Topics for Today:

• Announcements
  • Software: Matlab? Will begin using as early as next week.
  • Office hrs: 1:30-2:30pm, Tues, Thurs
  • Office: EERC 623. Phone: 906.487.2857
  • Ch.2 Solutions posted on web page, go thru them for review.
  • XFMR exercises posted on web page, due end next week.

• Comments on sequence networks - add’l detail to last Wednesday’s notes.

• Chapter 2 - Review: Transformers and circuits w/transformers
  • Single phase transformers
  • Basic structure: winding R and Leakage, Core losses and saturation
  • 3-phase transformer banks and phase shifts (ANSI/IEEE vs. IEC)
  • Standard 30°shift transformers, non-standard connections
  • Pos/neg sequence phase shifts
  • Autotransformers
  • Load Tap Changing (LTC) transformers

CKTS - Due Fri pm. Box 35, 7th.
# EE 5200

**Advanced Methods in Power Systems Analysis**

**Fall Semester 2006**
EERC B45 - M,W,F 2:05-2:55 pm

**Dr. Bruce Mork | Office Hours**

- Course Syllabus
- Pre-Req Material
- Text & References
- Useful Web Links
- Homework Cover Sheet
- Grades to Date

List of Term Projects | Past Term Project Examples: **Ex:1**  **Ex:2**  **ATP Quick-Start**

Revised thru: **Week 2**

**Schedule and Coverage** (Subject to Change Depending on Learning Needs of Students):

<table>
<thead>
<tr>
<th>Weekly Coverage</th>
<th>Lecture Date</th>
<th>Material Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Read Material Before Class)</td>
<td></td>
<td>(Videostreamed Lectures</td>
</tr>
<tr>
<td><strong>1 - Ch. 1</strong></td>
<td>L1 - Sep 5th</td>
<td>Pre-req exercises - rate your foundational skills <strong>Solutions: Ch.1 Review Probs</strong> (Complete by Sep 7th)</td>
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<tr>
<td></td>
<td>L2 - Sep 7th</td>
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<tr>
<td></td>
<td><strong>Lect 1 (skip first 12 mins)</strong></td>
<td><strong>Lect 2</strong></td>
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<td><strong>Lect 6</strong></td>
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<tr>
<td><strong>2 - Ch. 1,2</strong></td>
<td>L3 - Sep 11th</td>
<td>Proper Use of &quot;Closed&quot; Voltage Phasor Diagrams for Graphical Analysis <strong>CKTS - Due</strong> Sep 15th</td>
</tr>
<tr>
<td></td>
<td>L4 - Sep 13th</td>
<td>Three-Phase network analysis, per-phase, per-unit, transformer basics</td>
</tr>
<tr>
<td></td>
<td>L5 - Sep 15th</td>
<td>Suggested Probs: 2.2, 2.4, 2.6, 2.8, 2.9, 2.14, 2.16, 2.17, 2.18, 2.21 (Ch.2 Soln) <strong>XFMR Homeword</strong></td>
</tr>
<tr>
<td><strong>3 - Ch. 2</strong></td>
<td>L6 - Sep 15th</td>
<td>Transformer connections (Delta, Y, auto, zig-zag), core structure (G&amp;S Overview)</td>
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<tr>
<td></td>
<td>L7 - Sep 20th</td>
<td>IEEE/IEC Phase Shifts (<strong>std 30°</strong>, non-std), 3-Winding Transformers, <strong>Nameplate, Schematic</strong></td>
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<tr>
<td></td>
<td>L8 - Sep 22th</td>
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</tbody>
</table>

http://www.ece.mtu.edu/faculty/bamork/ee5200/

Useful references, in addition to the course text, are listed on the course web page.

The course web page provides approximate schedule of topic coverage and chapters in textbook. Text and other related material provided by your instructor are to be perused prior to lecture.

Homework problems (computer applications and MatLab programming tasks may be integrated). Use homework submission cover sheet. Depending on scope and nature of each assignment, you will sometimes work by yourself, or with a partner, or in a group. You are encouraged to share concepts and ideas via our e-mail discussion forum, but may not copy each other's homework or programs. Mini-Lectures on course topics and/or research papers are assigned. [Remote students can submit their mini-lecture summary/lecture notes.]

Up to two tests may be given (i.e. 0-2 tests). Format will usually be take-home, with 24-48 hrs to complete. There is no final exam. A term project will be completed by end of Week 13, with a formal presentation given during final exam timeslot.

The university's policy on Academic Integrity (informally known as the "cheating policy") shall be strictly enforced: http://www.sas.it.mtu.edu/usenate/propose/06/8-06.htm

Students are expected complete all tests during the scheduled timeframe. Excused absences must be arranged in advance. Absence due to serious illness or accident is of course allowed, contact your instructor as soon as you are well enough to plan make-up work. Absences due to job interviews or personal travel plans are unfortunately not considered excused by MTU policy. [Remote students may have immovable work conflicts, which can usually be accommodated if worked out in advance.]

Questions are encouraged in class, as time permits. Your instructor is available for help during designated office hours in his office in EERC 623. Individual or group help sessions can be prearranged for local students. All are encouraged to participate in our community forum at ee5200-l@mtu.edu. Please make an effort at solving the problem before asking for help, and be prepared and organized when presenting your problem. This allows your instructor to help as many students as possible during the available office hours.

Final averages will be based on the following distribution:

- Hour Tests (0-2): 20% each (unused % redistributed to items below)
- Presentations/Mini-Lectures: 10%
- Participation, other: 5%
- Homework & Software Aps: 30%
- Term Project, Presentation: 15%

Worst case cutoffs are: A = 90; AB = 85; B = 80; BC = 75; C = 70; F below 70. Students who complete the work at a high standard and on time are generally assured of an A or B grade. Low standard or incomplete or late work can result in a C or lower grade. Grades to date will be periodically made known to the students -- generally these are updated following each test. Please verify that your grades have been correctly entered.

Note that participation and other qualitative aspects are weighted 5%. Factors include: value of your classroom participation and discussions in e-mail forum, attendance, anticipation and proactivity, submitting work on time, quality and legibility of submitted work, and other issues of professional merit. These factors are also considered if your final average falls at or just below a grade cutoff.
ASSIGNMENT GUIDELINES:

Assignments will be given out regularly - typically one larger one each week. You will typically have 2-7 days to complete an assignment, depending on how long it is. **Late penalties may be assigned - typically 10% off for each day of inconvenience.** If there is not already enough room on the assignment sheet, attach additional sheets of 8½ x 11 engineering grid paper (not notebook paper), stapled in upper left corner. Show all work, illustrate by schematic or a diagram, provide assumptions, give equations before substitution, show all units and underline or circle all answers. If attaching computer simulation results, highlight important results and provide complete annotations so that the significance of the results is clear - let’s develop the documentation habits of a design engineer - could someone else reconstruct your work? **Neatness and clarity of the documentation are important.** You are strongly encouraged to discuss concepts and theory related to homework via the course e-mail forum, send e-mail to ee5200-L@mtu.edu to reach all of us and start a discussion.

**In some cases you will work together in pairs.** Remote students may have to work alone if they are the only one at their site. Although it’s not recommended, each of you may work alone on your part of the exercise, meeting and tutoring each other on the details prior to handing in the homework. Partners are to sign off on each other’s work. Your approval signifies that:

- you’ve checked your partner’s calculations for correctness,
- you understand the theory, concepts, and solutions method of your partner’s work, and
- your partner has done a proportionate share of the work.

Answers (but not necessarily the solutions) will be posted or marked on the graded homework.

**Local Students: Put your homework in Drop Box #35 on the 7th Floor of EERC.**
[Remote Students: Scan and e-mail as .pdf attachment, or fax to 906.487.2949 (high-res mode).]

Graded homework may be claimed in the box outside of your instructor’s office (EERC 623). [Remote students: your work will be returned via mail.] After claiming your returned homework, please follow up on any incorrect solutions.

Your professor is typically available for office hours help from 2:05-2:55pm Mon, Wed, Fri, plus other times by arrangement. E-mail: bawork@mtu.edu; Office: 487-2857; Home: 487-9552. A classroom office hour can be scheduled on demand, this works extremely well. Contact your professor.
1) [15pts] A 3φ transformer has a total series impedance of \( j0.1 \) pu. A balanced 3φ source is connected to the primary and a balanced 3φ load of \( S = 1.0/36.87^\circ \) pu is connected to the secondary. The terminal voltage at the load is \( 1.0/0^\circ \) pu. Using the per phase equivalent below, and leaving all quantities in per unit,

a) Calculate the phasor value of the load current in per unit.
b) Calculate the phasor value of the source voltage in per unit.
c) Calculate the voltage regulation at the load terminals of the transformer.

\[
\begin{align*}
S &= \bar{V}\bar{I}^* \\
\bar{V}_S &= \bar{V}_L + \bar{I}_L jX_t \\
VR &= \frac{\bar{V}_{NL} - \bar{V}_{FL}}{\bar{V}_{FL}}
\end{align*}
\]

2) [10 pts] It is desired to construct a 480Δ-208Y volt 3φ transformer from 3 single phase 480-120 volt transformers. Positive sequence LN voltages on the 480V side must lead the corresponding LN voltages on the secondary side by \( 90^\circ \). Labeling the 480-volt terminals as H1, H2 and H3 and the 208-volt terminals X1, X2 and X3,

a) Sketch out the phase shift diagrams that would appear on the transformer nameplate.
b) Correctly connect the windings, labeling H1, H2, H3, X1, X2 and X3.
3) [20 pts] For the transformer shown, draw the closed phasor diagrams for positive and negative sequence voltages (both LL and LN) for the transformer shown. The effective turns ratio of the transformer is $a_{eff} = 5.0$. Use reference angles: $0^\circ$ for $V_{A1}$ and $+90^\circ$ for $V_{A2}$.

a) Positive sequence voltage for primary
$(V_{A1}, V_{B1}, V_{C1}, V_{AB1}, V_{BC1}, V_{CA1})$

Positive sequence voltage for secondary
$(V_{a1}, V_{b1}, V_{c1}, V_{a1b}, V_{b1c}, V_{c1a})$

b) Negative sequence voltages for primary
$(V_{A2}, V_{B2}, V_{C2}, V_{AB2}, V_{BC2}, V_{CA2})$

Negative sequence voltages for secondary
$(V_{a2}, V_{b2}, V_{c2}, V_{a2b}, V_{b2c}, V_{c2a})$

c) What is the magnitude and phase relationship between $V_{A1}$ and $V_{a1}$? Between $V_{A2}$ and $V_{a2}$?
4) [10 pts] Answer both of the following short essay questions.

a) [5 pts] A coworker questions the calculations you performed when converting \( Z_{12} \), \( Z_{13} \) and \( Z_{23} \) to \( Z_1 \), \( Z_2 \) and \( Z_3 \) for a 3-winding transformer. He says that since \( Z_2 \) is negative, you’ve made a mistake. What do you tell him (be polite)?

\[
\begin{align*}
Z_{12} &= Z_1 + Z_2 \\
Z_{13} &= Z_1 + Z_3 \\
Z_{23} &= Z_2 + Z_3
\end{align*}
\]

b) [5 pts] A conceptual phase-shifting transformer is used in positive and negative sequence networks to represent the phase shift of the phase A voltages and currents from one side to the other. Ratios like \( 1/30^\circ \) or \( 1/-30^\circ \) are common. What effect do these phase shifting transformers have if you want to transfer an impedance from one side to the other?

5) [15 pts] A 3\( \phi \) transformer has the following ratings:

Primary: Y-connected, 138kV, 15MVA
Secondary: Y-connected, 69kV, 15MVA
Tertiary: \( \Delta \)-connected, 13.8kV, 5MVA

\[
\begin{align*}
Z_1 &= \frac{1}{2} (Z_{12} + Z_{13} - Z_{23}) \\
Z_2 &= \frac{1}{2} (Z_{12} + Z_{23} - Z_{13}) \\
Z_3 &= \frac{1}{2} (Z_{13} + Z_{23} - Z_{12})
\end{align*}
\]

Short-circuit tests give the following results:

\[
\begin{align*}
Z_{12} &= 5\% \text{ on 15-MVA 138-kV base.} \\
Z_{13} &= 9\% \text{ on 15-MVA 138-kV base.} \\
Z_{23} &= 3\% \text{ on 10-MVA 13.8-kV base.}
\end{align*}
\]

Find the per unit impedances \( Z_1 \), \( Z_2 \) and \( Z_3 \) on a base of 15MVA, 138-kV.
6) [30 pts] A simple 3φ power system consists of a generator, a transformer, a transmission line, and a large synchronous motor. Nameplate data for each piece of equipment is given below. The transformer has ANSI standard phase shift (high-voltage LN voltages lead the low-voltage LN voltages by 30°).

G1: 50MVA, 24kV, \( X_0 = 5\% \), \( X_1 = 20\% \), \( X_2 = 10\% \), \( X_\phi = 0.4\Omega \)
T1: 100MVA, 24-13.8kV, \( X_0 = 5\% \), \( X_1 = X_2 = 10\% \)
M1: 50MVA, 13.2kV, \( X_0 = 5\% \), \( X_1 = X_2 = 20\% \)
T-Line: \( X_0 = 1\Omega \), \( X_1 = X_2 = 0.5\Omega \)

\[
\begin{align*}
  Z_{ne,j} &= Z_{ol} \left( \frac{\sqrt{3} \, S_{ol}}{\sqrt{3} \, S_{new}} \right) \\
  &= Z_{ol} \left( \frac{\sqrt{3} \, S_{ol}}{\sqrt{3} \, S_{new}} \right)
\end{align*}
\]

a) [15 pts] Using a system base of 100MVA and 24kV at bus 1, determine the base impedance for both sections of the system and convert all impedances to per unit values on the common system base.

b) [15 pts] Construct the zero, positive and negative sequence impedance diagrams. Label all impedances with their correct values in per unit. Include the effects of positive and negative sequence phase shift.