

**Worcester Polytechnic Institute**  
**Department of Electrical and Computer Engineering**  
**ECE 559 F (SECTION 103F) SPECIAL TOPICS: FUNDAMENTALS OF POWER DISTRIBUTION ---**  
**FALL, 2007**  
**COURSE GUIDELINES AND SYLLABUS**

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Lecturer: Prof. Marc T. Thompson, AK316  
Email: [marctt@aol.com](mailto:marctt@aol.com)  
Course website: Found on myWPI (my.wpi.edu)  
Level: Graduate level  
Lecture: Tuesdays, 3:00-7:00 at Northeast Utilities, Berlin CT  
Course Secretary: (508) 831-5231

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### **PHILOSOPHY**

An intermediate course in analysis and operation of electrical power distribution. Topics include electrical loads characteristics, modeling, metering, customer billing, voltage regulation, voltage levels, and power factor correction. The design and operation of the power distribution system components will be introduced: distribution transformers, distribution substation, distribution networks, and distribution equipment. Emphasis is on the design of electrical systems in accordance with the National Electrical Code (NEC). Supplemental materials on power quality and other projects related to power and power distribution will be supplied by the instructor. Numerous case studies will be done on the blackboard (in closed form) and using electrical and magnetic simulation tools.

### **PREREQUISITES**

Permission of instructor is required. Prerequisites are basic background in circuits and magnetic systems.

### **COURSE LOAD**

#### ***Lectures***

Attendance in lecture and class participation is required. It is expected that the lecture will be very interactive with a lively "give-and-take."

#### ***Problem Sets***

Homework assignments will be given and due the following week. Material covered will be derived from lecture topics and reading assignments. Some homework assignments may contain a lab or simulation (SPICE or MATLAB component). **Late problem sets will not be accepted.**

#### ***Exams***

There will be several exams.

### **GRADING**

Grading will be done with the *approximate* percentage distribution:

- Problem sets: 50%
- Classroom participation: 10%
- Exams: 40%

**The grader will not search for your answers. Answer questions in a clear, concise manner. If graphs are required, make sure that you label all axes. If we can't find your answers easily, you don't get the credit !**

### **REQUIRED TEXT**

- Theodore R. Bosela, *Electrical Systems Design*, Prentice-Hall, 2003
- Other course notes distributed by the instructor via email.

### **PSPICE AND PSIM SIMULATION TOOLS**

Student (evaluation) version of PSPICE will be provided. We'll be using the Microsim evaluation version 8.0. A tutorial on how to use this is found here:

- [http://www.coe.uncc.edu/mosaic/mosaic\\_help/pc\\_help/pspice/getting\\_started1.html](http://www.coe.uncc.edu/mosaic/mosaic_help/pc_help/pspice/getting_started1.html)

The demo version of PSIM is available here:

- <http://www.powersimtech.com/download.html>

### **MAGNETIC SIMULATION TOOLS**

I'll be intermittently using magnetic finite-element analysis tools to illustrate magnetic fields, etc. The program that I use for 2-dimensional analysis is freeware, provided by Dr. David Meeker of Foster-Miller (Waltham, MA), and the software can be found here:

- <http://femm.foster-miller.net/wiki/HomePage>

### **OTHER RECOMMENDED REFERENCES**

James J. Burke, *Power Distribution Engineering*, Marcel Dekker, 1994

Edison Electric Institute, *Handbook for Electricity Metering*, 8<sup>th</sup> edition, 1981

Lucas Faulkenberry and Walter Coffey, *Electrical Power Distribution and Transmission*, Prentice Hall, 1996

Ralph Fehr III, *Industrial Power Distribution*, Prentice Hall, 2002

C. H. Flurscheim, editor, *Power Circuit Breaker Theory and Design*, Peter Peregrinus, 1982

IEEE Std. 519, "Recommended Practices and Requirements for Harmonic Control in Electric Power Systems"

IEEE Std. 1159, "IEEE Recommended Practice for Monitoring Electric Power Quality"

John Mason, *Switch Engineering Handbook*, McGraw-Hill, 1993

J. L. Marshall, *Lightning Protection*, John Wiley, 1973

NFPA 70: "National Electrical Code," 2005 edition

NFPA: *NEC 2005 Handbook*

NFPA 70E: "Standard for Electrical Safety in the Workplace," 2004 edition

NFPA 75: "Standard for the Protection of Electronic Computer/Data Processing Equipment," 1999 edition

