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 next 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
\[ S_1 = S_2 \]

\[ \text{in} \hspace{1cm} \text{out} \]

\[ \tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^* \]

\text{IDEAL!}

\text{Non-Ideal}

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

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

Faraday

Lenz
- 3φ AC System (PRI)
  "" (Sec) via CTs, VFS, etc
- "3-Lines"
- dc control schemes
- relay settings, strategies
- Comm/SCADA
- Operational, forensics
Bushings - HV Lead
Connections into equipment.

4-Bolt Pad

Oil-Level gage

Porcelain Bushing

Dry: Porcelain

"Wet": Oil-Filled

Bushing Collar

Sheet metal tank

Bushing Well

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Instructor: Bruce Mork  Phone (906) 487-2857  Email: bamork@mtu.edu
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

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 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
- Stanchion
- Suspension/Bell

Bus Bar

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

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Insulator:

- Creep Distance or Tracking Distance

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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
No CB?

Zone A

Zone B

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

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

Ex:

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

\[ Q = \frac{1}{240} \]
$Z_B = \text{total "Burden"}$

Typical CT Equivalent Circuit
CT Secondary

240 turns

40
20
100
80

x1
x2
x3
x4

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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

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**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.
CO (Hi-LO) Overcurrent Relay

DEVICE NUMBER CHART

51 - OVERCURRENT RELAY, TYPE CO
51-N - GROUND OVERCURRENT RELAY, TYPE CO
52 - POWER CIRCUIT BREAKER
52A - BREAKER AUXILIARY CONTACT
ICS - INDICATING CONTACTOR SWITCH
TC - BREAKER TRIP COIL

Figure 1: External Schematic of HiLo CO Relay for Phase and Ground Overcurrent Protection on a Three Phase System

DEVICE NUMBER CHART

51 - OVERCURRENT RELAY, TYPE CO (DWG.182A755)
51-N - GROUND OVERCURRENT RELAY, TYPE CO
52 - POWER CIRCUIT BREAKER
52A - BREAKER AUXILIARY CONTACT
ICS - INDICATING CONTACTOR SWITCH
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Figure 2: External Schematic of HiLo CO Relay with ACS Unit for Phase and Ground Protection on a Three Phase System