Topics for Today:

- URL: [http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm](http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm)
- Labs - EE5224 - Starting Wednesday

Lecture Coverage:
- Relaying 3-lines
- Type 51 (inverse time-overcurrent relay) settings
- Instrument transformers: VTs, CTs, CCVTs, MOCTs, etc.
- CTs - pedestal vs. bushing

Next:
- Radial Protection (read sections 12.5, 12.6, also G&S Ch.10)
- CT saturation & accuracy, ratios, multi-ratio CTs
\[ S_1 = S_2 \]
\[ (\text{in}) \quad (\text{out}) \]
\[ \tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^* \]

**Ideal**

**Non-Ideal**

- Flux Leakage
- Winding Resistance
- Magnetic Saturation
- Core Losses (Eddy Currents)
- Hysteresis
Lenz's Law

Induced voltage causes a current, if coil is shorted, that produces a flux which cancels the voltage in first place.
\[ e_{\text{ind}} = N \frac{d\phi}{dt} = -\frac{d}{dt} \]

Faraday's Law

Lenz's Law
- 3Φ AC System (PRI)
- "" (Sec) via CTs, VFS, etc
- "3-Lines"
- dc control schemes
- relay settings, strategies
- Comm / SCADA
- Operational, forensics

\[ \text{Form } \text{C} \quad \text{NO } \text{a} \quad \text{INC } \text{b} \]
Bushings - HV Lead

Connections into equipment.

4-Bolt Pad

Porcelain Bushing

Dry: Porcelain

"Wet": Oil-Filled

Bushing Collar

Sheet metal tank

Bushing Well

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Spring 2001

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insulation, for example synthetic resin bonded paper or resin impregnated paper, may have very short lower ends compared with oil impregnated paper types in which the porcelain lower end is relatively long due to limitations of the permissible axial stress on porcelain.

Figure 3.10 Transformer bushings
A. 123 kV, 630 A outdoor bushing with solid insulation
B. 72.5 kV, 630 A outdoor bushing with solid insulation
C. 36 kV, 20000 A bus-duct bushing with solid insulation
D. 420 kV, 1600 A outdoor bushing with oil impregnated paper insulation
E. 145 kV, 1600 A transformer/gas bushing with solid insulation
F. 420 kV, 2000 A transformer/gas bushing with oil impregnated paper insulation and 810 mm current transformer accommodation
INDOOR TERMINALS

c.-Cast epoxy bushing plate.

OUTDOOR TERMINALS

d.- H.V.
e. & f.-L.V.

OUTDOOR H.V. TERMINALS

CABLE BOXES

m.- With a disconnecting chamber.

Figure 4.1 Typical terminal arrangements. Precise constructional details not shown

Whether the h.v. winding will be operated unearthed.
Apparatus or material to be tested.
Voltage tests - magnitude and duration.
If to be used with a rectifier or similar specialised equipment
Insulators:
- Station Post
- Stahlof
- Suspension/Bell

Bus Bar

4: 69 kV
7: 115 kV
11-13: 230 kV

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Insulator:

- Creep Distance or Tracking Distance

water drops

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Lower Voltage Switchgear (15-kV)

Main Bus

- No CTs here.

- Draw-out Breaker

- CTs are all here.

Cable connection

Radial Line/Cable
87B Zone

87B → 86B → Trip all buses

50/51 L
No CB?

Zone A

Zone B
Instrument transformers - used to "step down" primary voltages and currents to lower standard levels.

- Current: 0-5 A - CT
- Voltage: X1-X3: 0-120 V
- X2-X3: 0-69.3 V
- X1-X3: 0-115 V
- X2-X3: 0-66.4 V

Note that "PT" designation is obsolete - new designation is "VT". Economics usually point to use of CVT or CCVT for voltages above 69-kV, VTs for lower voltages.

Note that linear couplers, which produce a secondary voltage proportional to the primary current, were in vogue for a while in the 50's & 60's but never caught on, used mainly in bus differential schemes. Requires special relays (voltage instead of current input) - this additional cost hobbled it. (See p. 353, Blackburn)
Current ratio: 1200:5
Typical CT Equivalent Circuit

\[ Z_B = \text{total "Burden"} \]
these have built-in overcurrent relay units that determine the level of the ac current at and above which their contacts will open. All of these types are used at the lower-voltage level of the power system.

At the higher power system voltages each station at which circuit breakers are installed has a station battery to supply direct current to the breaker trip coils, the control and protective relay circuits as required, emergency alarms and lighting, and so on. In the United States this is generally 125-V dc; 250-V dc is used in some large power stations, and 48-V dc is

![Diagram of a three-phase ac connection system]

**Figure 1.10** Typical three-phase ac connections of a set of phase and ground relays for the protection of an ac power system. The relays may be separate, as shown, or combined together in one unit.
Figure 1: External Schematic of HiLo CO Relay for Phase and Ground Overcurrent Protection on a Three Phase System

Figure 2: External Schematic of HiLo CO Relay with ACS Unit for Phase and Ground Protection on a Three Phase System