Topics for Today:

• Announcements
  Software: Matlab? Will begin using as early as next week.
  Office hrs: 2pm, M, W, F
  Office: EERC 614.
  Phone: 906.487.2857
  Ch. 2 Solutions posted on web page, go thru them for review.
  XFMR exercises to be posted, due Sep 21

Chapter 1 / Review (6 pre-req videos on course web page):
  Voltage drop, current flow (circuit topology > algebraic eqns)
  Double subscript notations
  V, I, Z, Y, P, Q, S, PF
  Three-phase analysis, use of phasor diagrams
  Per-phase (L-N phase-A) equivalent.

Symmetrical Components
Per Unit system
Sequence networks
## EE 5200 Class Roster - Fall 2011

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Loadflow - Phasor
S.C. - "
Stability - Both phasor (Grid Cals) and time (machine dynamics)

\[ 0, \Delta t, 2\Delta t, \ldots \]

Lightning - time (impulse)
Switching - time (step)
Insulation Design -
\[ S = V I \cos \theta + j V I \sin \theta = V I^* \]

\[ \Theta = \angle V - \angle I \quad (\text{passive}) \]

\[ \Theta = \angle V - \angle I \]

\[ \theta \]

\[ S = \bar{V} I^* \]

\[ S = Q \]

\[ \text{LAB} \]

\[ \text{LEAD} \]

\[ P \]

\[ \frac{1}{\text{i}} \]

\[ R \]

\[ Q \]
Time Domain - Simulation

- ATP
- Matlab

\[ \Delta t = \text{uniform timestep} \]

real no.

\[ t \]

volts

\[ \frac{\text{time series}}{\text{real no.}} \]
Phasor Domain

\[ \vec{V} \quad \vec{I} \quad \frac{\vec{V}}{\vec{R}} \quad e^{j\omega} \]

Time Domain

\[ v(t) = V_p \cos(\omega t) \]

\[ V_p \]

\[ 360 \frac{\Delta t}{t} \]
Power

\[ P_{\text{avg}} = \frac{1}{T} \int_{0}^{T} P(t) \, dt \]

Matlab:

\[
\begin{array}{c|c|c|c}
\hline
V & I & P \\
\hline
\hline
\end{array}
\]

\[ P(t) = \sqrt{2} V(t) I(t) \]

PF = \text{power factor}

PF = 1

PF = \theta

P_{\text{avg}} = 0
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

Comments on sequence networks
Waukesha Quality Inside
Means Reliability Is On Your Side

Load Tap Changer is designed to withstand up to a half-million operations without need for contact replacement.

Low no-load losses result from use of laser-scribed, super-grain-oriented steel.

Transformer exterior is coated to a minimum thickness of 3 mils. This coating has superior endurance characteristics and meets the ANSI C57.12.28 standard.

Material-stabilized coils are pressure-fit within the core frame.

Galvanized radiators provide excellent corrosion resistance and minimal maintenance.

De-energized tap changer features simple and compact in-line contact arrangement.

Coil assembly is rigidly braced in a high-strength frame that distributes clamping forces around the full circumference of the windings.

Submerged-arc process produces deep weld penetration, virtually eliminating leakage from welded tank joints.

Inside tank surfaces are painted white to facilitate internal inspection.

Lamination width customized to achieve a near perfect-circle core cross section, resulting in the most efficient use of materials plus a lighter, more compact high-performance transformer.

Waukesha Electric Systems offers component parts for transformer upgrades and repair, as well as extensive field service support that includes transformer moving, hauling and rigging, vacuum filling and oil processing, inspection, testing and customer training.