NFPA 780, "Standard for the Installation of Lightning Protection Systems," 2004 edition

*National Electrical Code Handbook*

Syed Nasar, *Electric Energy Systems*, Prentice-Hall, 1996

A. S. Pabla, *Electric Power Distribution*, McGraw-Hill, 2005

Ragnar Holm, *Electric Contacts Theory and Applications*, 4<sup>th</sup> edition, Springer-Verlag, 1967

J. D. Glover and M. Sarma, *Power System Analysis and Design*, 2<sup>nd</sup> edition, PWS Publishing, Boston, 1994

Alex Kusko and Marc Thompson, *Power Quality in Electrical Systems*, McGraw-Hill, 2007

## **LATE POLICY**

Late work will not be accepted, unless there is a family emergency.

## **COLLABORATION AND ACADEMIC HONESTY<sup>1</sup>**

All the rules of WPI's Academic Honesty Policy will be in effect (<http://www.wpi.edu/Pubs/Policies/Judicial/sect5.html>). You **must** review them and be familiar with them. They describe procedures that will be taken if dishonesty is suspected.

You may not copy from any source (person, book, old homework, web etc.). If any part of your answer is copied from a source, you must cite this source. If you are not sure whether your or a classmate's behavior follows the Honesty Policies, be sure to ask.

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<sup>1</sup> Excerpted from Prof. Fred Loofit's Academic Honesty webpage, <http://ece.wpi.edu/~fjlooft/honesty.htm>

## TENTATIVE COURSE SYLLABUS

Syllabus subject to change.

#	Date	Lecture material covered	Homework assignment	Reading
1	9/11/07	<ul style="list-style-type: none"> <li>• Course overview and logistics</li> <li>• Introduction to power distribution</li> <li>• Review of electrical circuits               <ul style="list-style-type: none"> <li>• Fundamentals</li> <li>• Power, real and reactive, VA ratings</li> <li>• Phasors</li> <li>• 3-phase circuits</li> <li>• Power factor</li> <li>• Harmonics and Fourier analysis</li> <li>• Root-mean-square (RMS) and its meaning</li> </ul> </li> <li>• One-line diagrams</li> <li>• Review of system voltages               <ul style="list-style-type: none"> <li>• Single phase distribution</li> <li>• 3-phase</li> </ul> </li> <li>• Capacitive, resistive and inductive loads</li> <li>• The per-unit system</li> <li>• Review of modeling tools for electrical circuits -- - PSPICE and PSIM</li> </ul>	<ul style="list-style-type: none"> <li>• PS1 out</li> </ul>	<ul style="list-style-type: none"> <li>• <i>Bosela</i>, Chapters 1 and 2</li> <li>• Powerpoint notes</li> </ul>
2	9/18/07	<ul style="list-style-type: none"> <li>• One-line diagrams (PDF notes; NOTES 01B)</li> <li>• System voltages (PDF notes: NOTES 01 and 01D)</li> <li>• Energy storage (Notes 01C)</li> <li>• The per-unit system (Notes 02)</li> <li>• Source configurations (Notes 02B)</li> <li>• Loads (Notes 03)               <ul style="list-style-type: none"> <li>• Linear loads</li> <li>• Nonlinear loads and harmonic generation                   <ul style="list-style-type: none"> <li>• Rectifier loads, harmonics and neutral currents</li> <li>• 6-pulse and 12-pulse rectifiers (Kusko/Thompson, chapter 5)</li> </ul> </li> </ul> </li> <li>• Demand factors</li> <li>• Wiring devices (Notes 04)               <ul style="list-style-type: none"> <li>• Switches</li> <li>• Receptacles</li> <li>• GFIs</li> <li>• Disconnect switches</li> </ul> </li> <li>• Arcing and contacts</li> </ul>	<ul style="list-style-type: none"> <li>• PS1 due</li> <li>• PS2 out</li> </ul>	<ul style="list-style-type: none"> <li>• <i>Bosela</i>, Chapters 3 and 4</li> <li>• Supplemental notes</li> <li>• Excerpt on "Substations"</li> <li>• NEC Article 220</li> <li>• Kusko/Thompson, Ch. 5</li> <li>• PDF notes: 01, 01B, 01C, 01D, 02, 02B, 03, 04</li> <li>• Motorola AN843 --- Supplemental notes on transient voltage suppressors</li> </ul>
3	9/25/07	<ul style="list-style-type: none"> <li>• Overview of substations</li> <li>• Overcurrent protection devices (Notes 05)               <ul style="list-style-type: none"> <li>• Fuses</li> <li>• Circuit breakers</li> </ul> </li> <li>• Begin conductors (Notes 06, NEC excerpts. Powerpoint notes)</li> <li>• Overvoltage protection devices --- MOVs, Zeners, etc.</li> </ul>	<ul style="list-style-type: none"> <li>• PS2 due</li> <li>• PS3 out</li> </ul>	<ul style="list-style-type: none"> <li>• PDF notes: 05, 06</li> <li>• <i>Bosela</i>, Chapters 5 and 6</li> <li>• Sakshaug --- "A Brief History of AC Surge Arresters"</li> <li>• Supplemental notes on "Distribution Circuits"</li> <li>• Powerpoint: Supplemental notes on cable and wire charts</li> </ul>

		<ul style="list-style-type: none"> <li>• Magnetic field from current-carrying wires <ul style="list-style-type: none"> <li>• Review of magnetic FEA software (FEMM)</li> <li>• FEA study (PDF notes: “Magnetic field from power cables; Powerpoint notes) <ul style="list-style-type: none"> <li>• Magnetic field from single isolated wire</li> <li>• FEA --- dipole</li> <li>• FEA --- quadrupole</li> </ul> </li> </ul> </li> </ul>		<ul style="list-style-type: none"> <li>• PDF notes (new): “Magnetic field from power cables”</li> <li>• Powerpoint notes: “FEA studies of magnetic field from power cables”</li> <li>• NEC Art. 330, 334, 338, 406</li> <li>• Thompson, IEEE paper on levitation</li> <li>• Experiment: eddy current levitation</li> </ul>
4	10/2/07	<ul style="list-style-type: none"> <li>• Conductors (Notes 06) <ul style="list-style-type: none"> <li>• Cable types, construction and insulation</li> <li>• Cable derating</li> <li>• Temperature limitations</li> <li>• High frequency losses in wires <ul style="list-style-type: none"> <li>• Skin effect</li> <li>• Proximity effect</li> </ul> </li> </ul> </li> <li>• Overview of distribution circuits</li> <li>• Feeder and branch circuit design (Notes 07)</li> <li>• Conduits and raceways</li> <li>• High frequency effects and losses <ul style="list-style-type: none"> <li>• Other case studies via magnetic FEA <ul style="list-style-type: none"> <li>• Wire in metallic conduit</li> </ul> </li> </ul> </li> <li>• <b>Quiz 1, covering weeks 1-3</b></li> <li>• <b>Note: no class next week on 10/9/07</b></li> </ul>	<ul style="list-style-type: none"> <li>• PS3 due</li> <li>• PS4 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapters 6 and 7</li> <li>• Parese, et. al., “The Arc-Fault Circuit Protection”</li> <li>• PDF notes: 06 and 07</li> </ul>
5	10/16/07	<ul style="list-style-type: none"> <li>• Conduits and raceways (Notes 08)</li> <li>• Grounding (Notes 09)</li> </ul>	<ul style="list-style-type: none"> <li>• PS4 due</li> <li>• PS5 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapters 8 and 9</li> <li>• NEC excerpts on grounding</li> <li>• Camara excerpt: “Lightning Protection and Grounding”</li> <li>• PDF notes: 08 and 09</li> </ul>
6	10/23/07	<ul style="list-style-type: none"> <li>• Services and metering (Notes 10) <ul style="list-style-type: none"> <li>• Service drops</li> <li>• Service entrance conductors</li> <li>• Service disconnect requirements</li> <li>• Service overcurrent protection devices</li> <li>• Metering</li> </ul> </li> <li>• Begin switchgear (Notes 11)</li> </ul>	<ul style="list-style-type: none"> <li>• PS5 due</li> <li>• PS6 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapter 10, 11</li> <li>• Supplemental notes on metering</li> <li>• He: “Aging Characteristics and Mechanisms of ZnO Nonlinear Varistors”</li> <li>• Sakshaug paper</li> <li>• APC --- “Hazards of Neutral Overloads”</li> <li>• Wagner --- “Effects of Harmonics on Equipment”</li> <li>• NEC notes, Article 230</li> </ul>

7	10/30/07	<ul style="list-style-type: none"> <li>• Switchgear (Notes 11) <ul style="list-style-type: none"> <li>• Panelboards</li> <li>• Overcurrent protection</li> <li>• Clearances and safety issues</li> </ul> </li> <li>• Review of magnetics --- magnetic laws (supplemental notes) <ul style="list-style-type: none"> <li>○ Inductors</li> <li>○ Transformers</li> <li>○ Energy conversion</li> </ul> </li> <li>• Overview of magnetic FEA modeling tools</li> <li>• Motors (Notes 13, Fehr notes) <ul style="list-style-type: none"> <li>• Motor basics</li> <li>• Motor ratings</li> <li>• OCPD issues</li> </ul> </li> <li>• <b>Quiz 2, 5:15-6:15, covering weeks 1-6</b></li> </ul>	<ul style="list-style-type: none"> <li>• PS6 due</li> <li>• PS7 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapter 11, 13</li> <li>• Supplemental notes on magnetics and transformers</li> <li>• Fehr --- “Basics of AC Motors” and “Direct Current Motor Basics”</li> </ul>
8	11/6/07	<ul style="list-style-type: none"> <li>• More on basic magnetics</li> <li>• Transformers (Notes 14) <ul style="list-style-type: none"> <li>• Basics of power transformers</li> <li>• Service transformers</li> <li>• Standard ratings</li> <li>• Loading and sizing</li> </ul> </li> <li>• Transformer design study: 2 kW noncontact battery charger <ul style="list-style-type: none"> <li>• Specs</li> <li>• EMI requirements</li> <li>• Basic design</li> <li>• Thermal</li> </ul> </li> <li>• Capacitors (Notes 15)</li> </ul>	<ul style="list-style-type: none"> <li>• PS7 due</li> <li>• PS8 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapter 14, 15</li> <li>• Supplemental notes on magnetics and transformers</li> <li>• Fehr --- “Basics of Transformers”</li> <li>• MTT note/simulations on book examples</li> </ul>
9	11/13/07	<ul style="list-style-type: none"> <li>• Voltage drops (Notes 16)</li> <li>• Faults (Notes 17) <ul style="list-style-type: none"> <li>• Symmetrical faults</li> <li>• Introduction to symmetrical components</li> </ul> </li> <li>• Introduction to power quality and standards (IEEE Std. 519 and Std. 1159)</li> <li>• Begin voltage distortion (Notes 19)</li> <li>• Guest lecture, 5:15-6:30: Dr. Duncan Glover, “Loading Power Transformers Above Nameplate”</li> </ul>	<ul style="list-style-type: none"> <li>• PS8 due</li> <li>• PS9 out</li> </ul>	<ul style="list-style-type: none"> <li>• Chapter 16, 17, 19</li> <li>• Powerpoint: Supplemental notes on faults and symmetrical components</li> <li>• Excerpts from Kusko/Thompson <i>Power Quality in Electrical Systems</i> (chapters 2, 3)</li> <li>• Glover powerpoint presentation</li> </ul>
10	11/20/07	<ul style="list-style-type: none"> <li>• More power quality issues (Notes 19, supplemental notes, Kusko/Thompson excerpts) <ul style="list-style-type: none"> <li>• Harmonics</li> <li>• Harmonic current sources</li> <li>• Harmonic filters</li> <li>• Switching power supplies</li> <li>• PQ measurements</li> </ul> </li> <li>• Issues in electrical safety</li> <li>• <b>Quiz 3, covering weeks 1-9</b></li> <li>• <b>Course evaluations</b></li> </ul>	<ul style="list-style-type: none"> <li>• PS9 due</li> </ul>	<ul style="list-style-type: none"> <li>• Supplemental notes and excerpts from Kusko/Thompson <i>Power Quality in Electrical Systems</i> (chapter 4, 14)</li> </ul>