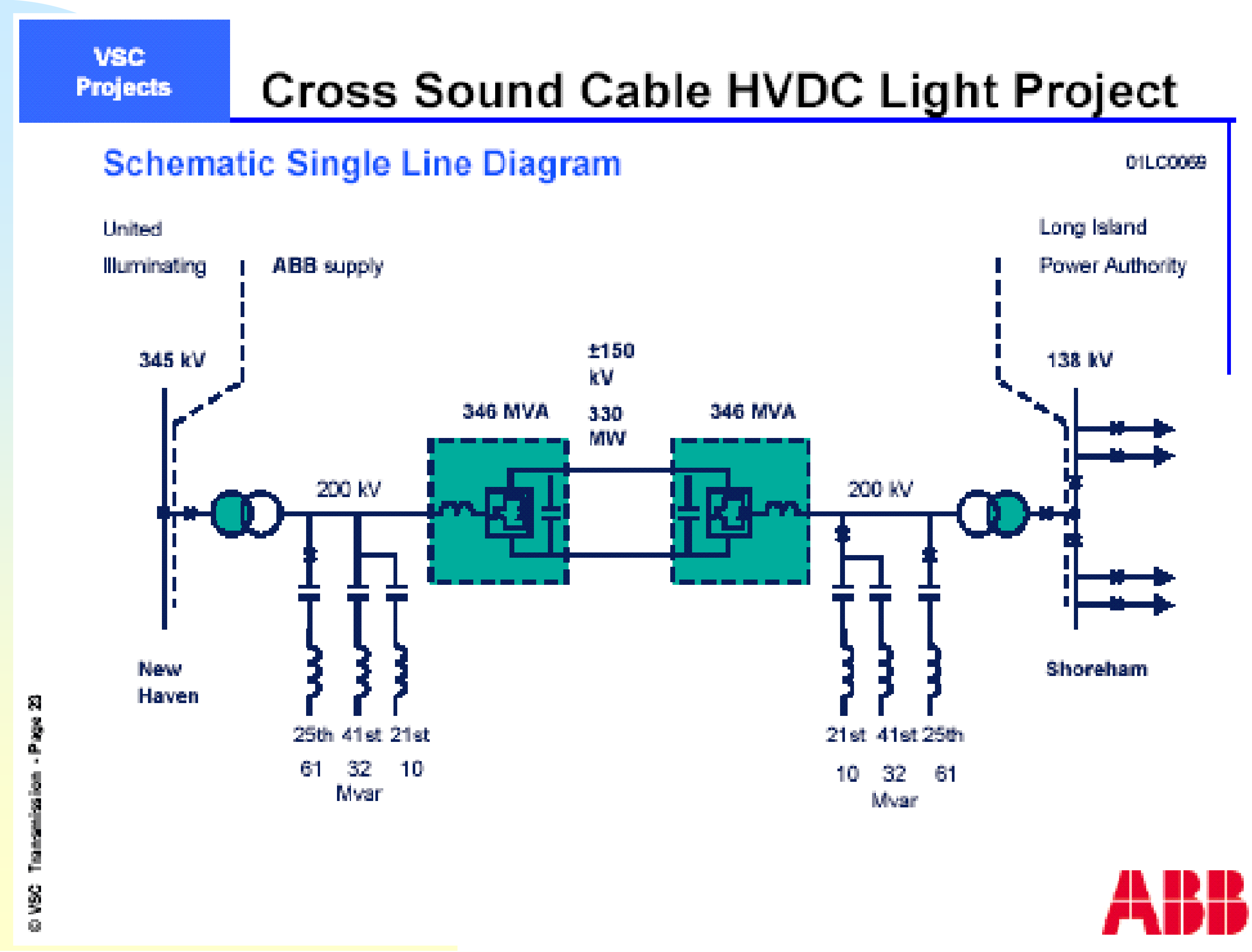
Enables Power Exchange between:

DC ⇔ DC

DC ⇔ AC

AC ⇔ Variable Frequency AC

Example:



VSC Projects

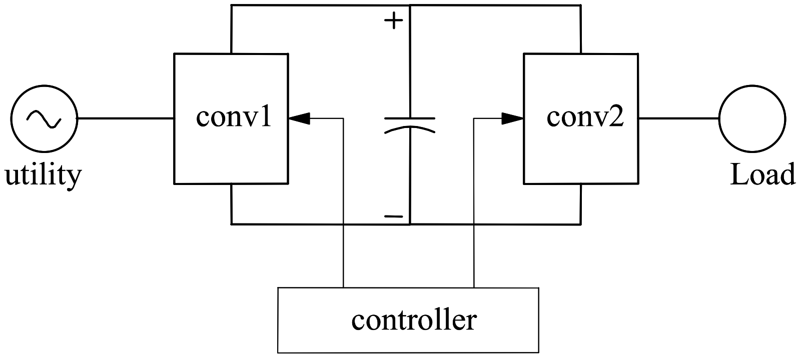
Cross Sound Cable HVDC Light Project

Schematic Single Line Diagram

01LC0069

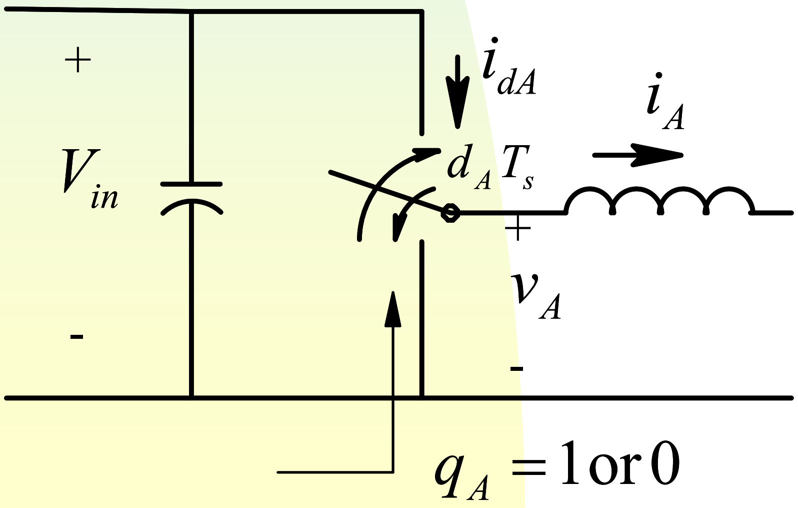
© VSC Transmission - Page 23

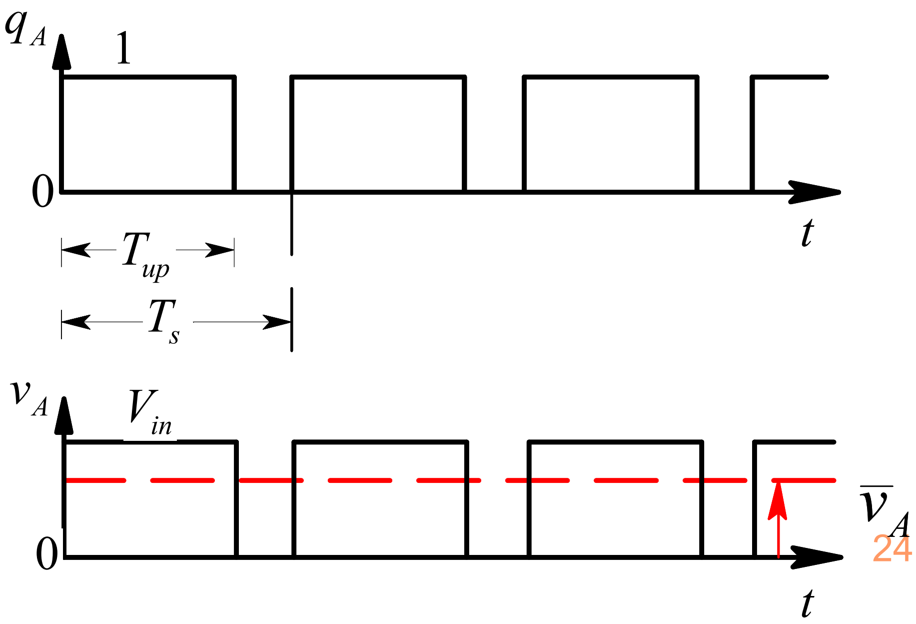
A Common Topology: Voltage-Link Converters



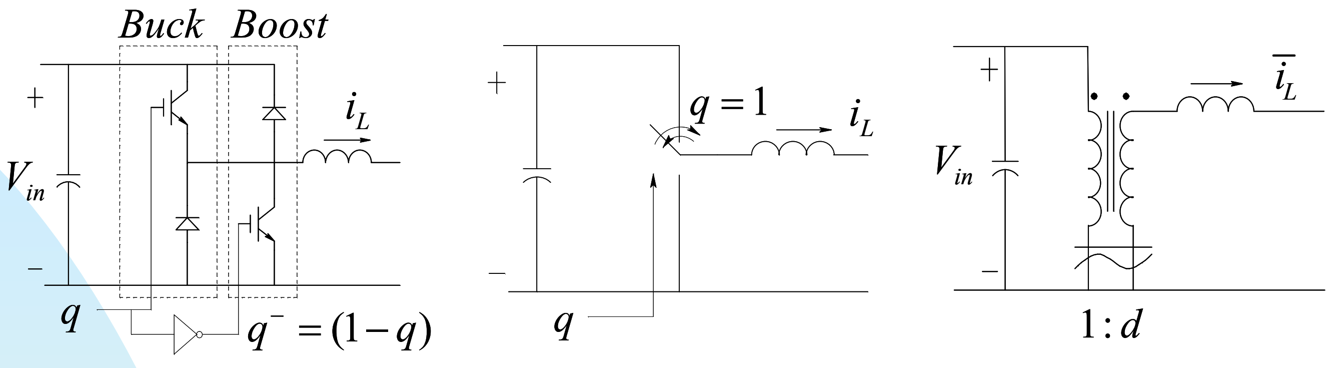
Switching Power-Pole: Building-block of converters

- Synthesis by Pulse-Width Modulation
- Bidirectional Power Flow



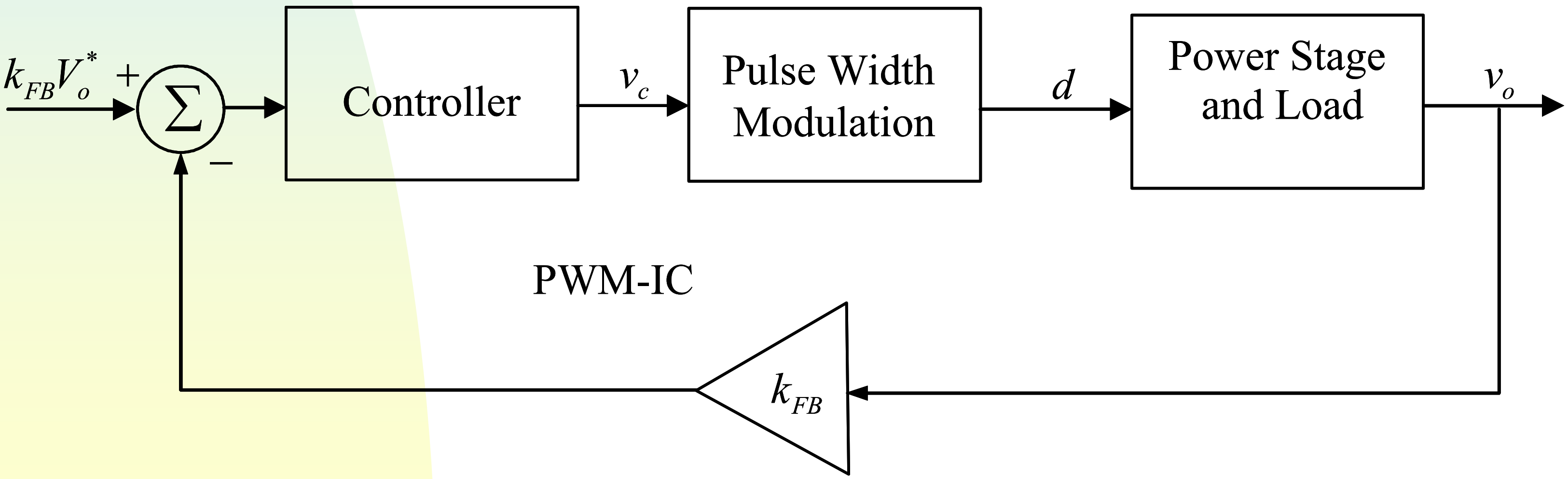


Average Representation of the Switching Power-Pole:

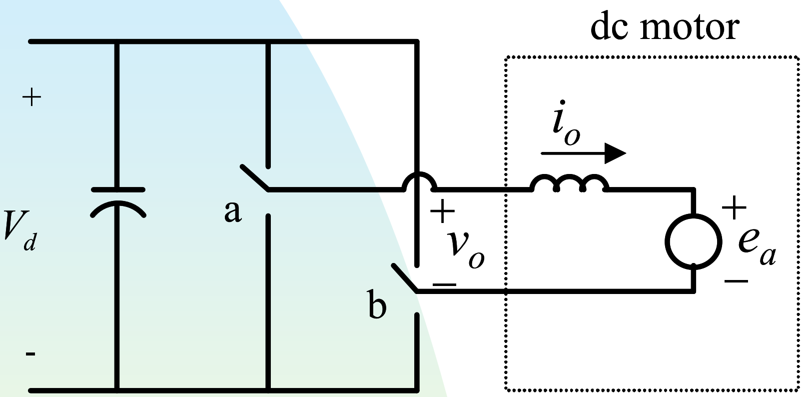


(a) (b) (c)

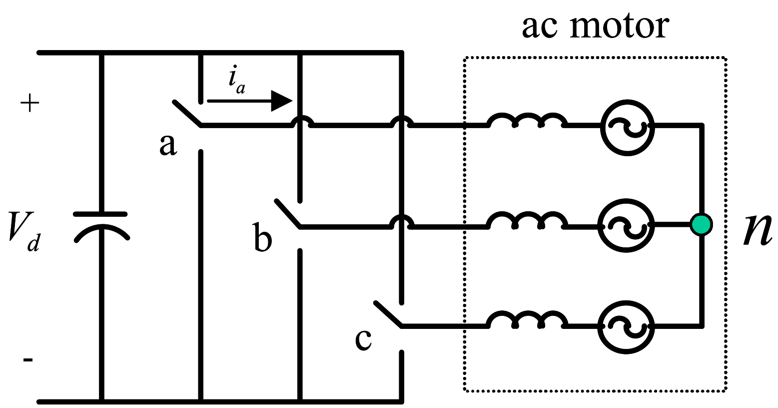
Feedback Controller Design assisted by PSpice:



Converters for DC and AC Motor Drives:



(*a*)



(*b*)

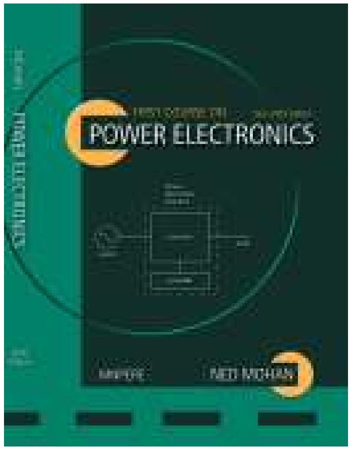
Topics Covered in this Course:

- 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:

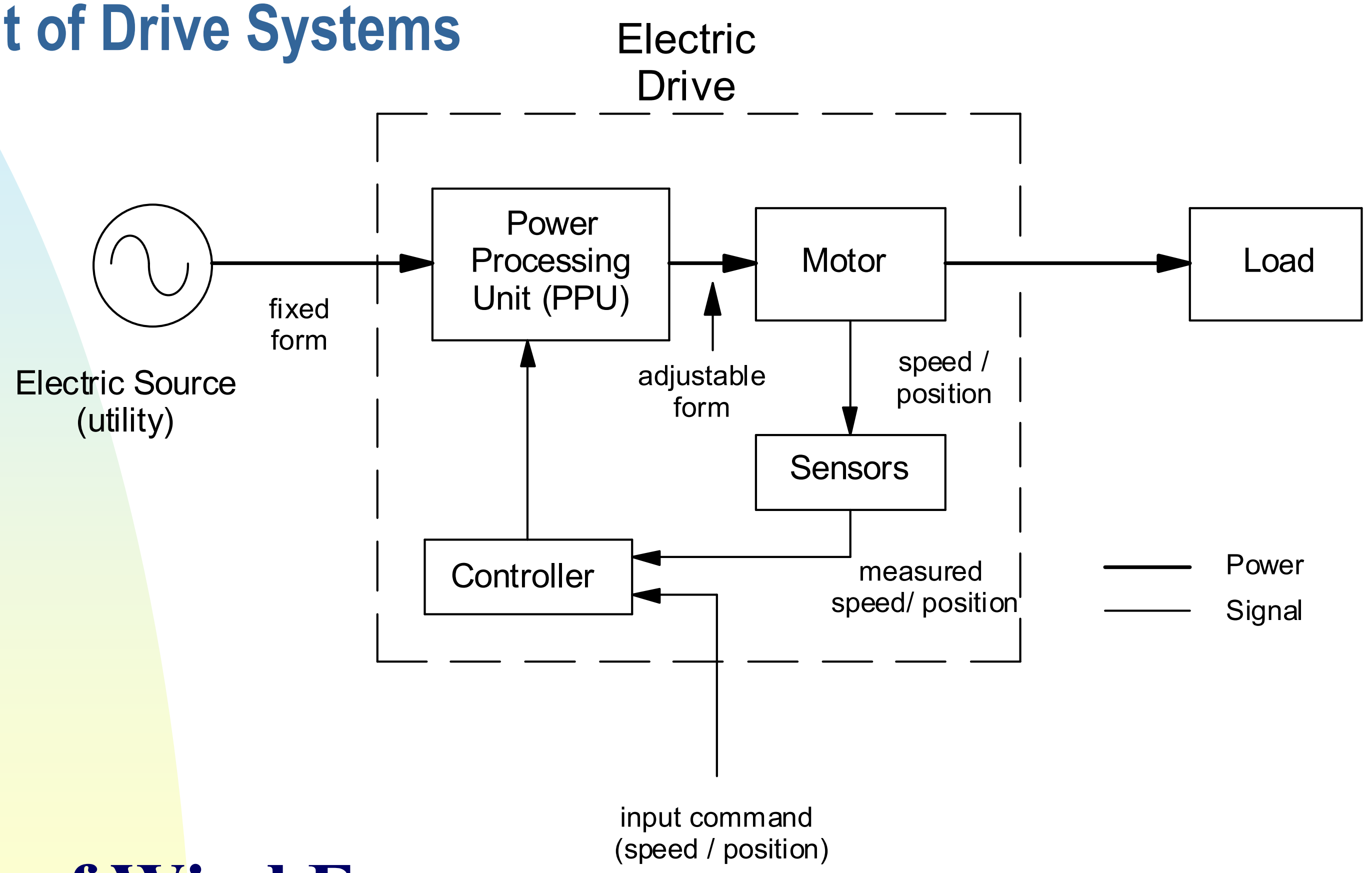
- Presentation Slides

- Solutions Manual



Course on
Electric Drives

Teaching Machines as a subcomponent of Drive Systems



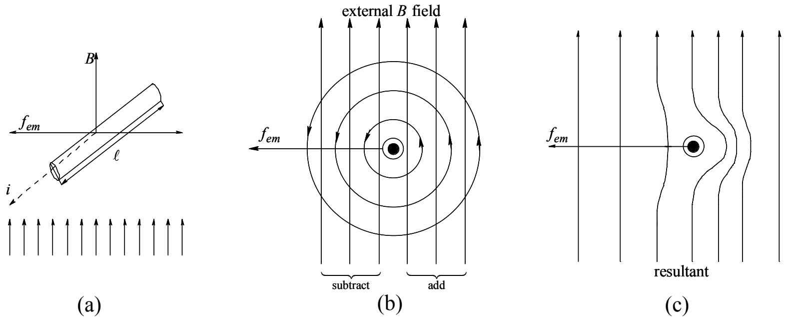
- **Harnessing of Wind Energy**
- **Electric and Hybrid-Electric Vehicles**

Course Objectives:

- Analyze
- Control
- System Design (not machine design)

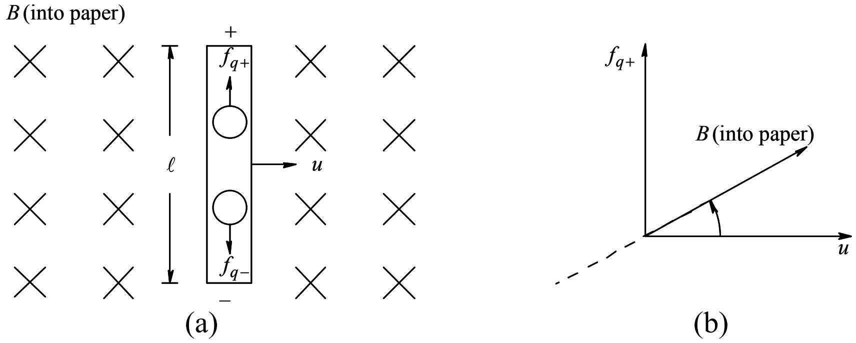
Two Common Principles:

$$f_{em} = B\,i\,\ell$$



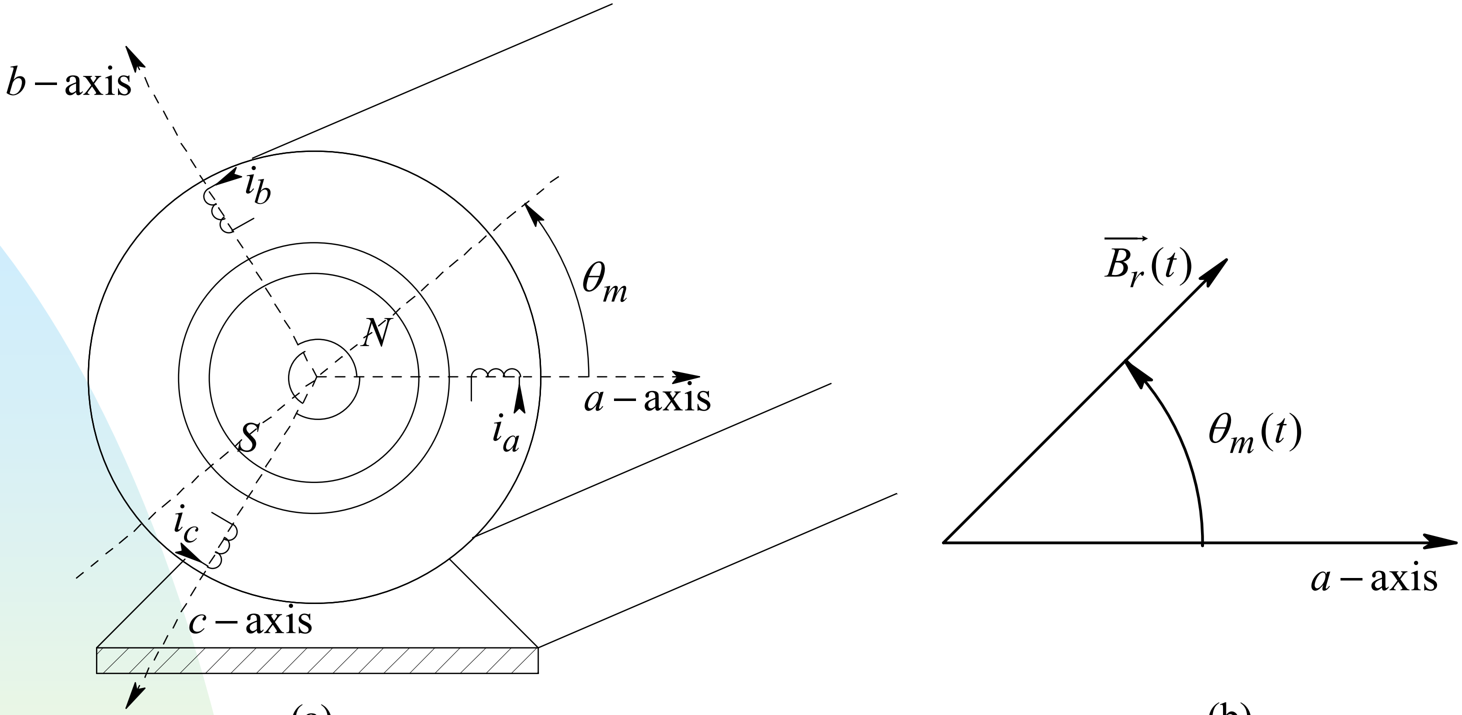
(a) (b) (c)

$$e = B\,\ell\,u$$



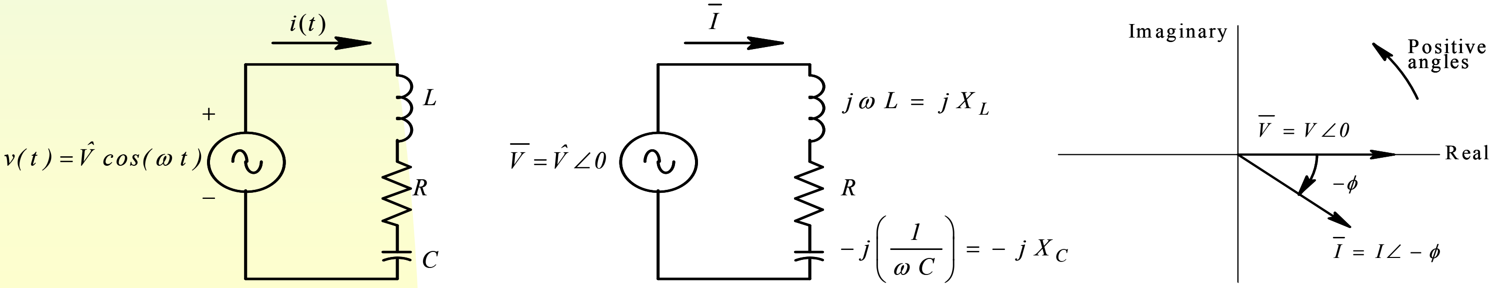
(a) (b)

Use of Space Vectors:



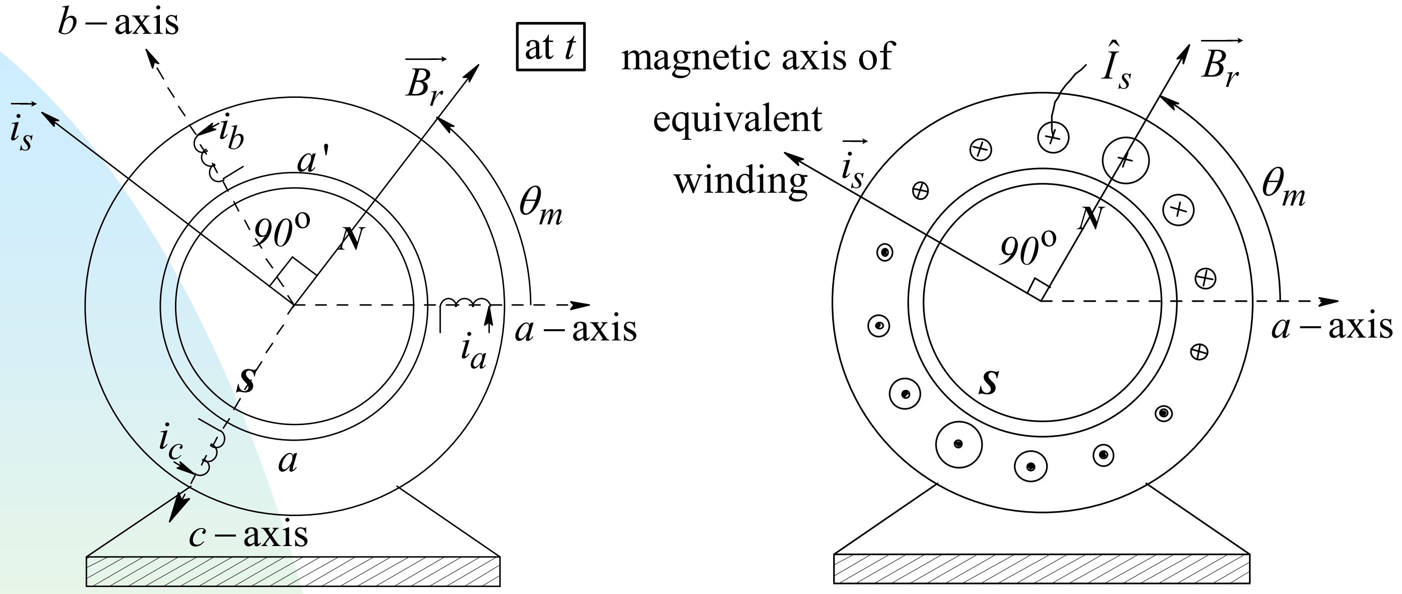
(a) (b)

Similar to use of Phasors:



(a) (b) (c)

Physics-based Analysis:



(a) (b)

$$dT_{em}(\xi) = r\ \underbrace{\hat{B}_r\cos\xi}_{flux\ density\ at\ \xi}\cdot\underbrace{\ell}_{cond.\ length}\cdot\hat{I}_s\cdot\underbrace{\frac{N_s}{2}\cos\xi\cdot d\xi}_{no.\ of\ cond.\ in\ d\xi}$$

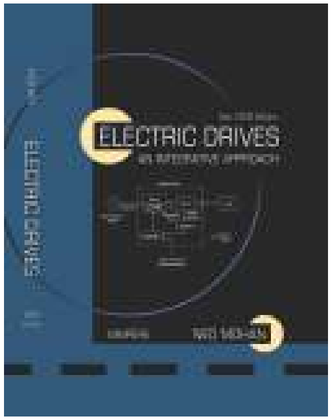
$$T_{em} = 2\times\int_{\xi=-\pi/2}^{\xi=\pi/2} dT_{em}(\xi) = 2\frac{N_s}{2}r\ell\hat{B}_r\hat{I}_s\int_{-\pi/2}^{\pi/2}\cos^2\xi\cdot d\xi = (\pi\frac{N_s}{2}r\ell\hat{B}_r)\hat{I}_s$$

Topics:

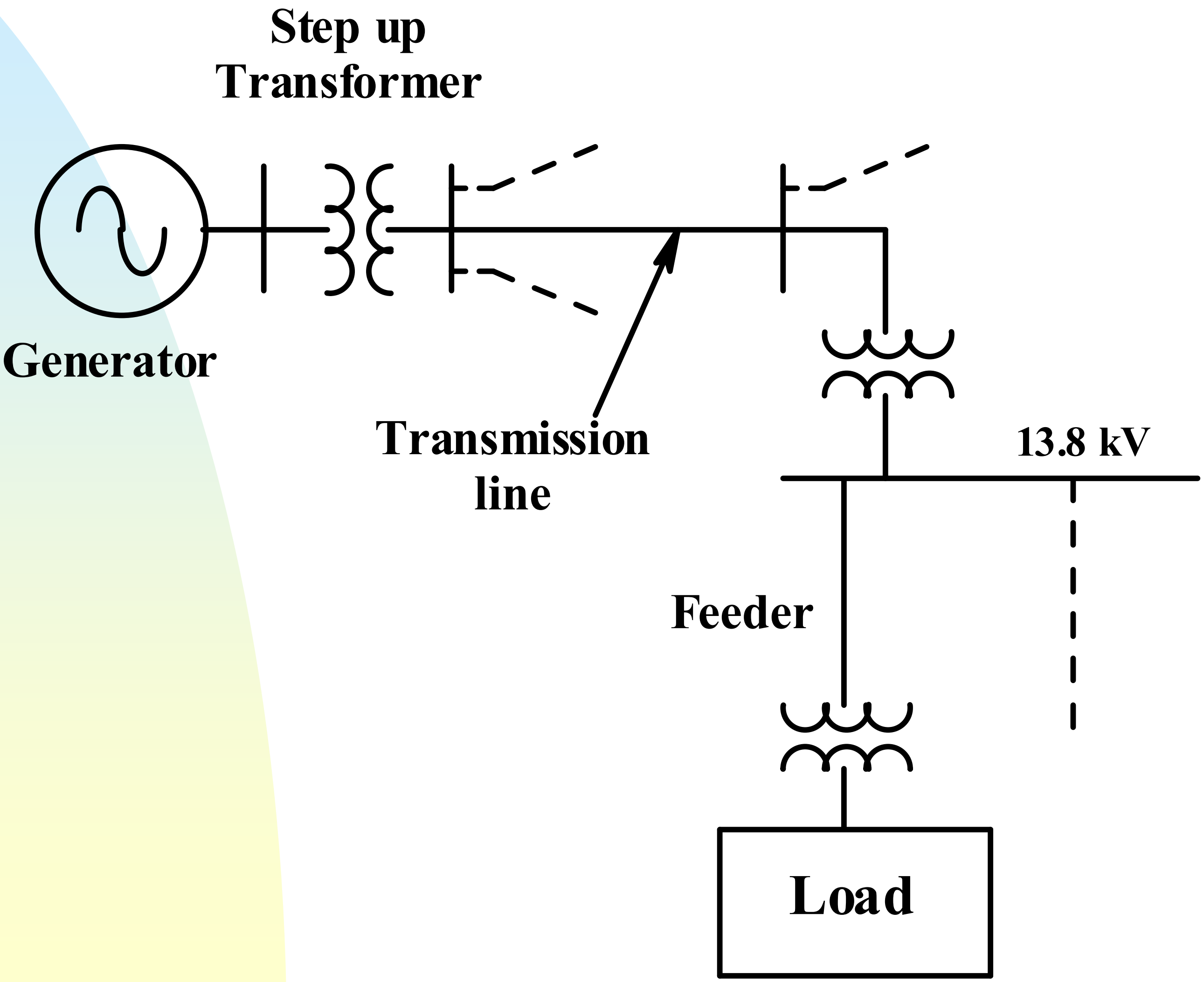
- Designing for the Mechanical Load
- DC Motor Drives
- Permanent Magnet AC Drives
- Induction Motor Drives: Steady State and V/f Control
- Stepper and Switched-Reluctance Drives
- Feedback Control
- Power Quality Considerations

Textbook:

- Presentation Slides
- Solutions Manual



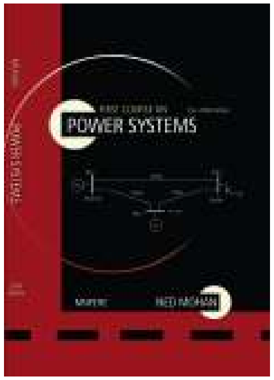
First Course on
Power Systems



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

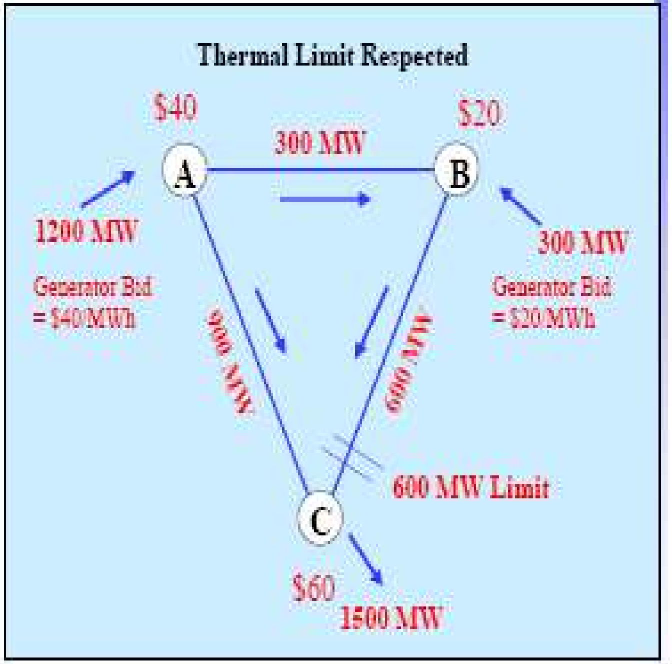
Textbook:

- Presentation Slides
- Solutions Manual



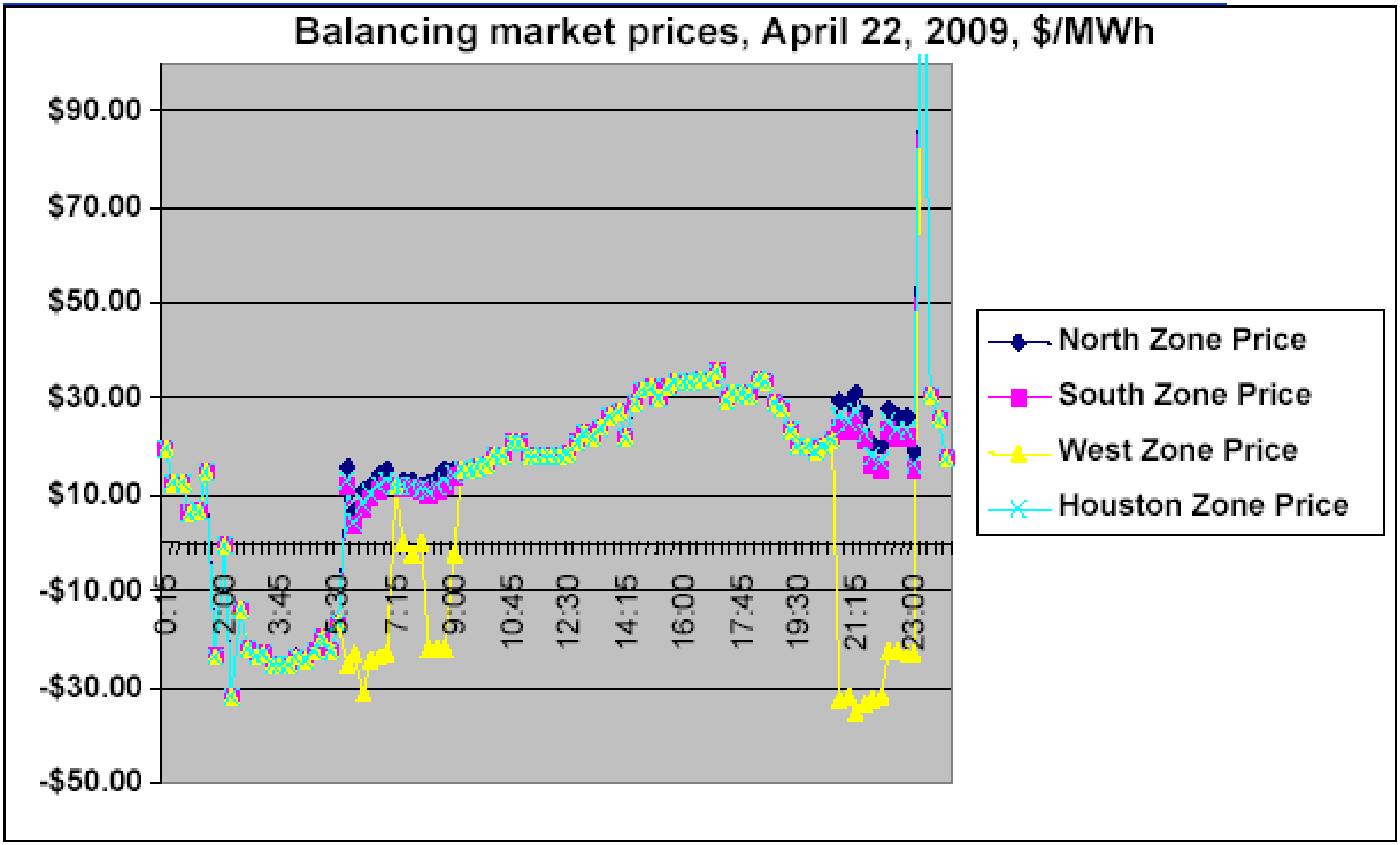
Price Derivation at Locations A & B

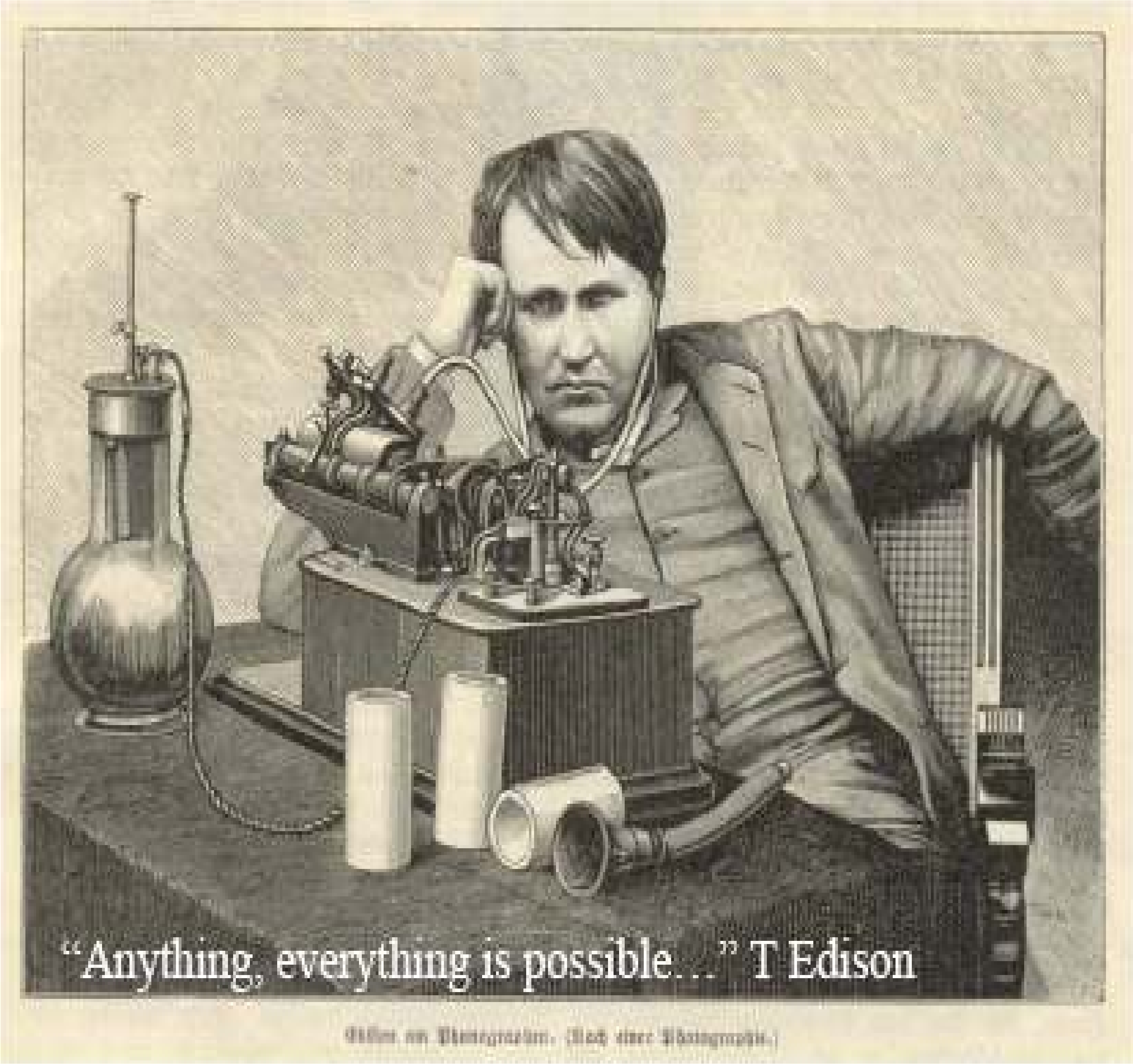
- The LMP at B is $20/MWh. An increment of load at B can be met at lowest bid cost by dispatching the generator at B at a price of $20.
- The LMP at A is $40/MWh. An increment of load at A can be met at lowest bid cost by dispatching the generator at A at a price of $40. Incremental generation at B cannot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



Miso

Wind and demand correlation.





"Anything, everything is possible…" T Edison