Waukesha Electric Systems
World Headquarters:
400 S. Prairie Avenue
Waukesha, WI 53186-5940
800.835.2732

U.S. Manufacturing:
Waukesha, WI  800.835.2732
Goldsboro, NC  800.758.4384

Service, Parts, Training:
High Voltage Supply
Dallas, TX  800.338.5526
1. Core (no-load) losses minimized by utilizing laser-scribed, super-grain-oriented steel.
2. Lamination width customized to achieve a near perfect-circle core cross section, resulting in the efficient use of materials plus a lighter, more compact, high performance transformer.
3. Coil assembly rigidly braced in a high-strength frame that distributes clamping forces around the full circumference of the windings.
4. Submerged-arc welding process produces deep penetration welds, virtually eliminating leakage from welded tank joints.
5. Inside tank surfaces are painted white to facilitate internal inspection.
6. Transformer exterior coated to a minimum thickness of 3 mils; this coating has superior endurance characteristics and meets the ANSI C57.12.28 standard.
7. Galvanized radiators provide excellent corrosion resistance and require minimal maintenance (fan guards and blades also galvanized).
8. Material-stabilized coils are pressure-fit within the core frame.
9. Patented DETC (De-Energized Tap Changer) features simple and compact in-line contact arrangement (Patent Number: 5,744,764)
10. Waukesha® Type UZD Load Tap Changer designed to withstand up to a half-million operations without the need for contact replacement.
11. Worldbox® Control Enclosure features IEC standard components and is easy to maintain and service in the field.
Cooling
- Oil
- Heat exch
- pumps, fans

Monitoring
- Temp: oil, coils
- Oil gases
- $N_2$

Coil Design
- insulation:
  - coil-core, coil-coil, phase-phase
  - $\Phi$ (higher $V$)
  - BIL, BSF
How many possibilities are there for $A-Y$ or $Y-A$ phase shifts?

6 each

= 12 total.

$+30^\circ$ $+90^\circ$ $+90^\circ$ $+150^\circ$

Auto - $A$

2i9 - 2i8

Extended $A$. 
Three-Phase Transformers

All of these can and are used to indicate the same winding connections:

IEEE Stds:

Schematic

Circuit 3-line diagram

In Europe and much of the world:

IEC Stds: Dyn11

'Old-down' diagram
Zig-Zag

0° phase shift.

Delta

H2
H3
H1

X2
X3
X1

Diagram of electrical connections.
Balanced 3-ph voltages:

\[ |\vec{V}_{AG}| = |\vec{V}_{BG}| = |\vec{V}_{CG}| \]
Extend Delta
Transformer Phase Shifts

- See Δ-Y transformer nameplate

\[ \begin{align*}
H_1 & \\
H_2 & \\
H_3 & \\
X_0 & \\
X_1 & \\
X_2 & \\
x_3 & \\
\end{align*} \]

pos seg voltage "phase shift"
3-PHASE XFMR BANK
Ex: Δ-Y (Oyn1)

From: Review Lecture 5
±30°, ±90° ±150°
SEQUENCE NETWORKS FOR TRANSFORMERS

[Diagram of sequence networks for transformers with labels and connections]
$I_A = -I_{co}$

$\text{B:} \quad I_N = 3I_{A0} \Rightarrow G$

$V_{DROP} = 3I_{A0}Z_N = V_{NG}$
triplet harmonics
buried tertiary
buried delta

delta: - trap triplet harmonics
    - zero seg circ path
    - Aux power (station service)
    - Protection
    - CTs
$$V_{A1} = V_{O1} \left(1/\sqrt{3}\right)$$

PRI POS SEQ VOLTAGES

SEC POS SEQ VOLTAGES

PRI POS SEQ CURRENTS

SEC POS SEQ CURRENTS

$$V_{a2} = V_{o2} \left(1/\sqrt{3}\right)$$

PRI NEG SEQ VOLTAGES

SEC NEG SEQ VOLTAGES

PRI NEG SEQ CURRENTS

SEC NEG SEQ CURRENTS

ANSI STANDARD 30-DEGREE SHIFT WYE-DELTA
\[ V_{A1} = V_{a1} (1/30^\circ) \]

PRI POS SEQ VOLTAGES

\[ I_{A1} = I_{AB1} - I_{CA1} \]

PRI POS SEQ CURRENTS

\[ V_{A2} = V_{a2} (1/-30^\circ) \]

PRI NEG SEQ VOLTAGES

SEC POS SEQ VOLTAGES

SEC POS SEQ CURRENTS

SEC NEG SEQ VOLTAGES

SEC NEG SEQ CURRENTS

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE