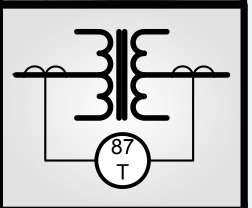
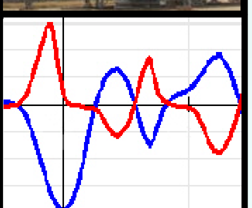


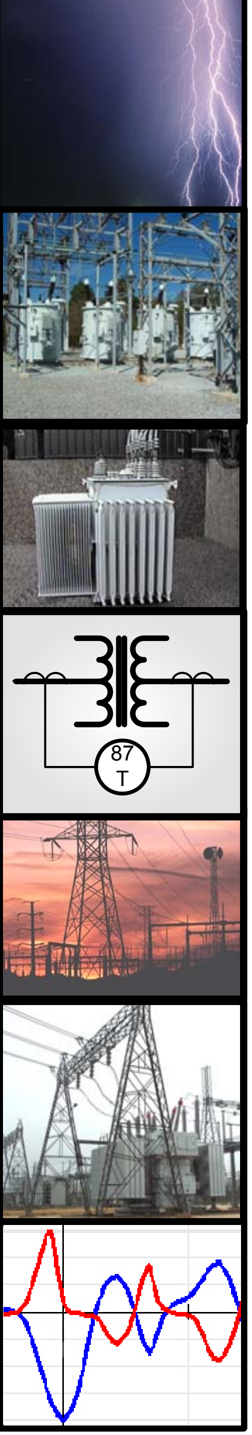







PROTECTION OF MV TRANSFORMERS AT UTILITY AND INDUSTRIAL FACILITIES

Chuck Mozina
Consultant
Beckwith Electric

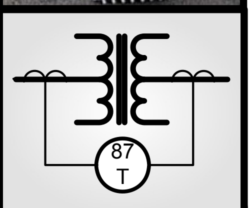


Chuck Mozina -- is a Consultant, Protection and Protection Systems for Beckwith Electric and resides in Palm Harbor (near Tampa), Florida. His consulting practice involves projects relating to protective relay applications, protection system design and coordination. He specializes in generator and power plant protection.

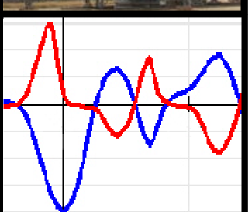
Chuck is an active 25-year member of the IEEE Power System Relay Committee (PSRC) and is the past chairman of the Rotating Machinery Subcommittee. He is active in the IEEE IAS I&CPS, PCIC and PPIC committees, which address industrial system protection. He is a former U.S. representative to the CIGRE Study Committee 34 on System Protection and has chaired a CIGRE working group on generator protection. He also chaired the IEEE task force that produced the tutorial "The Protection of Synchronous Generators," which won the PSRC's 1997 Outstanding Working Group Award. Chuck is the 1993 recipient of the Power System Relay Committee's Career Service Award and he recently received the 2002 IAS I&CPS Ralph Lee Prize Paper Award. His papers have been republished in the IAS Industrial Applications Magazine.

Chuck has a Bachelor of Science in Electrical Engineering from Purdue University and is a graduate of the eight month GE Power System Engineering Course. He has authored a number of papers and magazine articles on protective relaying. He has over 25 years of experience as a protection engineer at Centerior Energy, a major investor-owned utility in Cleveland, Ohio where he was the Manager of the System Protection Section. He spent 10 years as the Applications Manager for Relay Products for Beckwith Electric. He is also a former instructor in the Graduate School of Electrical Engineering at Cleveland State University as well as a registered Professional Engineer in the state of Ohio and a Life Fellow of the IEEE.



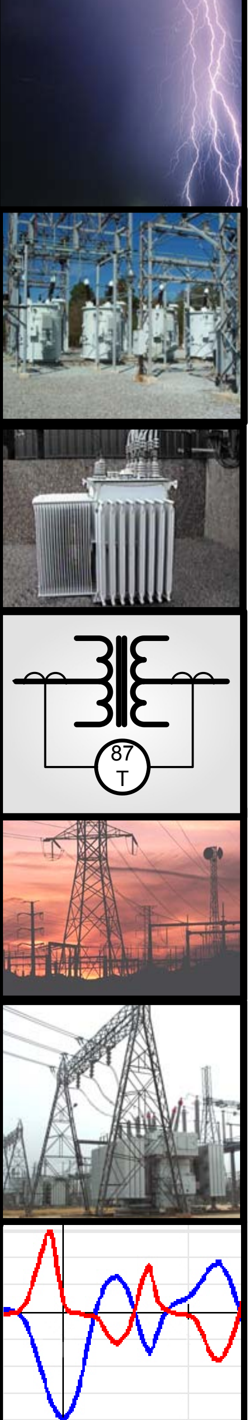







OUTLINE

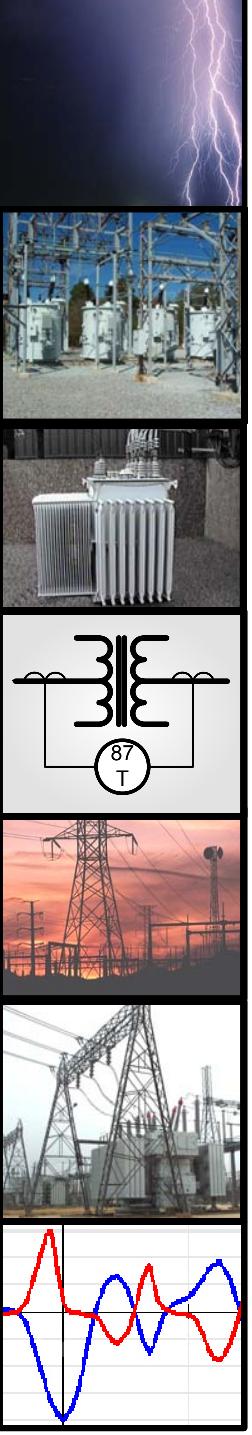
- IEEE PROTECTION STANDARDS
- WHY TRANSFORMERS FAIL
- TRANSFORMER BASICS
- PHASING STANDARDS
  - + IEEE/ANSI
  - + IEC
- TRANSFORMER DIFFERNTIAL
  - + Phase (87T)
  - + Gnd (87GD)
- OVEREXCITATION PROTECTION
- DIGITAL TRANSFORMER RELAYS



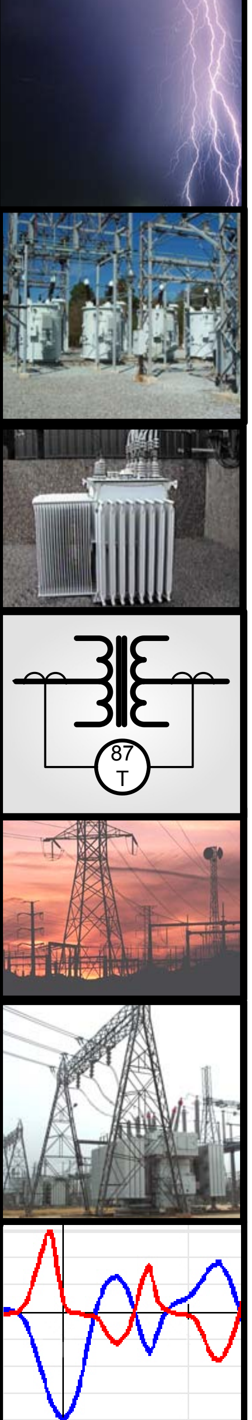
IEEE Standards

- Latest developments reflected in:
  - <u>Std. 242:</u> Buff Book Transformer Protection Chapter 11
  - ANSI / IEEEC37.91“Guide for Protective Relay Applications for Power Transformers”

These are created/maintained by the IEEE PSRC & IAS
They are updated every 5 years

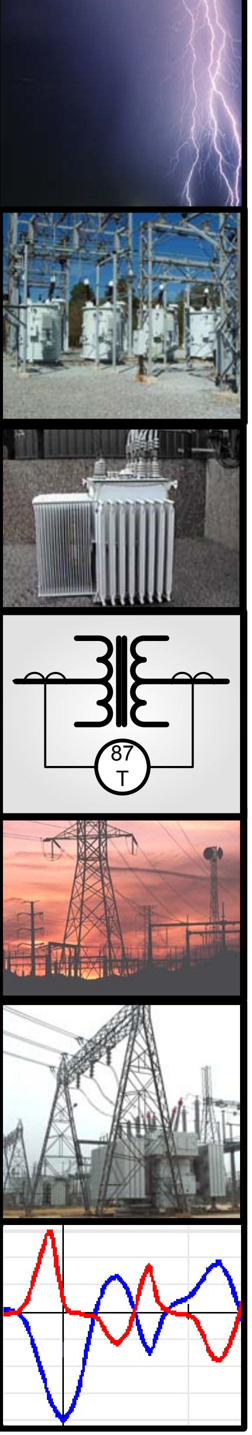


WHY TRANSFORMERS FAIL



What Fails in Transformers?

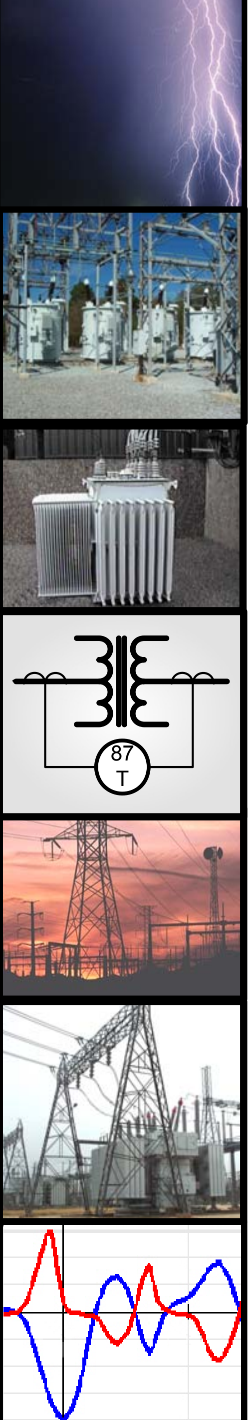
- Windings
  - Insulation deterioration from
    - Moisture
    - Overheating
    - Vibration
    - Voltage surges
    - Mechanical Stress from through-faults
- LTCs
  - Malfunction of mechanical switching mechanism
  - High resistance contacts
  - Overheating
  - Contamination of insulating oil



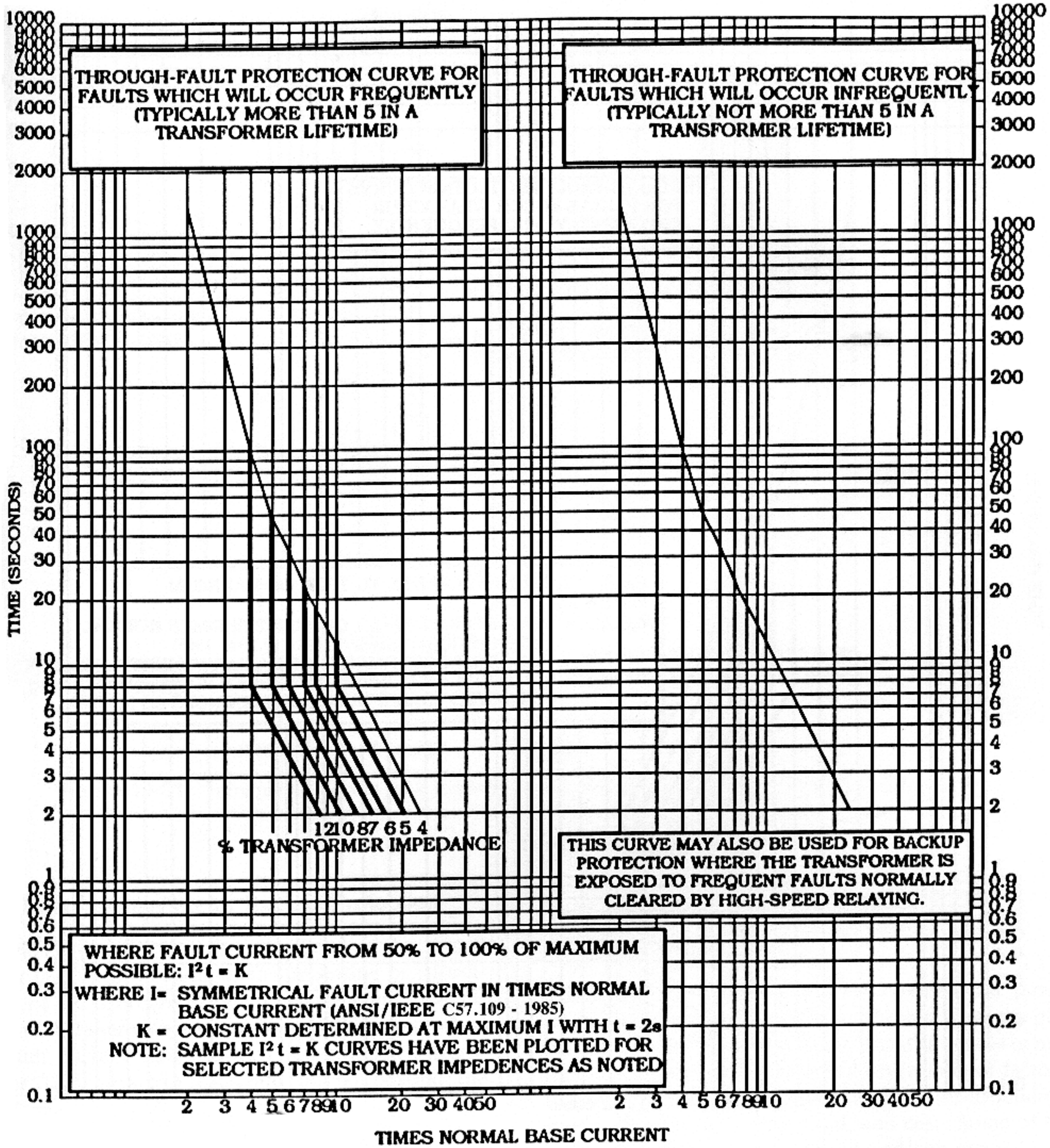
What Fails in Transformers?

HARTFORD STEAM BOILER INSPECTION & INSURANCE CO.

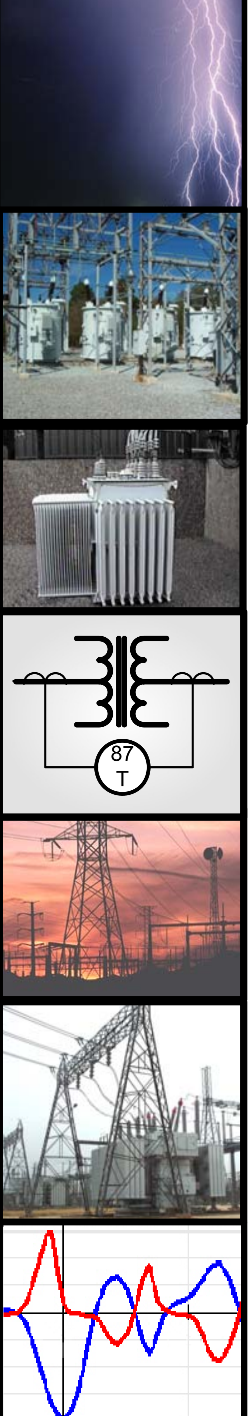
Cause	% of Failures
Insulation Failure	26%
Manufacturing Problems	24%
Unknown	16%
Loose Connections	7%
Through Faults	5%
Improper Maintenance	5%
Oil Contamination	4%
Overloading	4%
Fire/Explosions	3%
Lighting	3%
Floods	2%
Moisture	1%

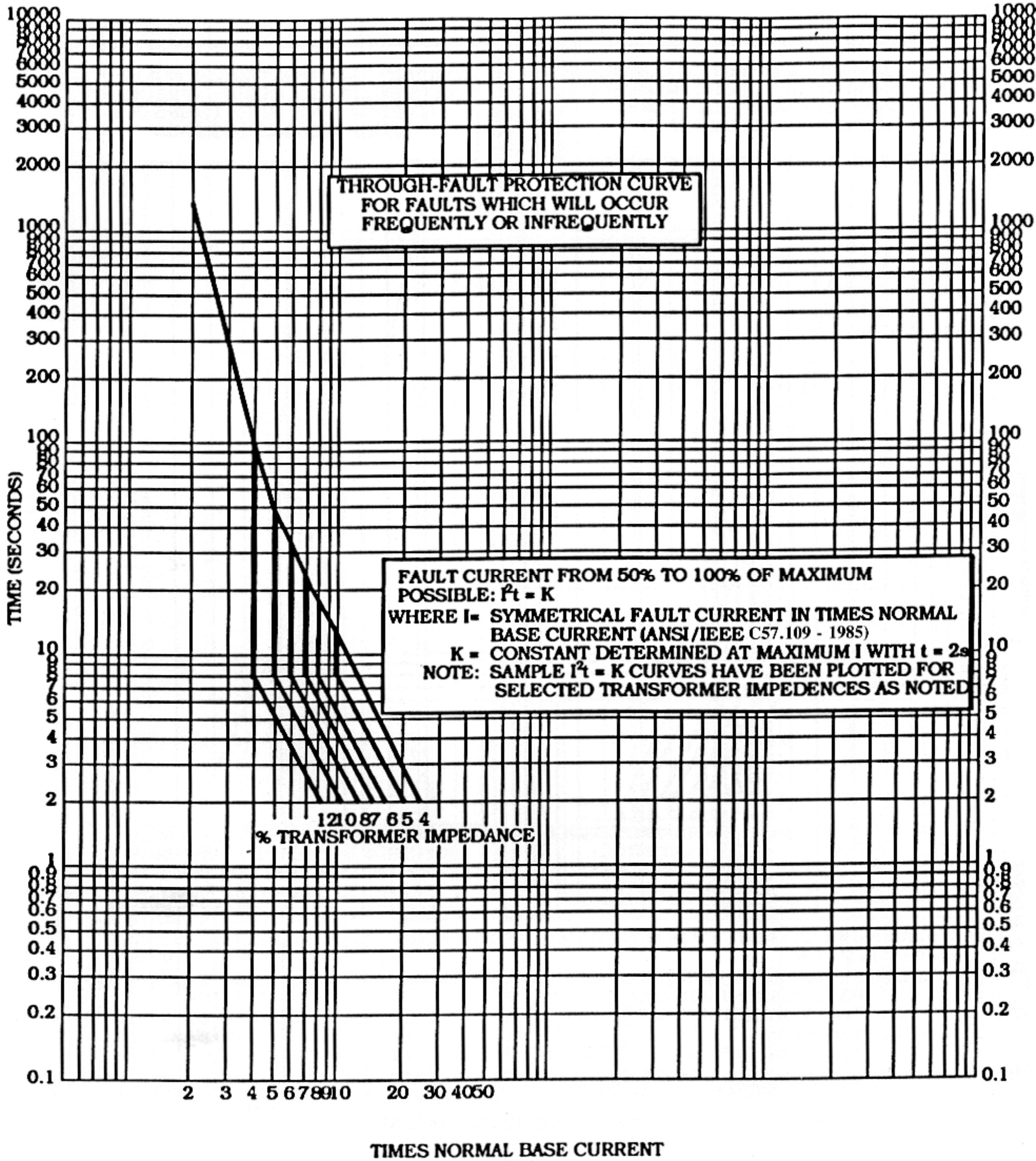


Through Fault Category 3 5-30 MVA

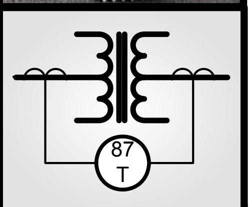


Through Fault Category 4 Larger than 30 MVA

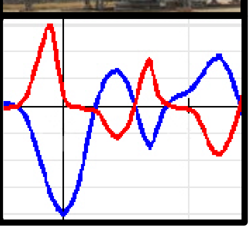




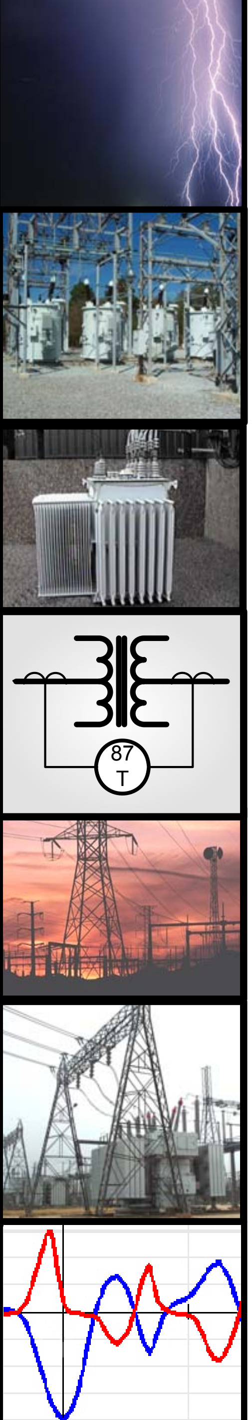




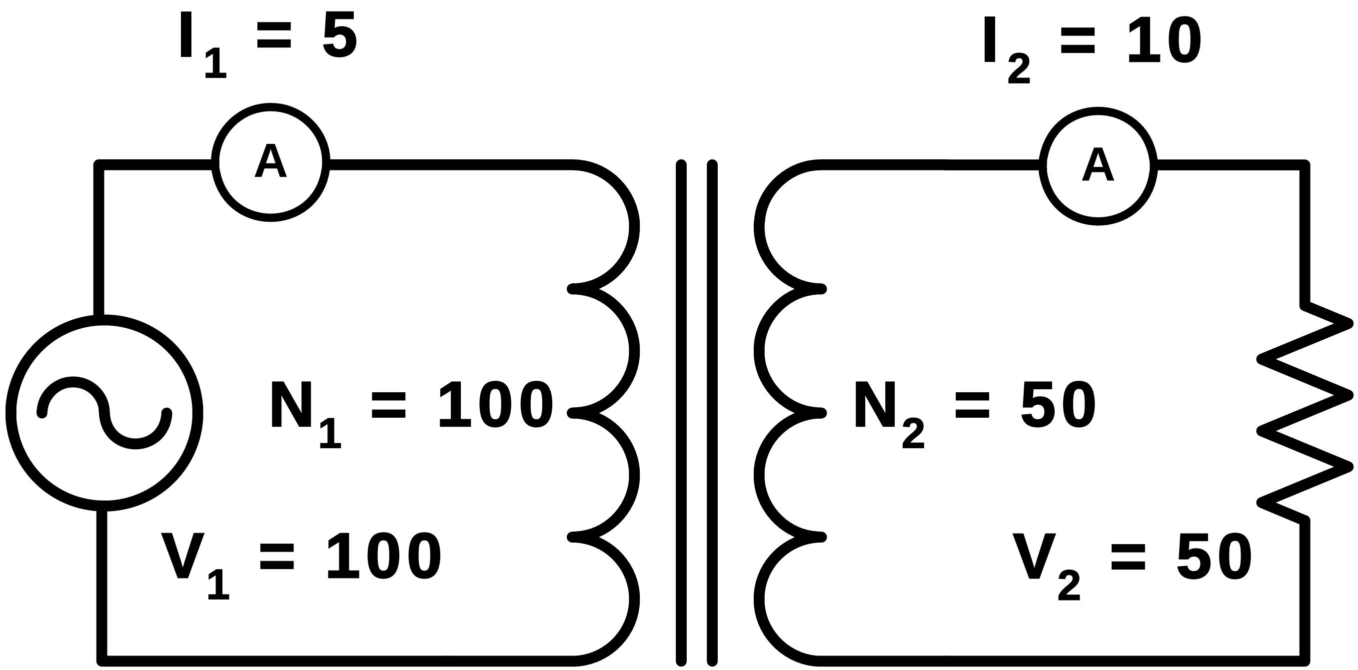


TRANSFORMER PROTECTION BASICS

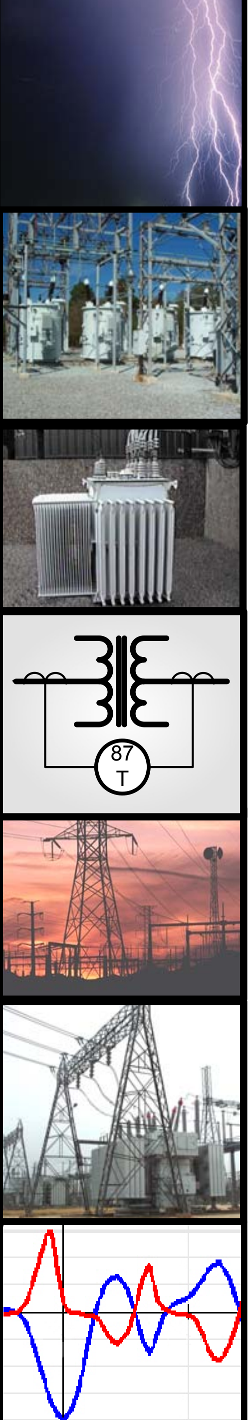


Transformer Formulas

- $V_1 I_1 = V_2 I_2$
- $N_1 V_2 = N_2 V_1$
- $N_1 I_1 = N_2 I_2$



Ideal Transformer – No Losses

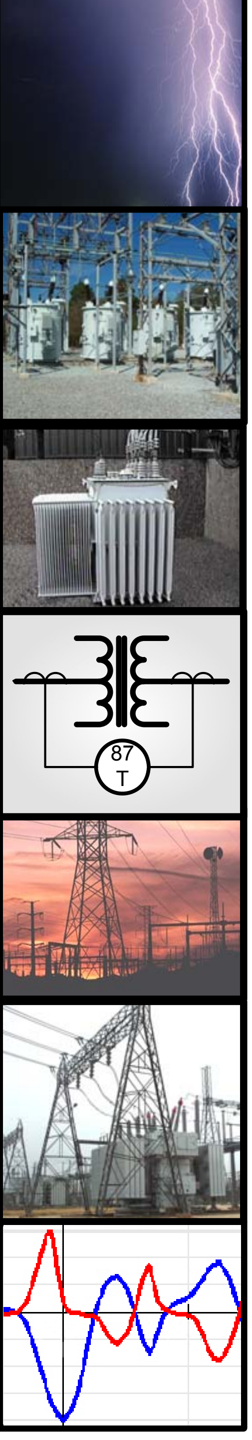


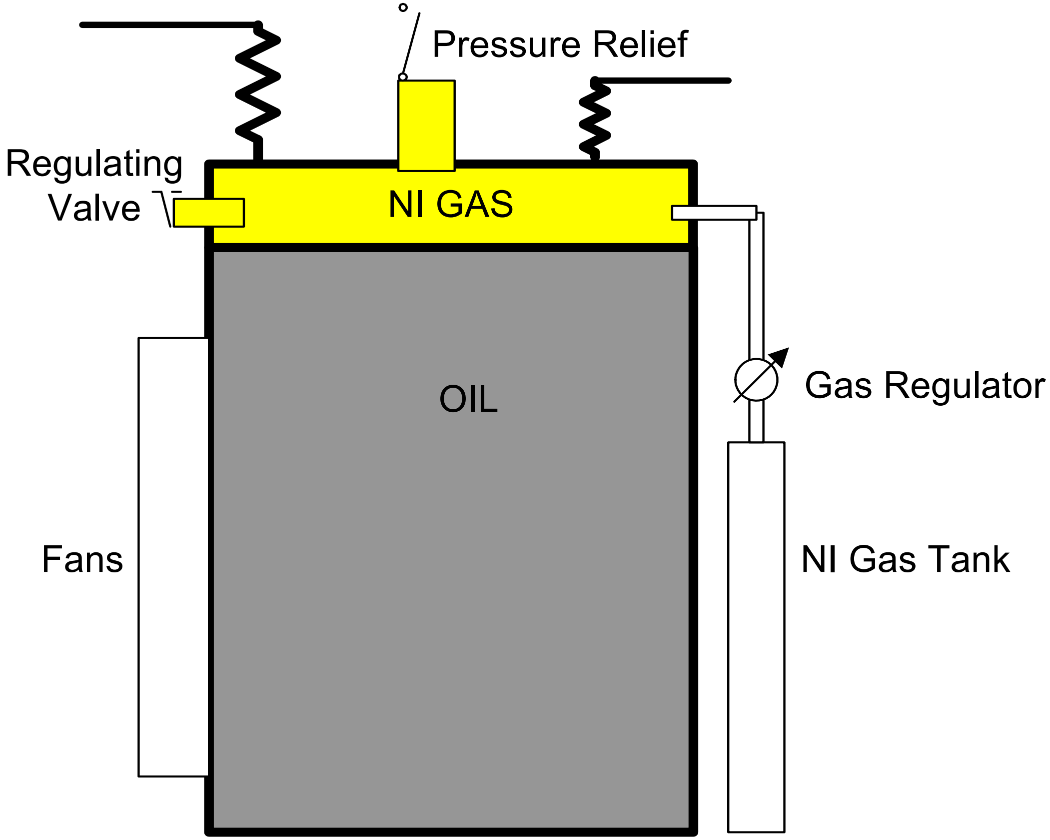
INSULATION MATERIALS

- **Dry**
  - Used where liquid spills cannot be tolerated
  - Small ratings, lower voltage distribution

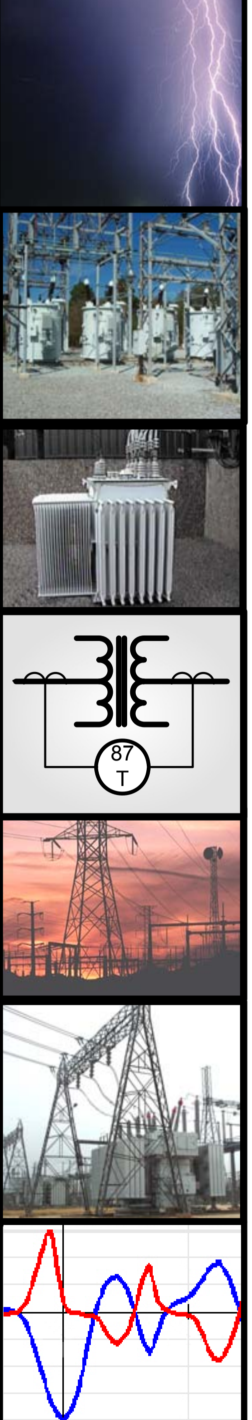
- **Wet**
  - Offers smaller size, lower cost and greater overload capacity
  - Liquids have greater coefficient of heat transfer then dry insulation
  - Vast majority of power transformers use wet (oil) insulation.

Basic Transformer Designs
Gas-Oil Sealed Transformers

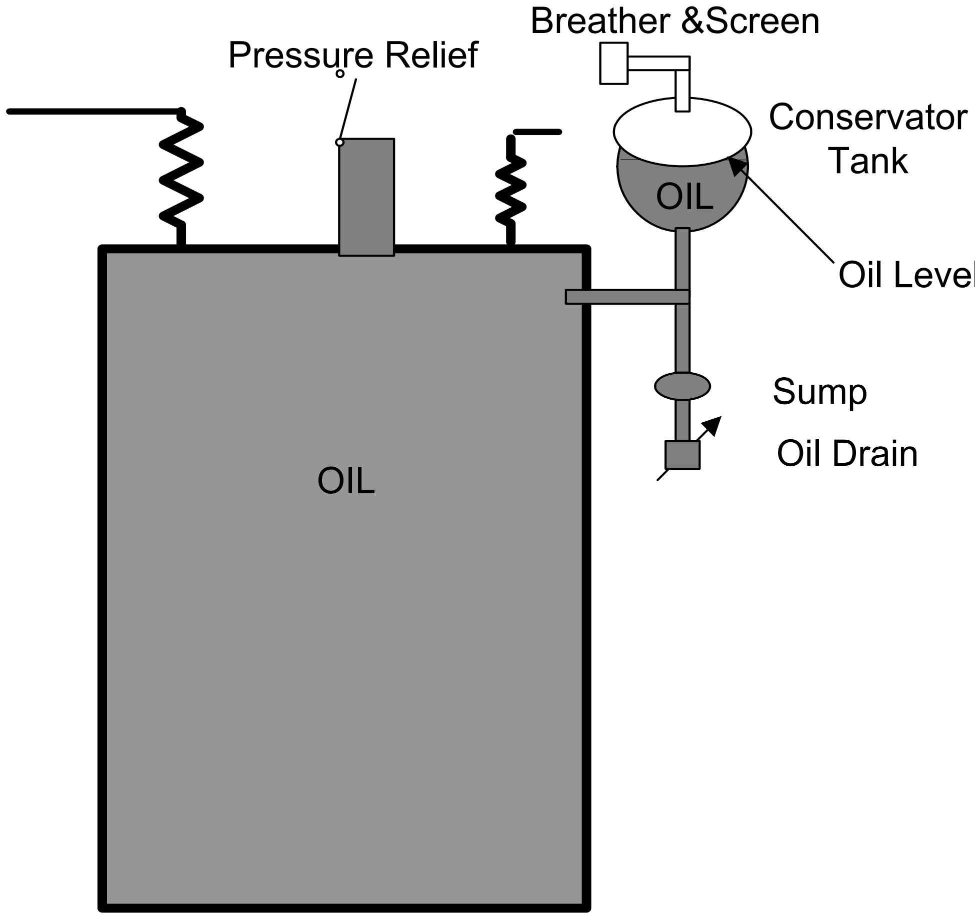




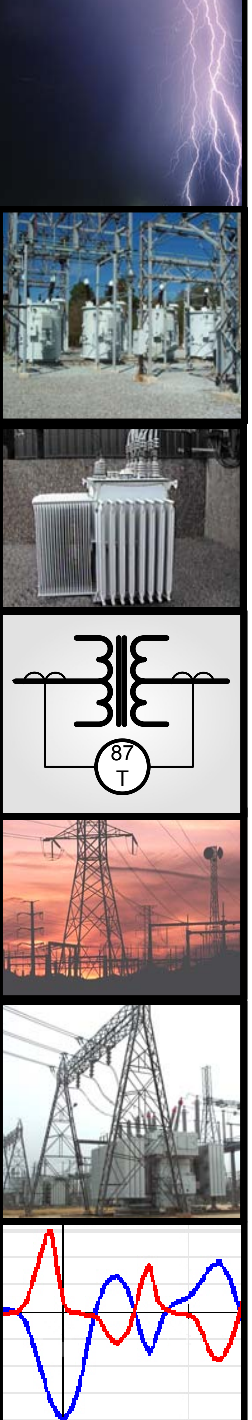
Transformer Ratings
OA/FA/FA



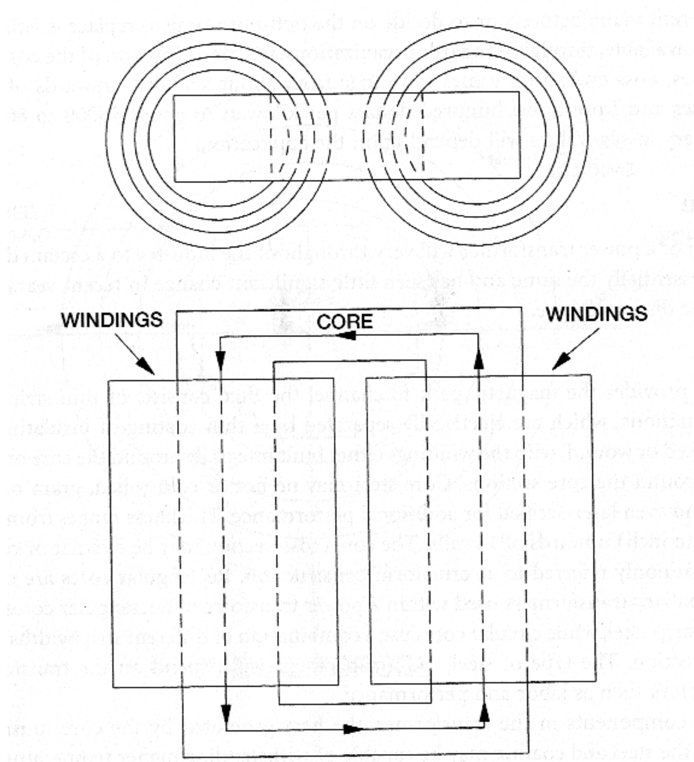
Basic Transformer Designs Conservator Tank System

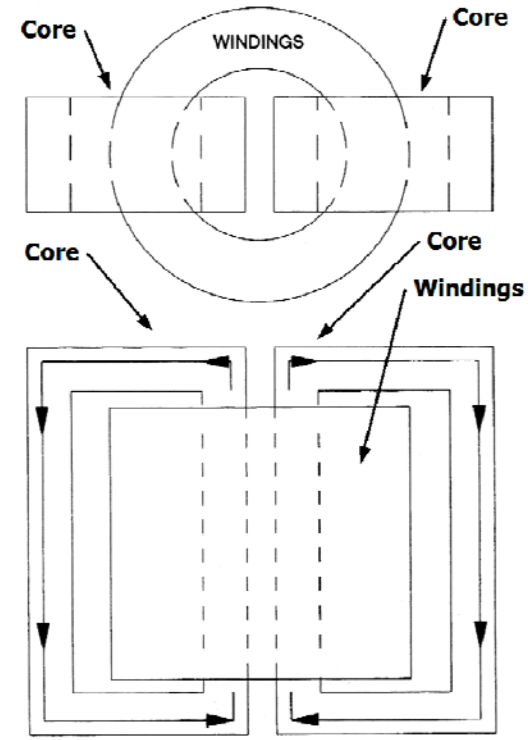


Transformer are Generally not Forced Cooled



Basic Transformer Designs
Shell & Core

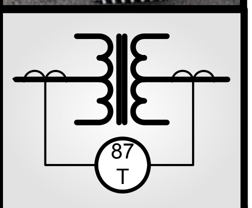




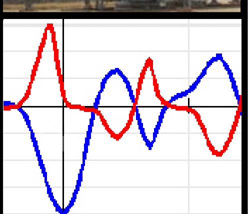
- **Core Form**
  - *Single path for the magnetic circuit*
  - *Less $$$*

- **Shell Form**
  - *Multiple paths for the magnetic circuit*
  - *Better through-fault withstand*



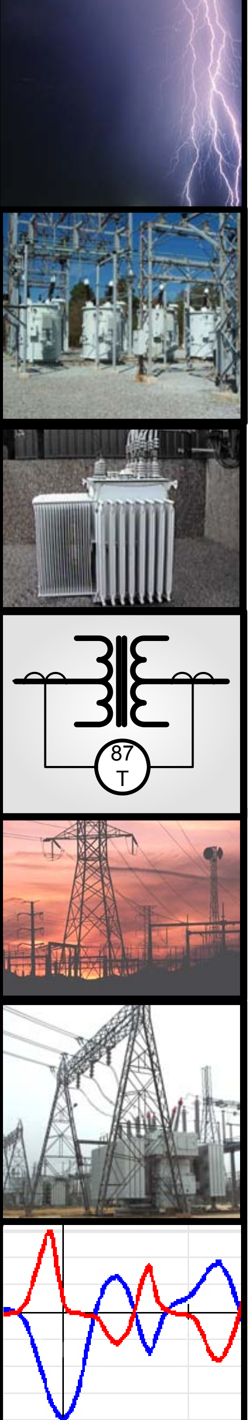





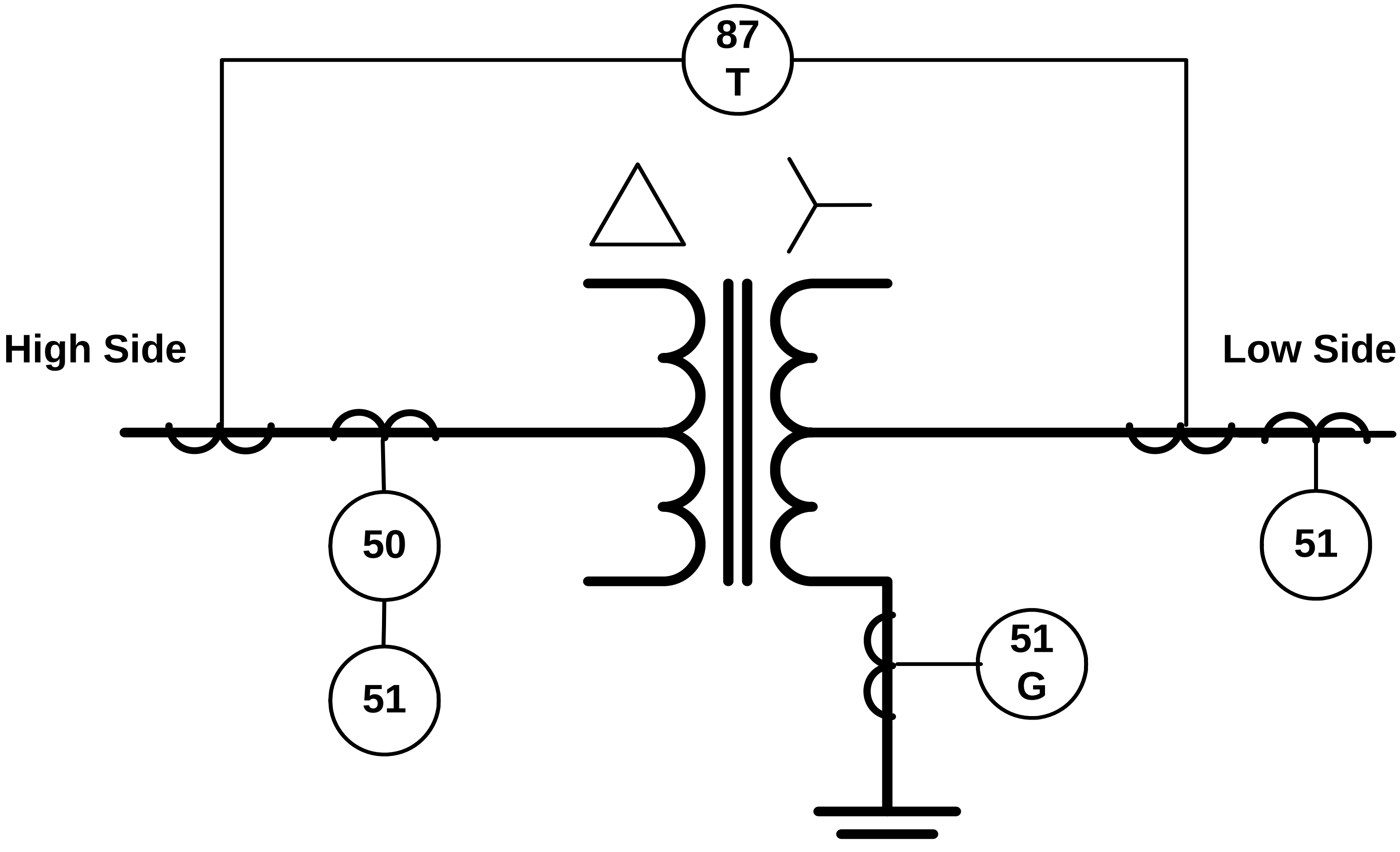


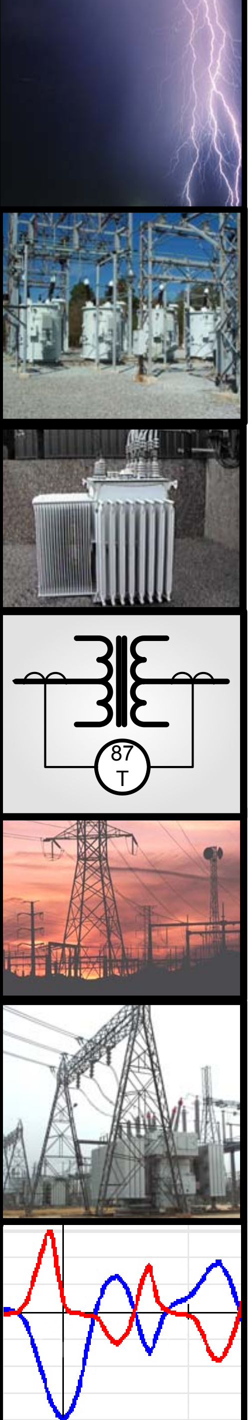
IEEE Devices used in Transformer Protection

- **24**: Overexcitation (V/Hz)
- **46**: Negative Sequence Overcurrent
- **49**: Thermal Overload
- **50**: Instantaneous Phase Overcurrent
- **50G**: Instantaneous Ground Overcurrent
- **50N**: Instantaneous Neutral Overcurrent
- **50BF**: Breaker Failure
- **51G**: Ground Inverse Time Overcurrent
- **51N**: Neutral Inverse Time Overcurrent
- **63:** Sudden Pressure Relay (Buccholtz Relay)
- **81U**: Underfrequency
- **87HS:** High-set Phase Differential (Unrestrained)
- **87T**: Transformer Phase Differential with Restraints
- **87GD**: Ground Differential (also known as “restricted earth fault”)

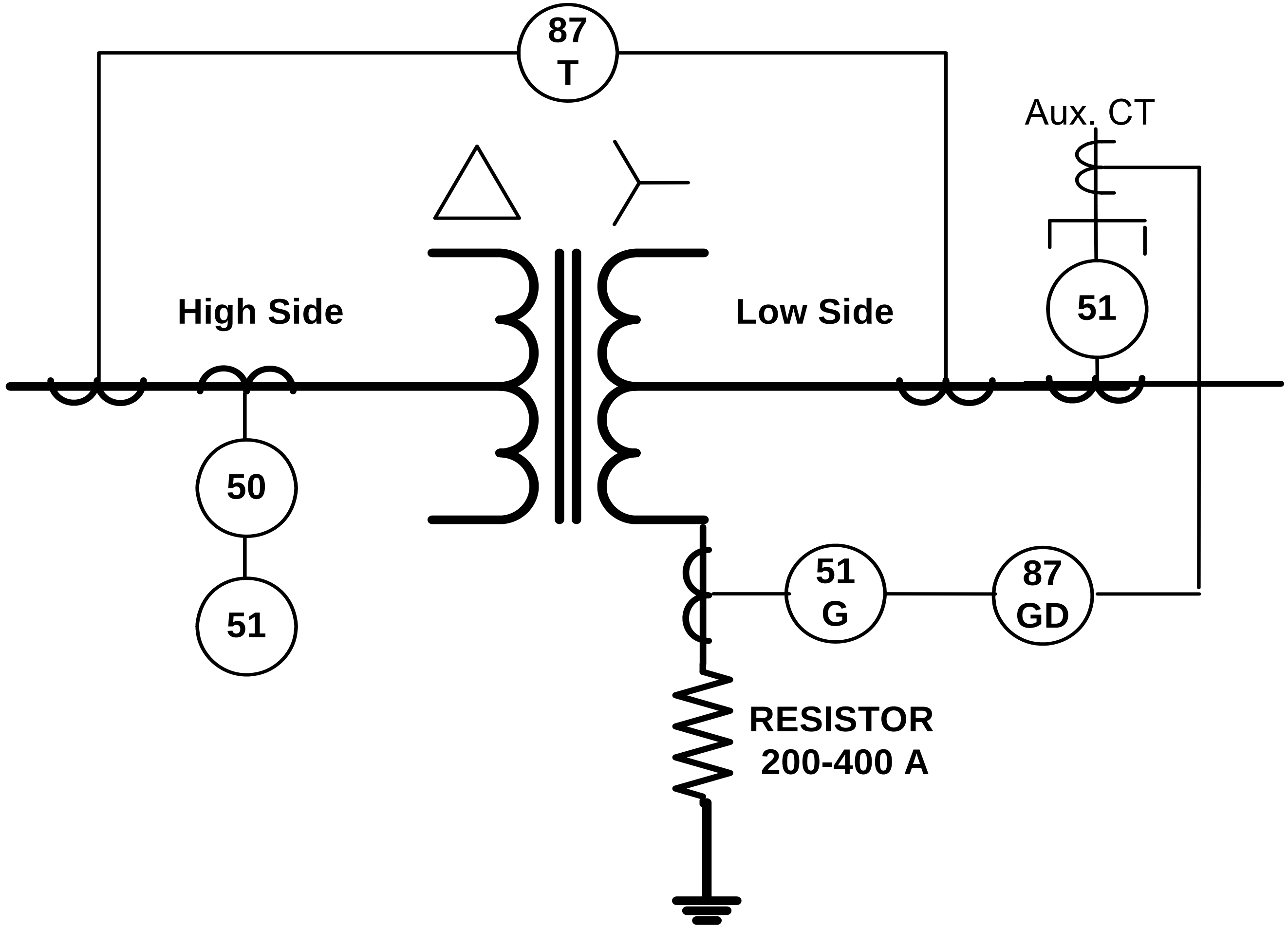


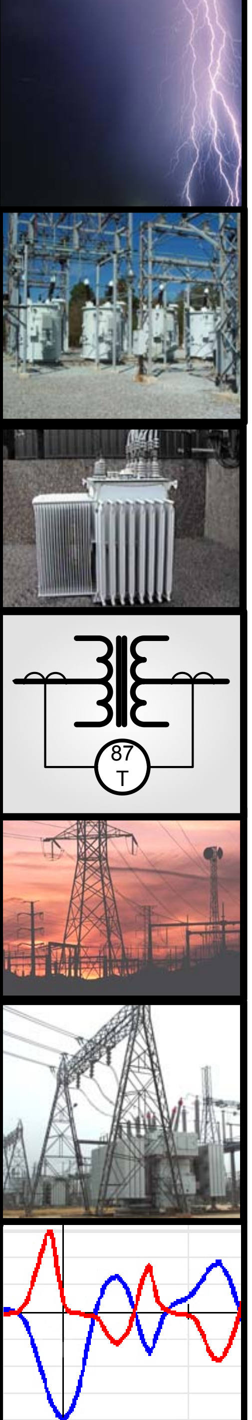
BASIC UTILITY SOLIDLY GROUNDED TRANSFORMER PROTECTIONS





Basic Industrial Transformer Protection

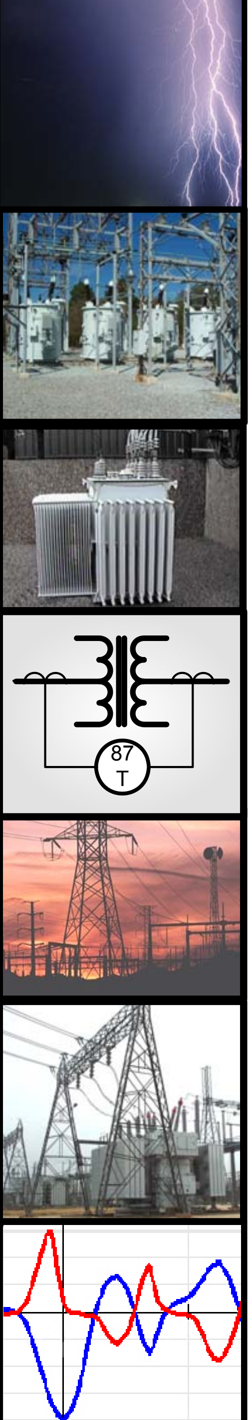




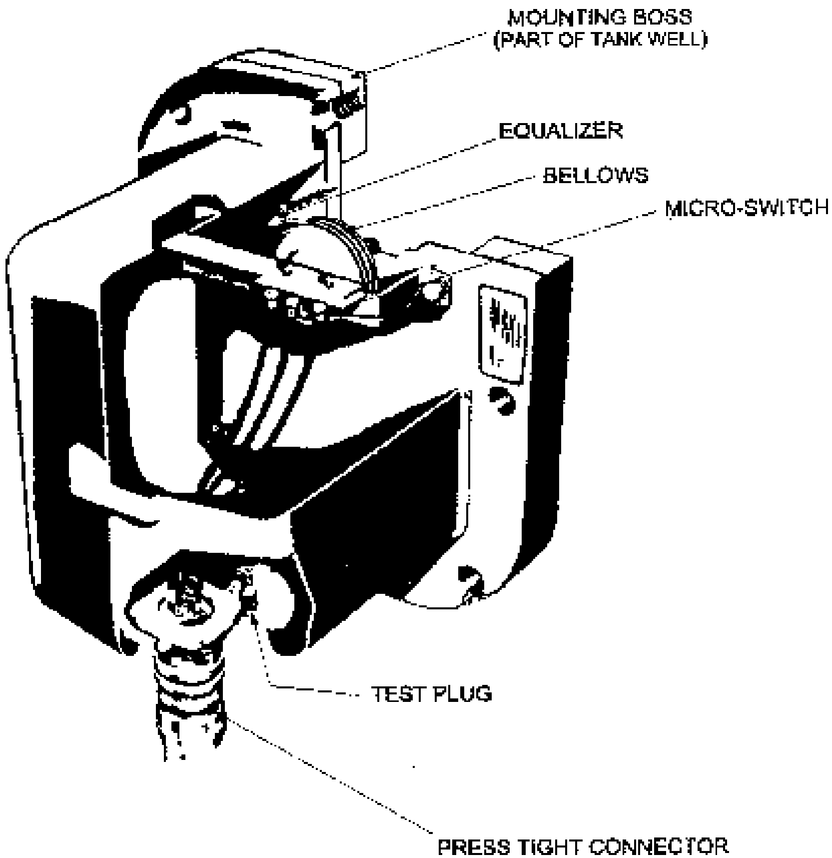
Types of Protection

Mechanical

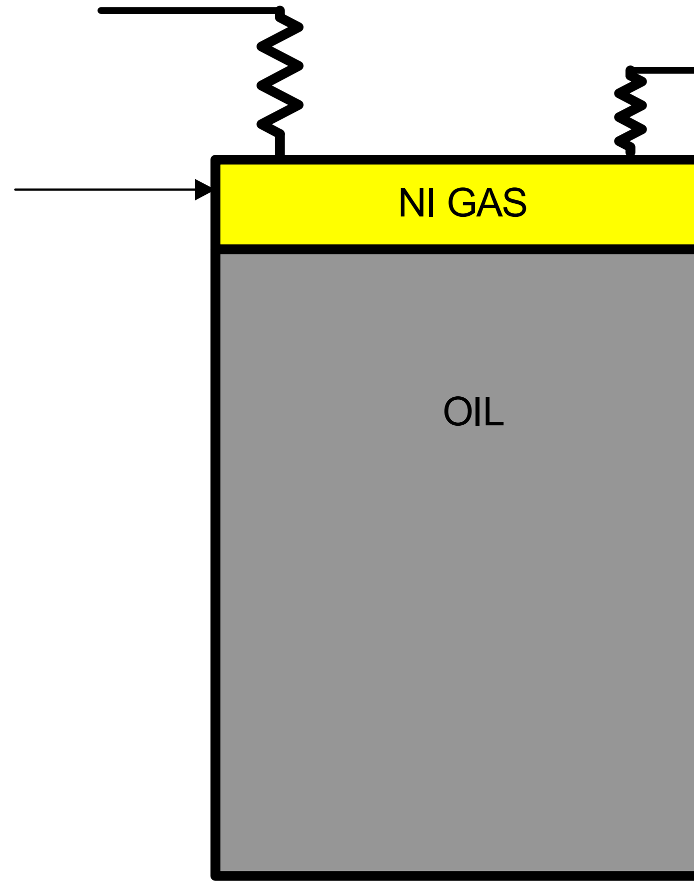
- Accumulated Gases
  - Arcing by-products
- Pressure Relays
  - Arcing causing pressure waves in oil or gas space
- Thermal
  - Caused by overload, overexcitation, harmonics and geo magnetically induced currents
    - Hot spot temperature
    - Top Oil
    - LTC Overheating



Sudden Pressure Relay (SPR) Protection

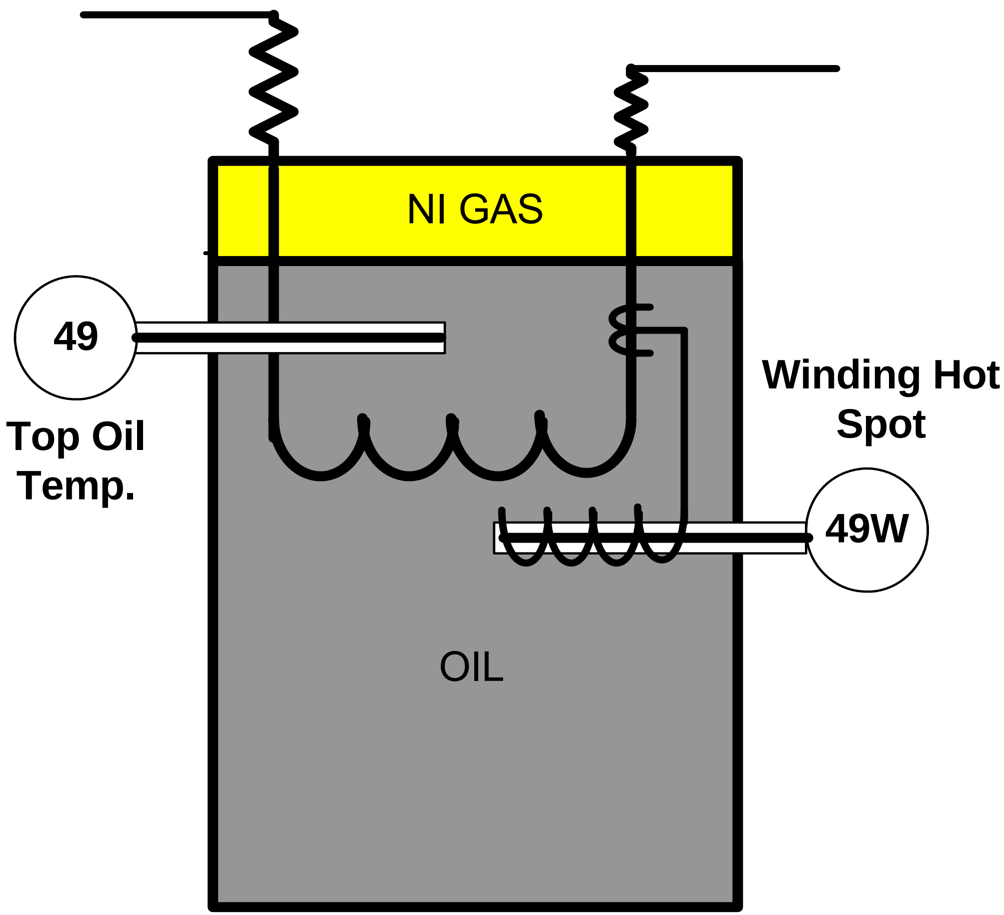


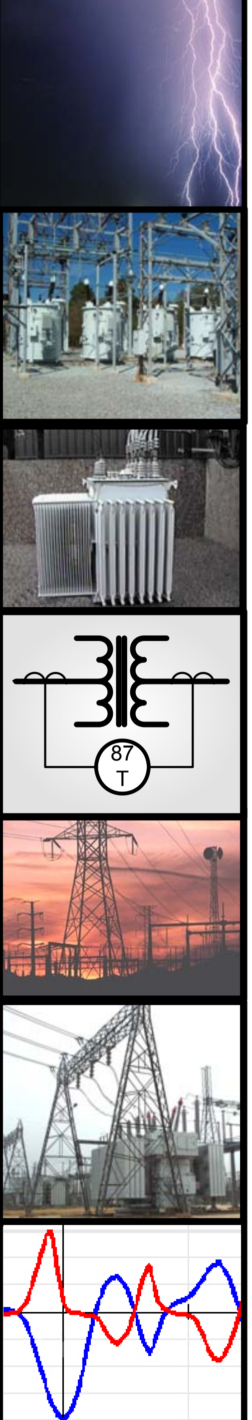
Sudden Pressure Relay



Transformer

Transformer Thermal Monitoring





Types of Protection

Fuses

Small transformers (<10 MVA Solidly Grounded)

Short circuit protection only

Overcurrent Protection

High side

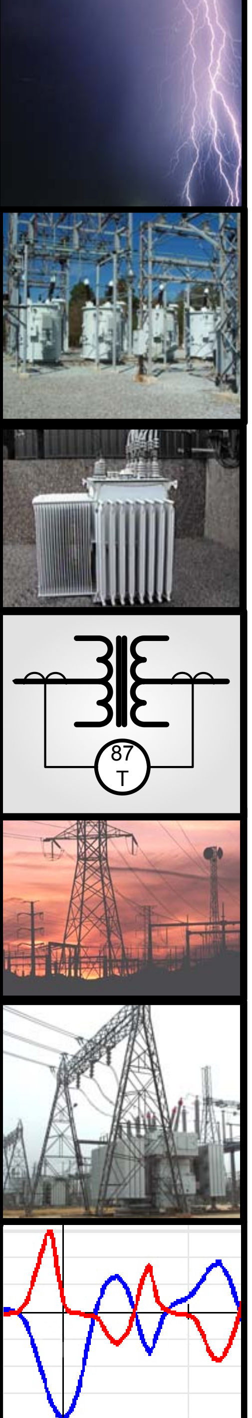
- Through fault protection
- Differential back-up protection for high side faults

Low side

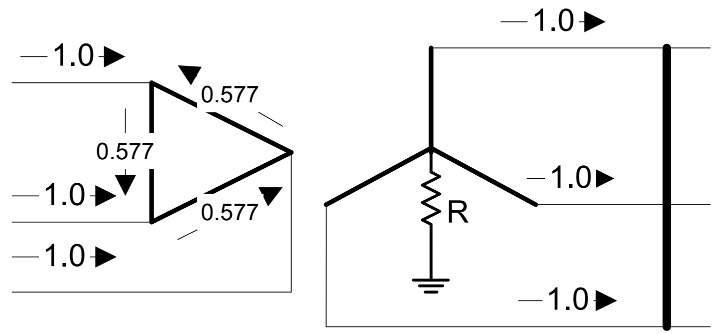
- System back up protection

Differential Protection

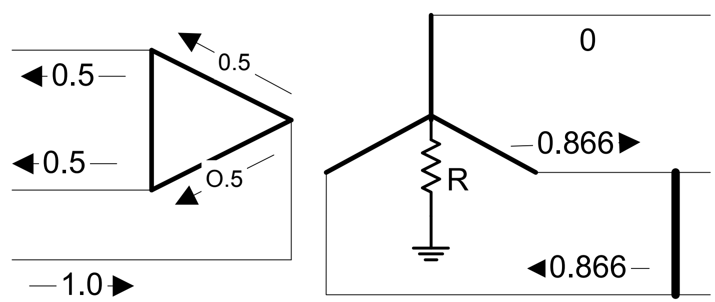
- Phase Diff.
- Ground Diff.



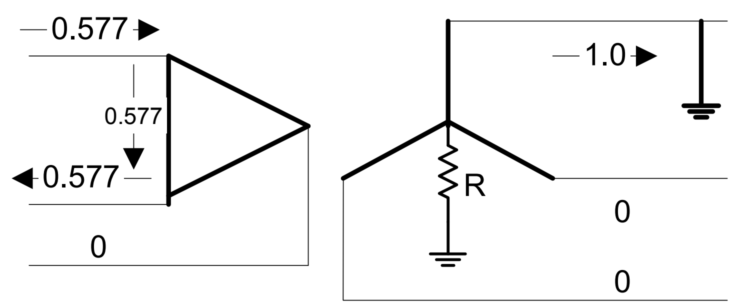
DELTA-WYE TRANSFORMERS UNDER FAULT CONDITIONS



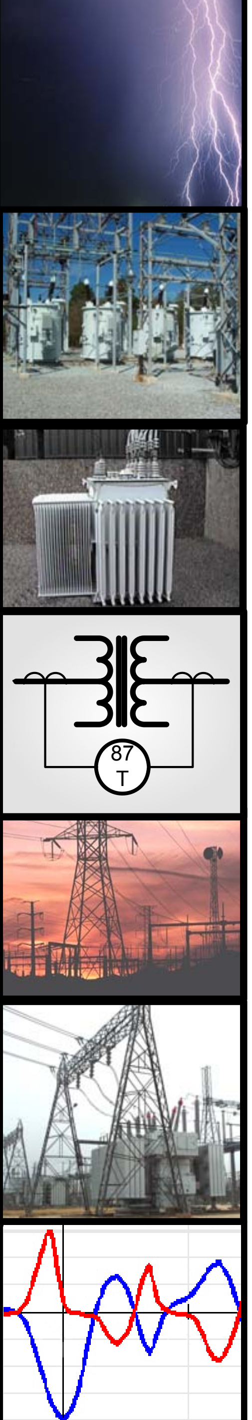
A) Three Phase Fault



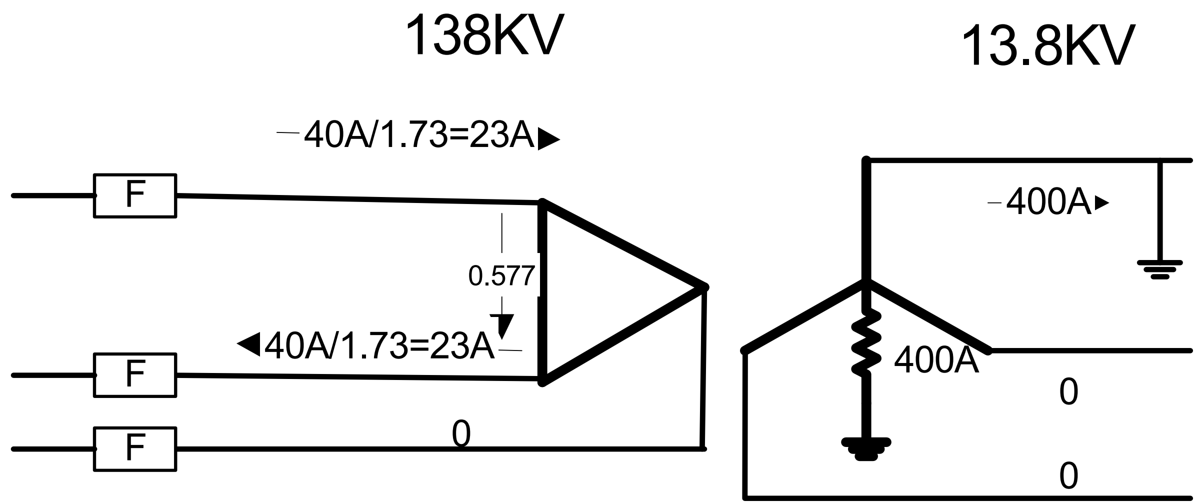
B) Phase to Phase Fault in pu of Three Phase Fault



C) Line to Ground Fault



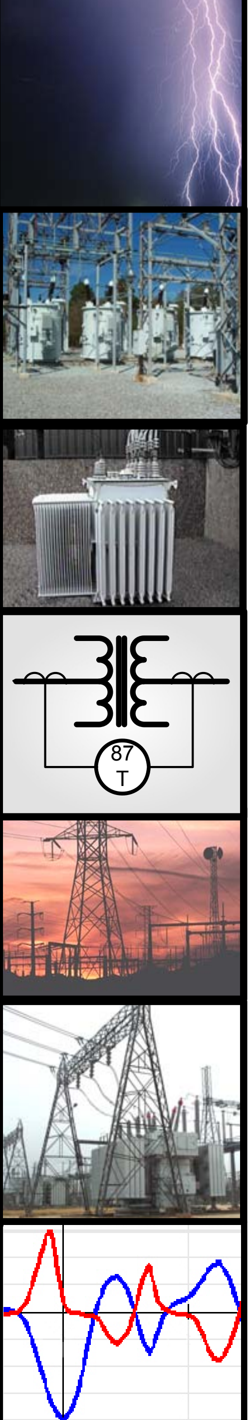
DELTA-WYE TRANSFORMERS LIMITATIONS OF FUSING



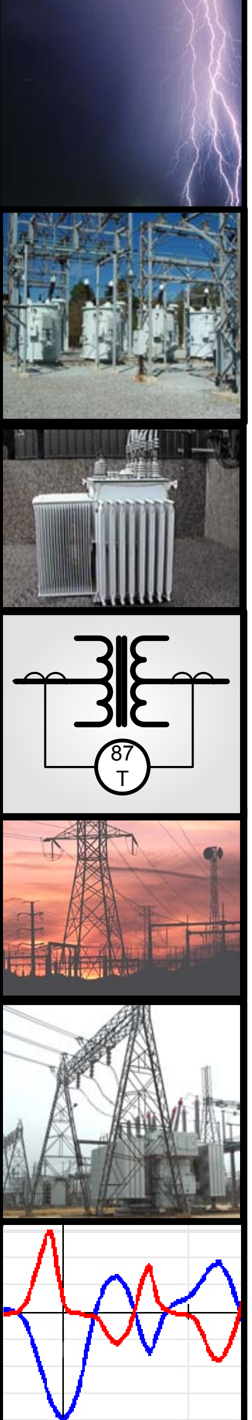
Line to Ground Fault 10 MVA 138/13.8KV

I_{FL} = 10,000/1.73 X 138 = 42A

WHEN FUSES ARE SIZED TO CARRY LOAD THEY CAN'T DETECT A GROUND FAULT

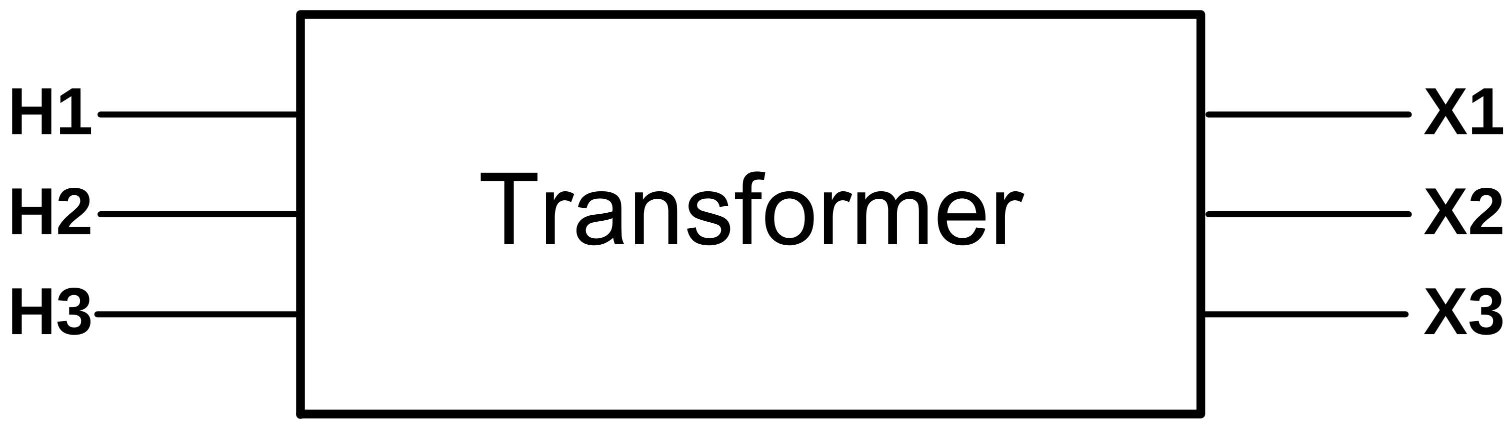


TRANSFORMER PHASING STANDARDS IEEE/ANSI & IEC



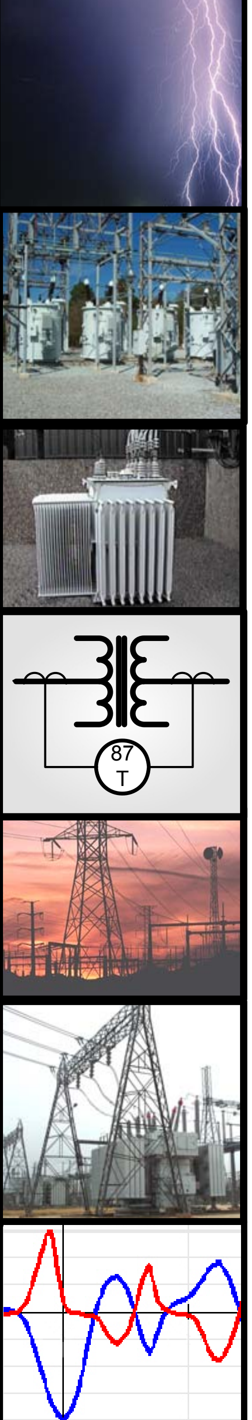
ANSI/IEEE PHASING STANDARD

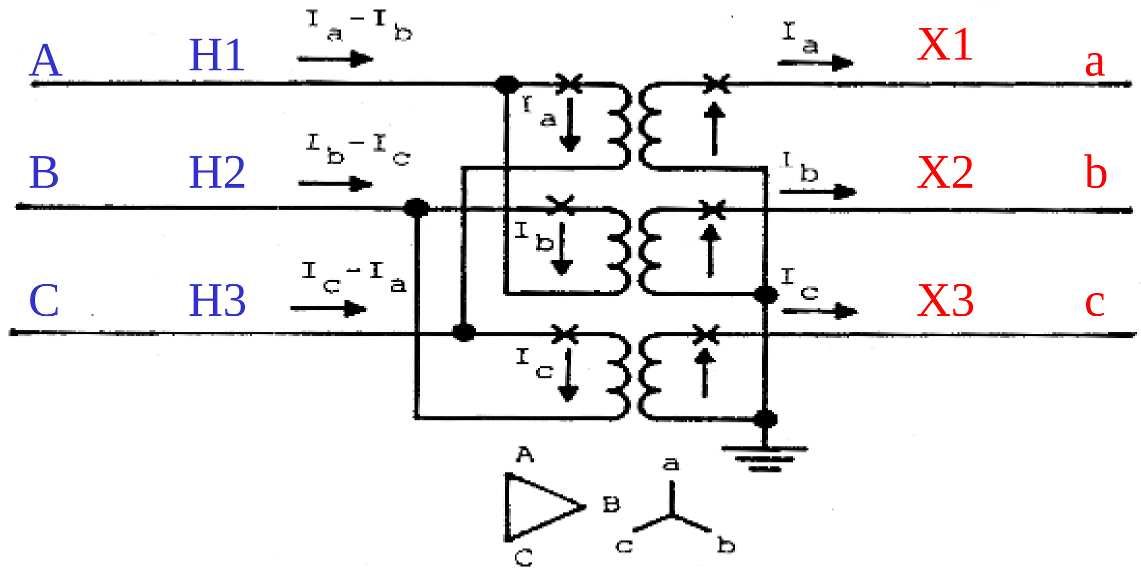
- H1, H2, H3
  - Primary Bushings
- X1, X2, X3
  - Secondary Bushings



Wye-Wye	H1 and X1 at zero degrees
Delta-Delta	H1 and X1 at zero degrees
Delta-Wye	H1 lead X1 by 30 degrees
Wye-Delta	H1 lead X1 by 30 degrees

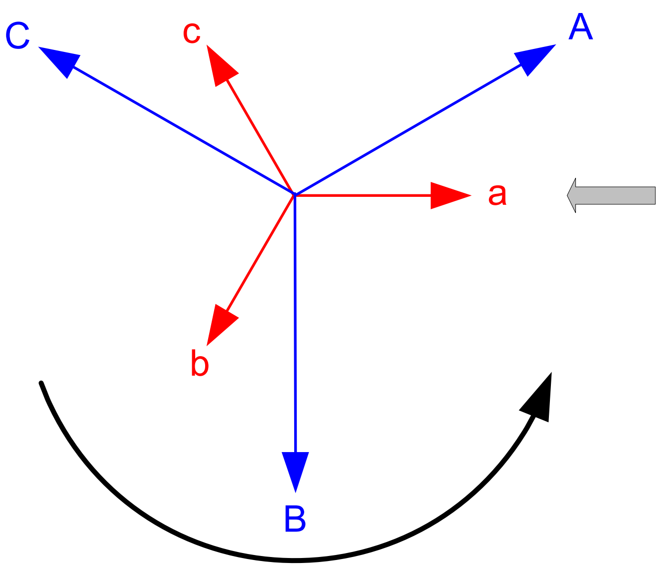
Angular Displacement - Development





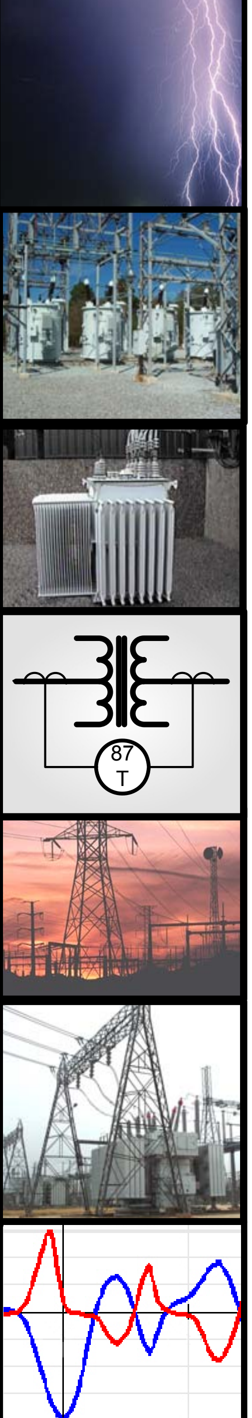
HV

LV

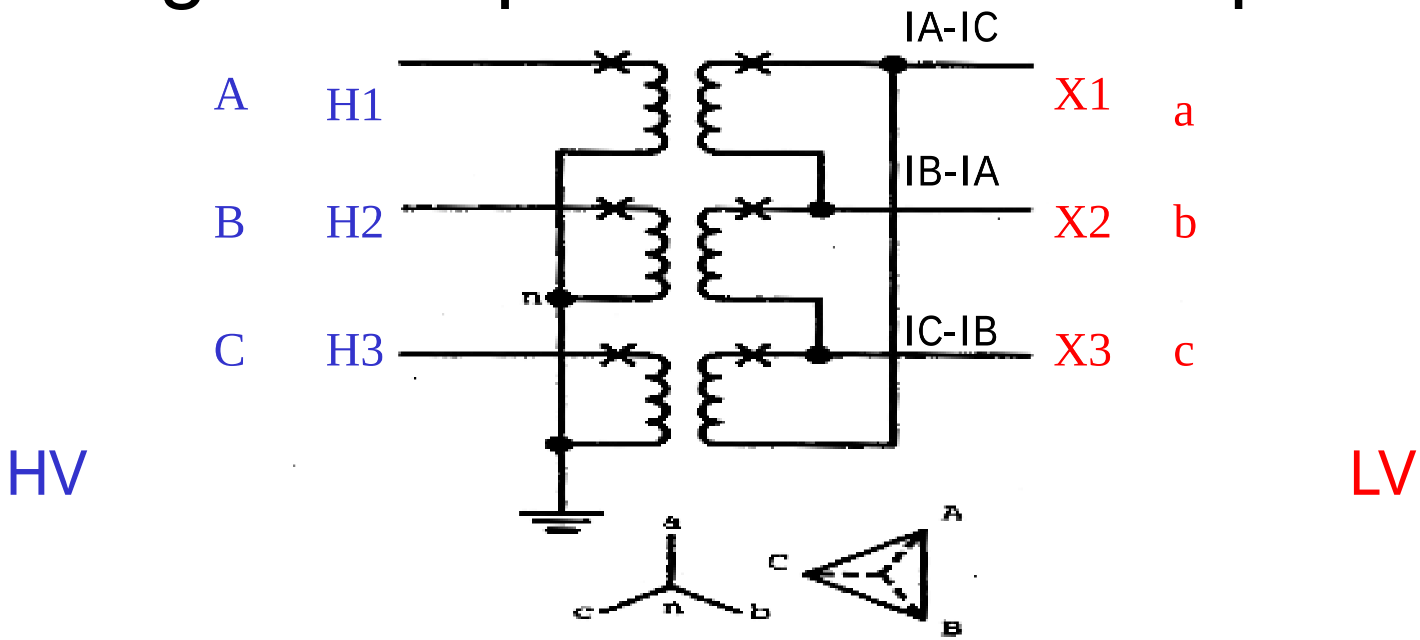


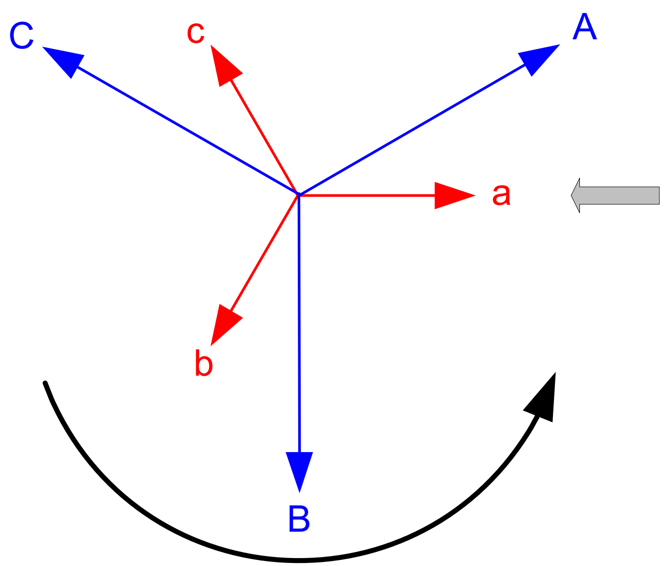
- H1 (A) leads X1 (a) by 30
- Currents on "H" bushings are delta quantities
- Can Describe as Delta AB (Ia =Ia-Ib)

Assume 1:1 transformer



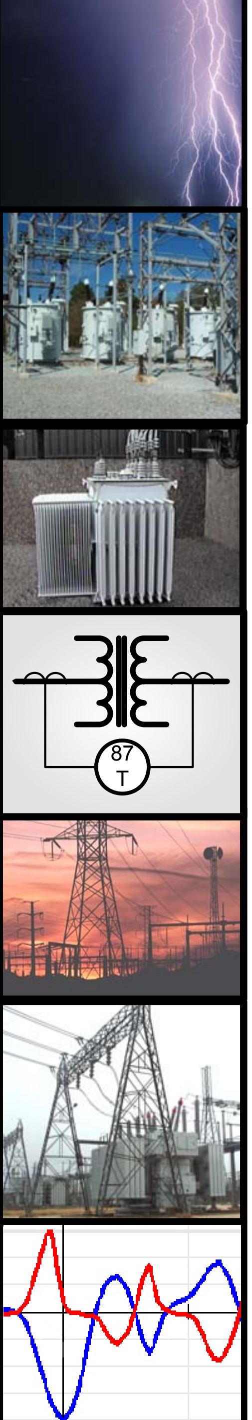
Angular Displacement - Development





- H1 (a) leads X1 (A) by 30
- Currents on “X” bushings are delta quantities
- Can Describe as Delta AC (Ia=IA-IC)

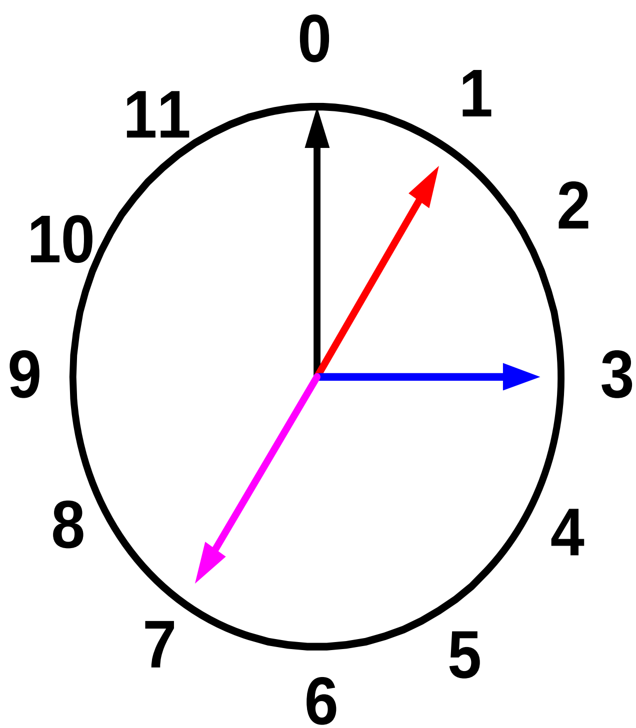
Assume 1:1 transformer



Transformer Phasing – IEC Phasing Standard

Euro-designations use 30° increments of LAG from the X1 bushing to the H1 bushings

30^0 CLOCK



EXAMPLES

For Delta Primary Transformers:

1 = Dy1 = X lags H by 30^0

3 = Dy3 = X lags H by 90^0

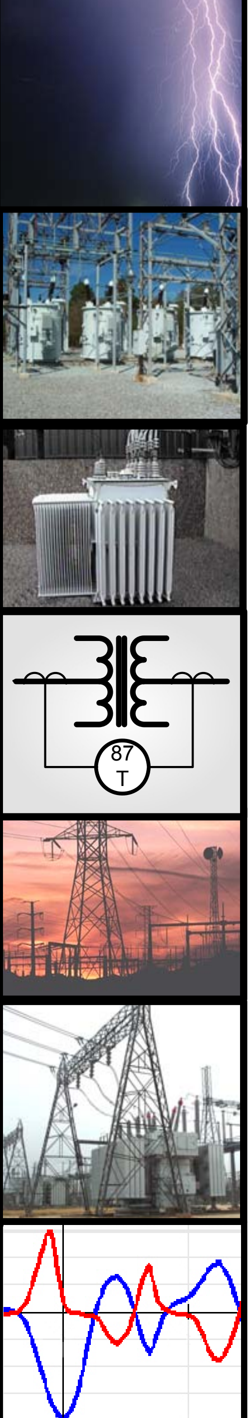
7 = Dy 7 = X lags H by 210^0

For Wye Primary Transformers:

1= Yd1 = X lags H by 30^0

3 = Yd3 = X lags H by 90^0

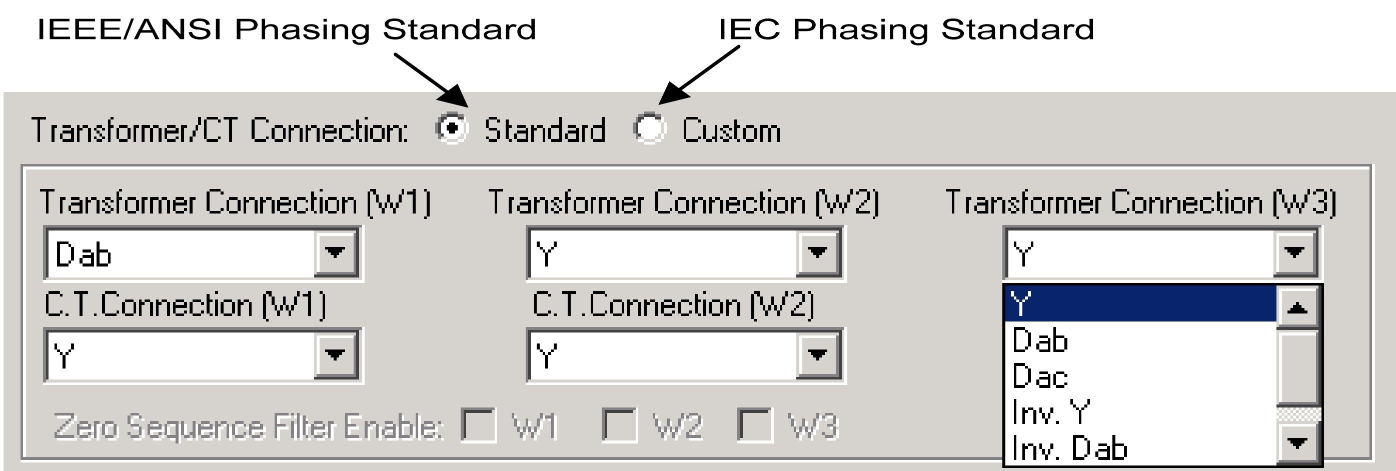
7 = Yd7 = X lags H by 210^0

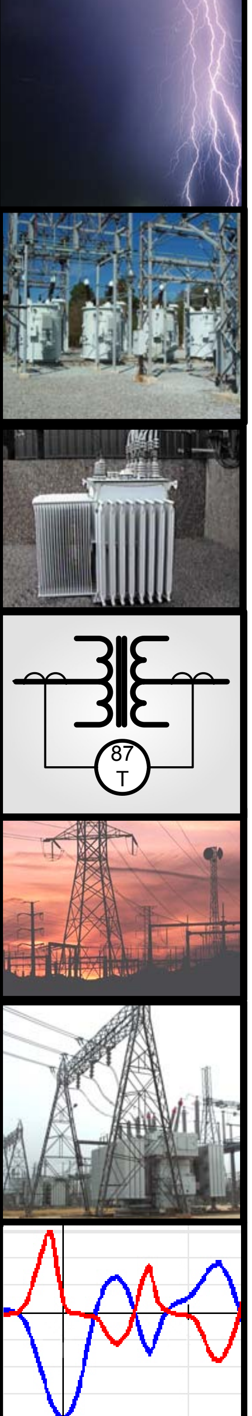


Transformer Phasing

Communicating Phasing To Digital Relays

- Major Source of Setting Error
- IEEE-ANSI – Can use Δ AB or Δ AC
- IEC – Need to Use 30^{o} Clock
- CT's Can be Δ or Y
- Solution: Let the Software Decide





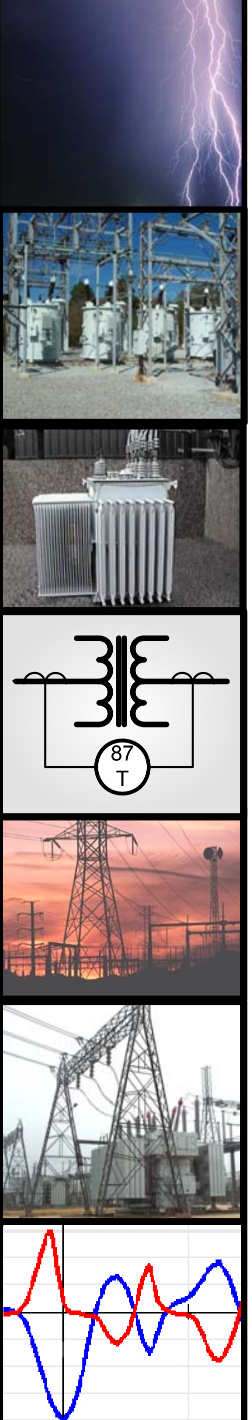
Angular Displacement

IEC Connection Description	Symbol	Beckwith Standard Connection Description	Symbol	
Yy0		YY		*1
Dd0		Dac Dac		*1
Yd1		Y Dac		*2
Yd11		Y Dab		
Dy1		Dab Y		*2
Dy11		Dac Y		
Yd5		Y Inverse Dab		
Dy5		Dac Inverse Y		
Dd10		Dac Dab		
Dz2		Dab Custom		

- IEC (Euro) practice does not have a standard like ANSI
- Most common connection is Dy11 (low lead high by 30!)
- *Obviously observation of angular displacement is extremely important when paralleling transformers!*

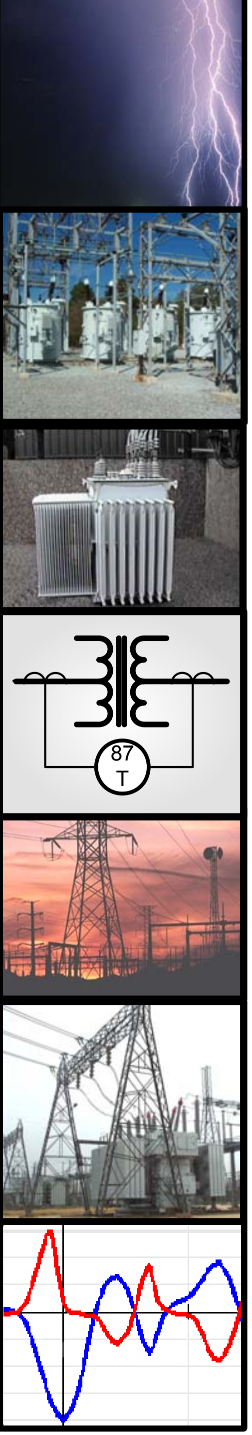
*1 = ANSI std. @ 0°

*2 = ANSI std. @ X1 lag H1 by 30°, or "high lead low by 30 ° "

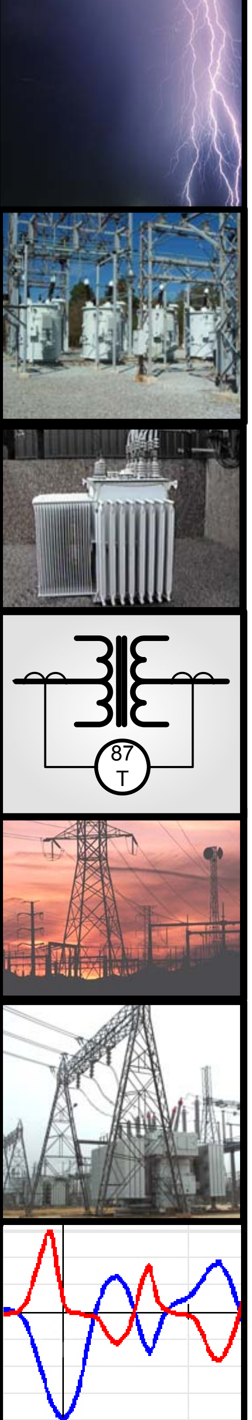


Winding Arrangements

- Wye-Wye
  - Conduct zero-sequence between circuits
  - Provides ground source for secondary circuit
- Delta-Delta
  - Blocks zero-sequence between circuits
  - Does not provide a ground source
- Delta-Wye
  - Blocks zero-sequence between circuits
  - Provides ground source for secondary circuit
- Wye-Delta
  - Blocks zero-sequence between circuits
  - Does not provide a ground source for secondary circuit



TRANSFORMER DIFFERENTIAL PROTECTION

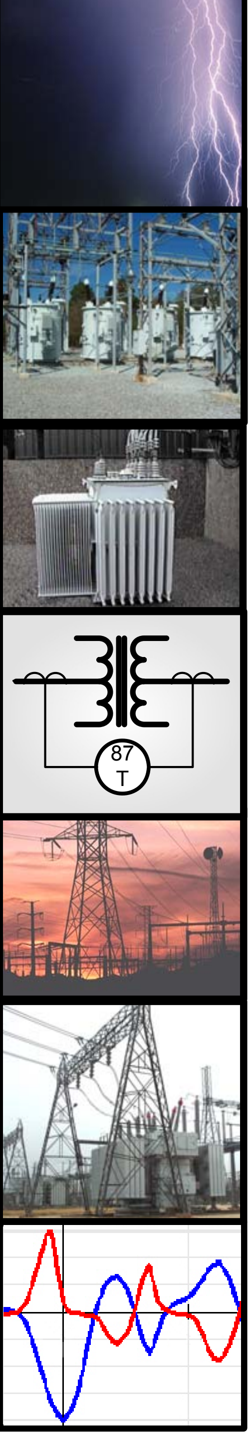


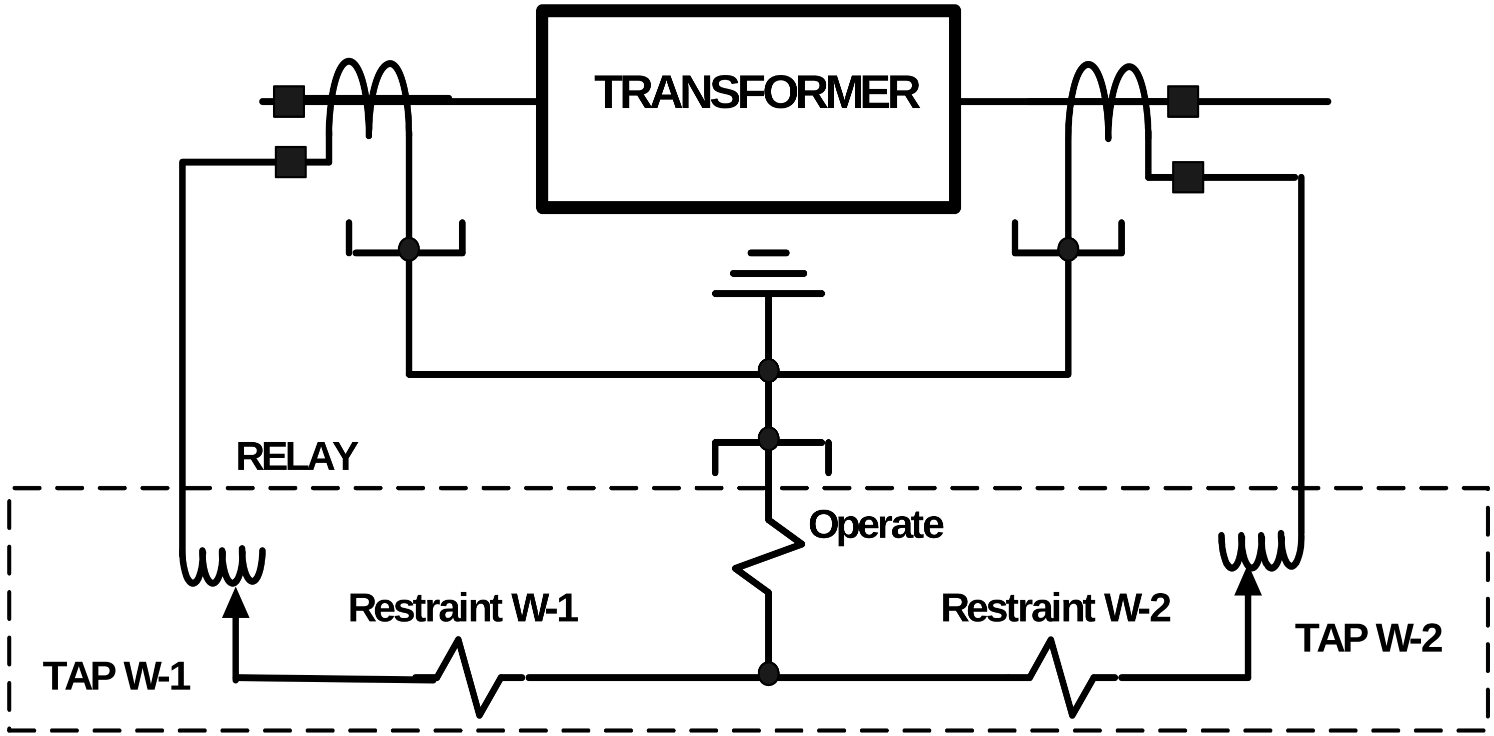
Types of Protection

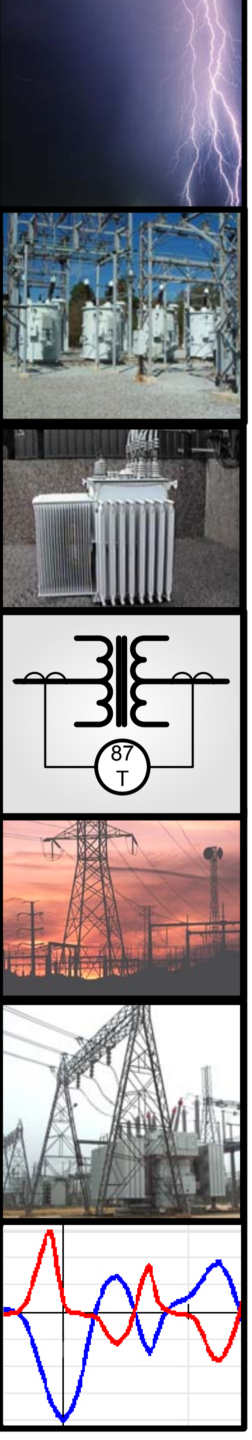
Electrical

- Phase Differential
  - Applied with variable percentage slopes to accommodate CT saturation and CT ratio errors
  - Applied with inrush and overexcitation restraints
  - Set with at least a 15% pick up to accommodate CT performance
    - Class “C” CT; 10% at 20X rated
  - If unit is LTC, add another 10%
  - May not be sensitive enough for all faults (low level, ground faults near neutral, resistor grounded transformers)

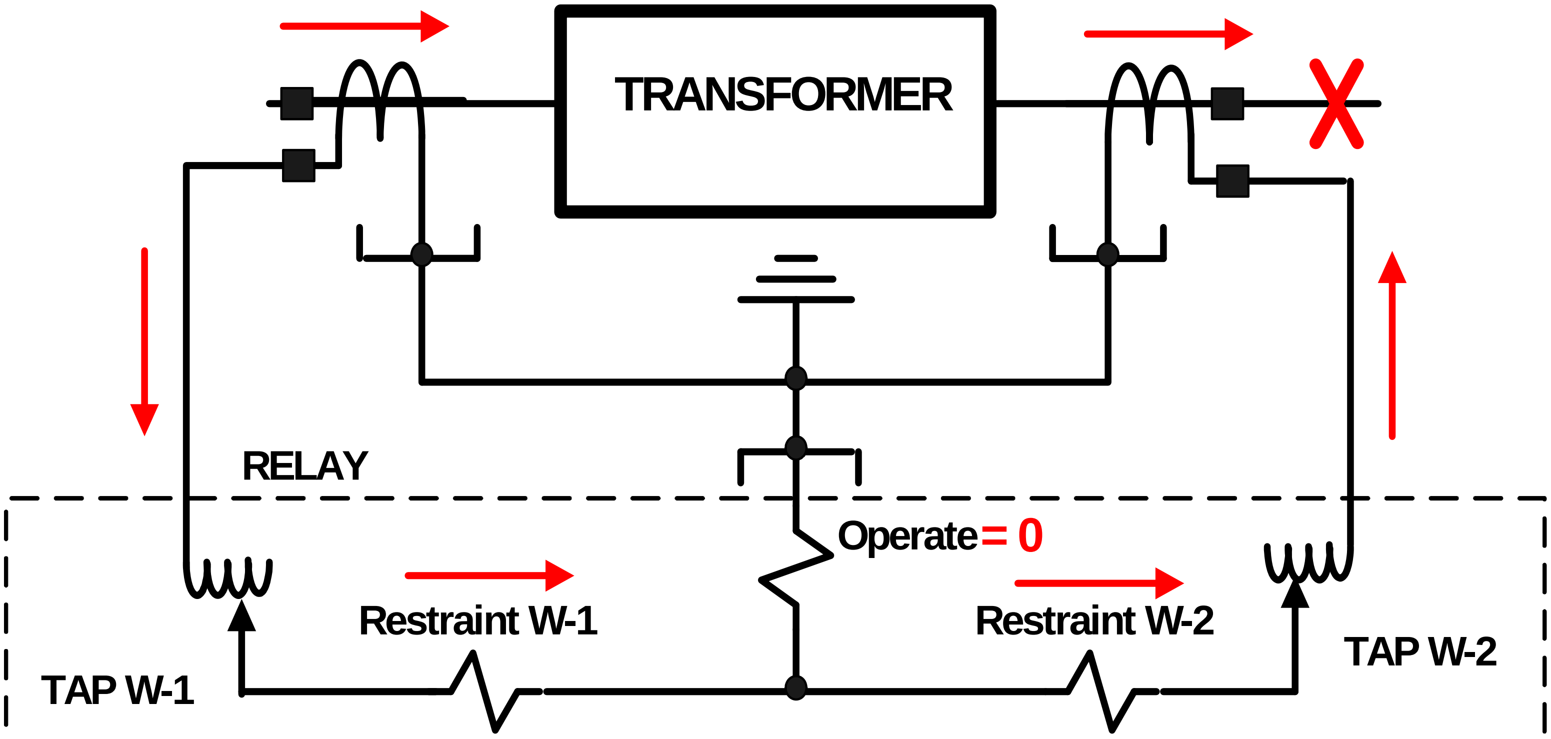
Basic Differential Relay

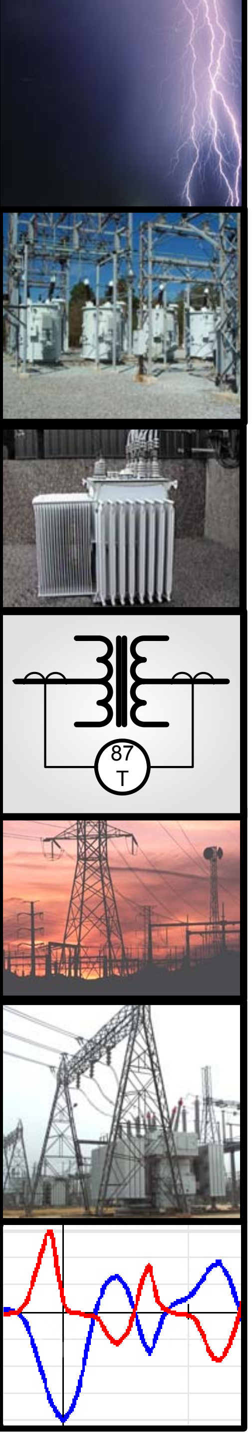




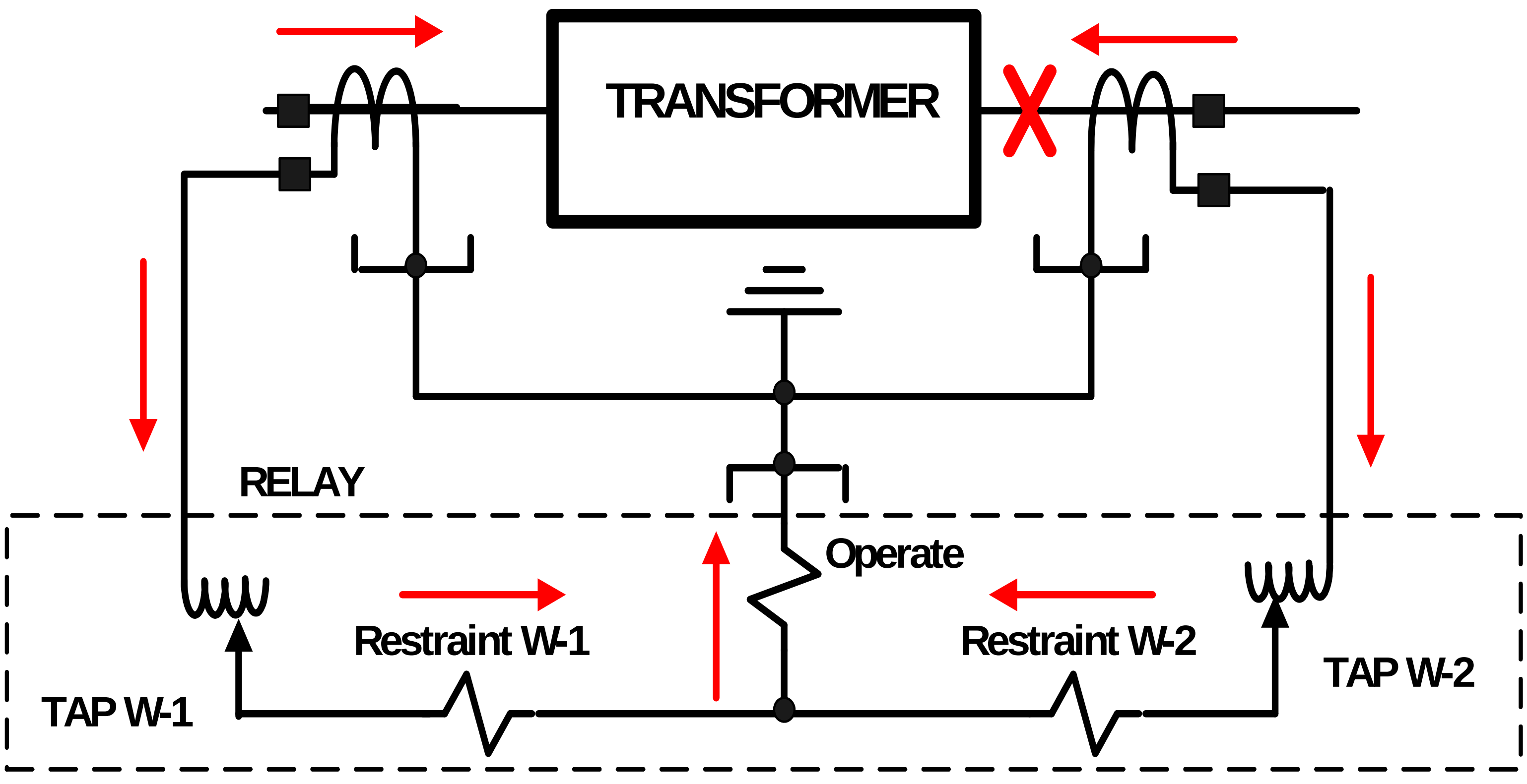


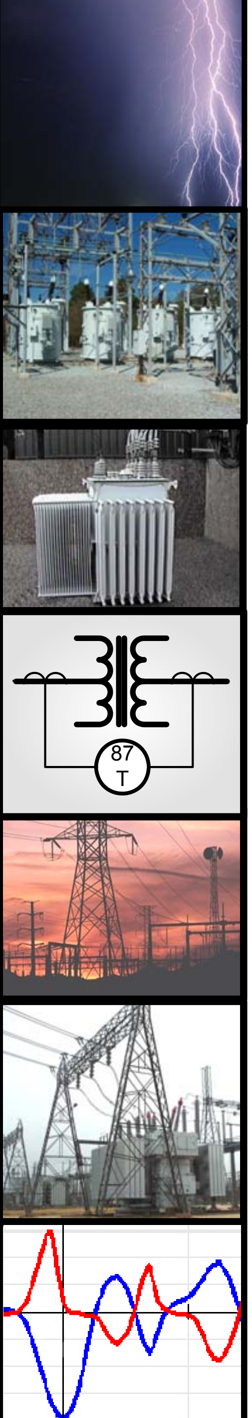
Basic Differential Relay
External Fault





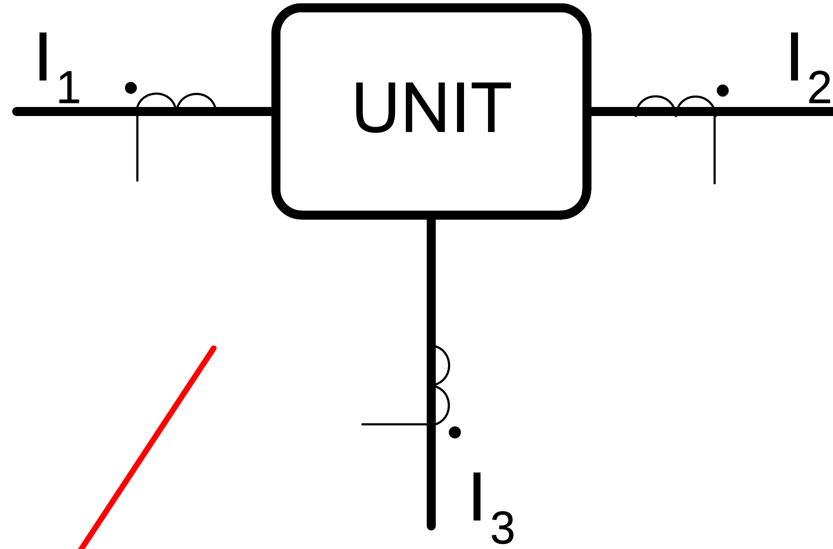
Basic Differential Relay
Internal Fault

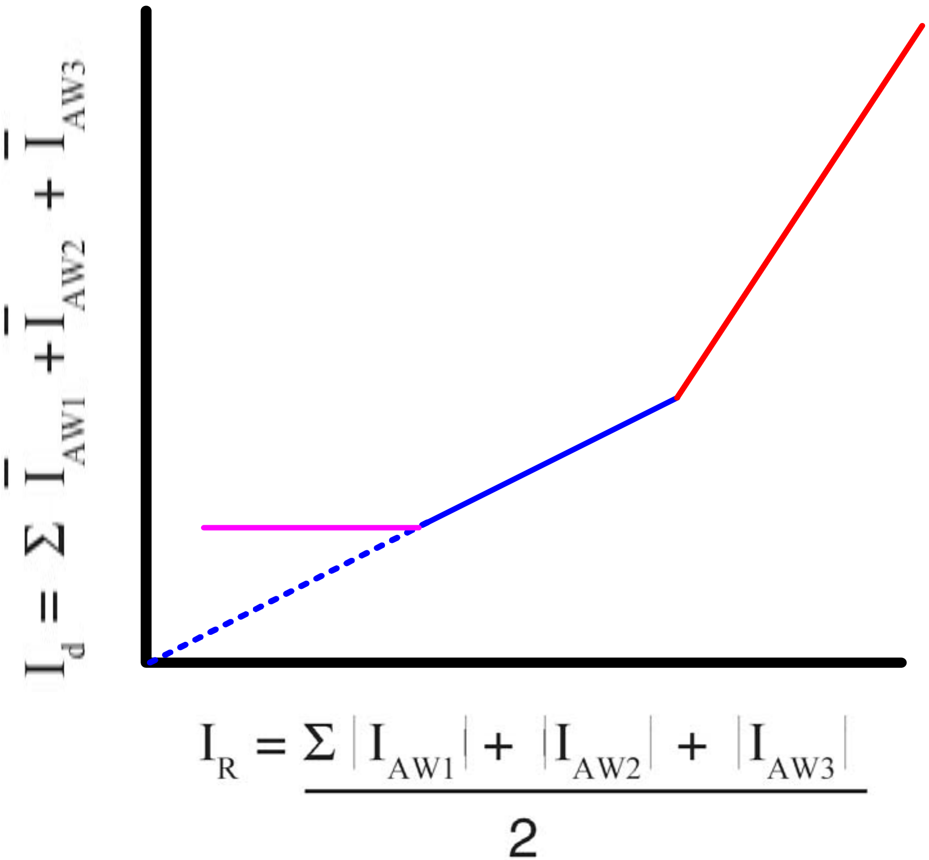




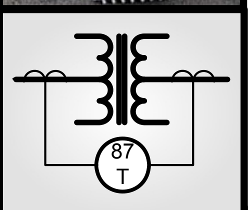
Typical Phase Differential Characteristic – Percentage Slope Concept

$$I_1 + I_2 + I_3 = 0$$

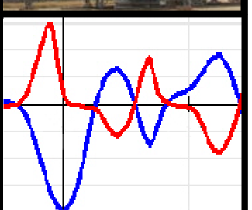






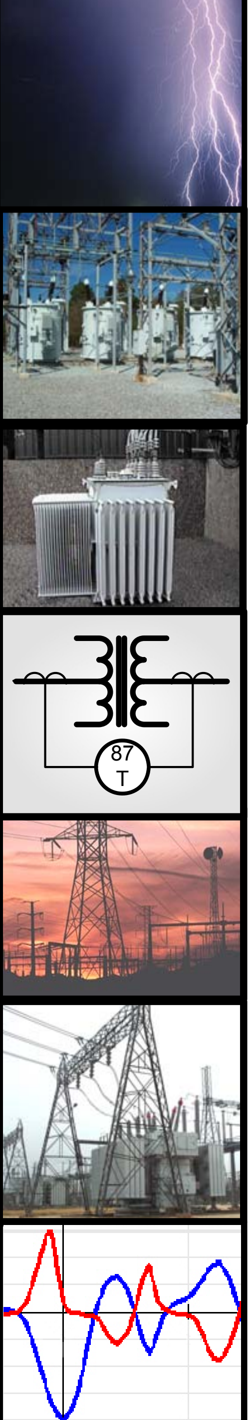







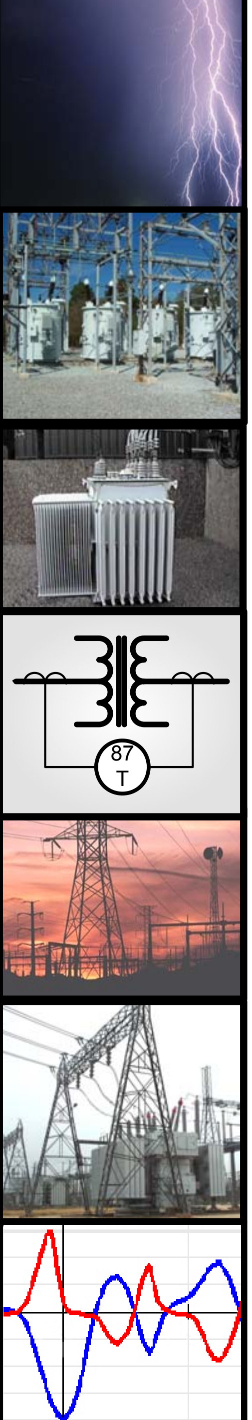
Unique Issues Applying to Transformer Differential Protection

- ***CT ratio*** caused current mismatch
- ***Transformation ratio*** caused current mismatch (fixed taps)
- ***LTC induced current mismatch***
- ***Delta-wye transformation*** of currents
  - Vector group and current derivation issues
- ***Zero-sequence current elimination*** for external ground faults on wye windings
- ***Inrush phenomena*** and its resultant current mismatch



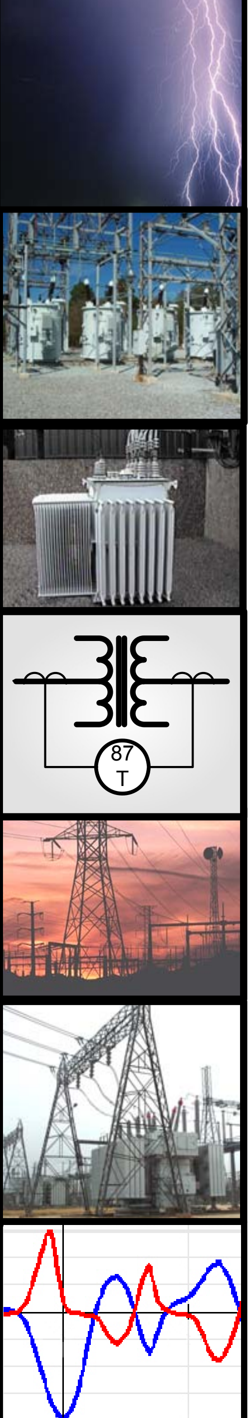
Classical Differential Compensation

- CT ratios must be selected to account for:
  - Transformer ratios
  - If delta or wye connected CTs are applied
  - Delta increases ratio by 1.73
- Delta CTs must be used to filter zero-sequence current on wye transformer windings

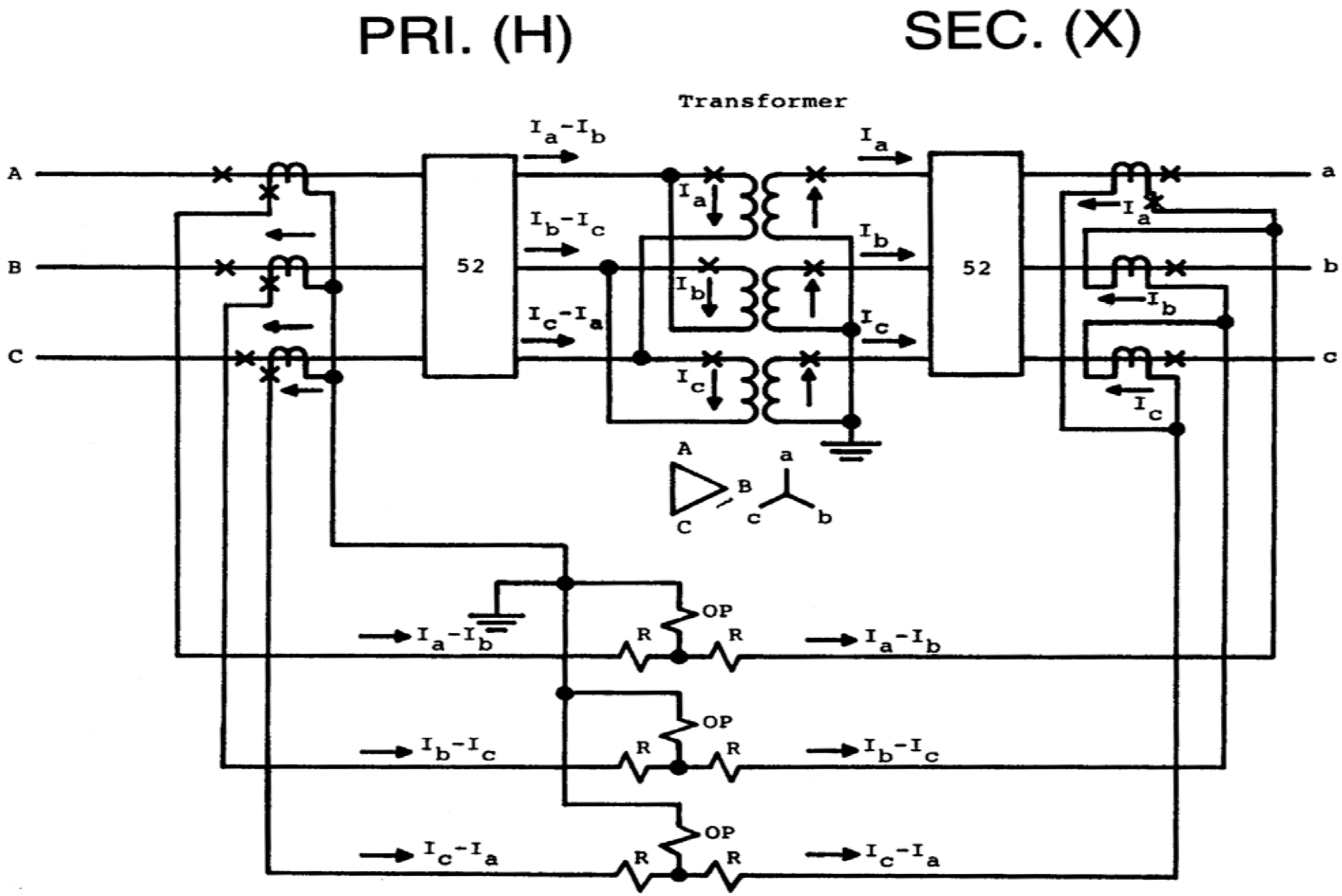


Unique Issues Applying to Transformer Differential Protection

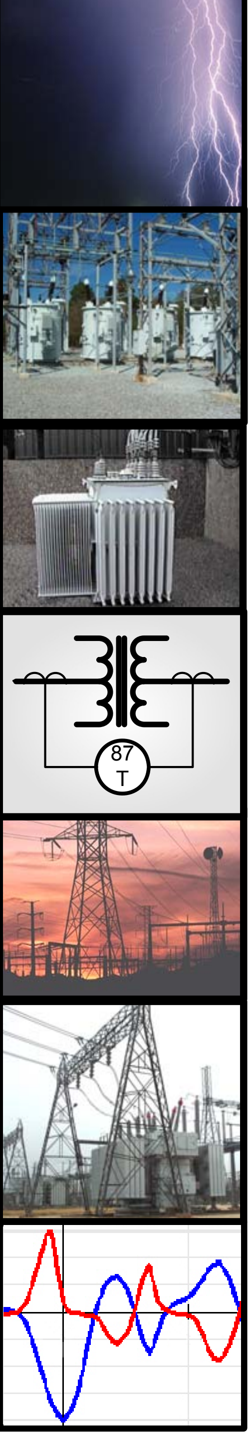
- ***Harmonic content availability*** *during inrush* period due to point-on-wave switching (especially with newer transformers)
- ***Overexcitation phenomena*** and its resultant current mismatch
- ***Internal ground fault sensitivity*** concerns
- ***Switch onto fault*** concerns
- ***CT saturation, remnance and tolerance***

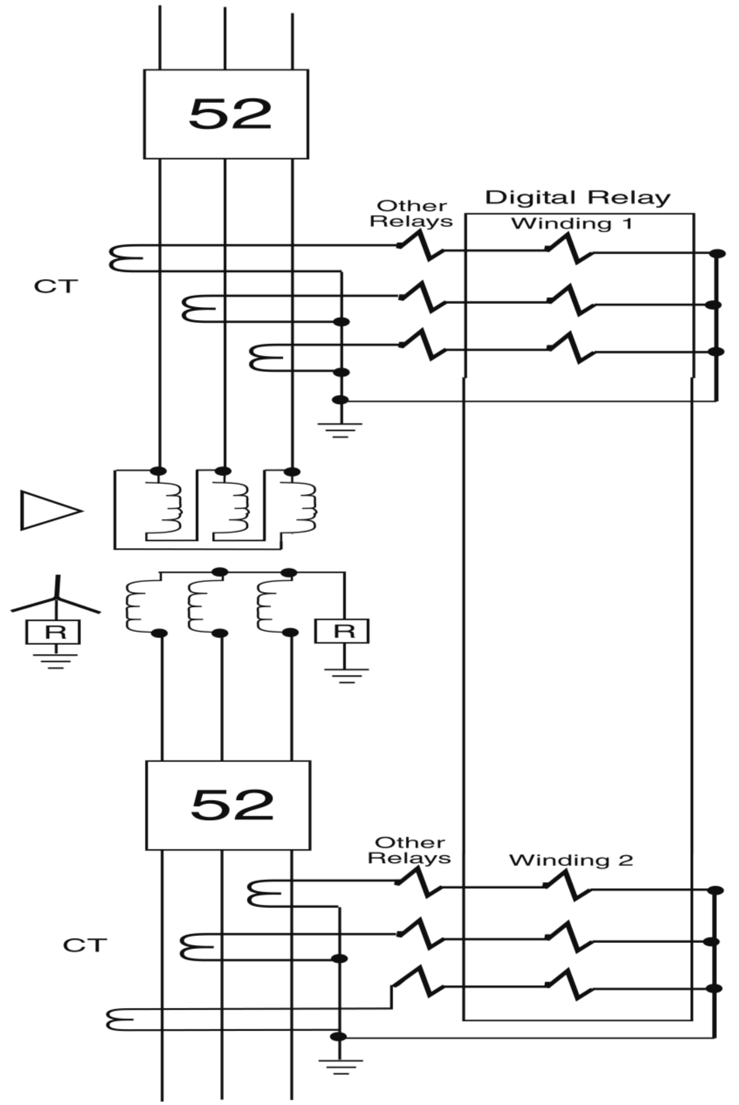


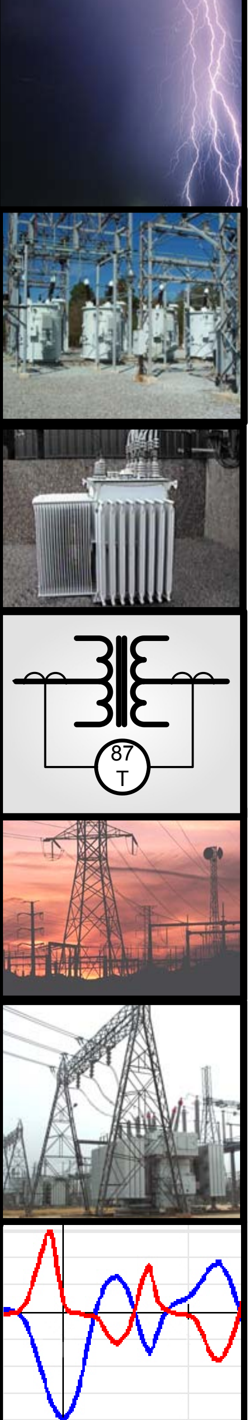
Classical Electro-Mechanical Differential Compensation



Digital Relay Application



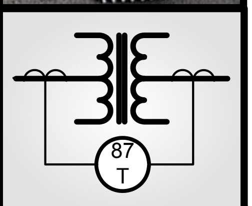




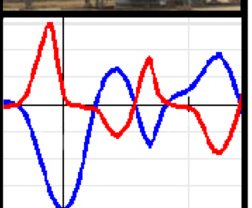
Compensation in Digital Relays

- Transformer ratio
- CT ratio
- Vector quantities
  - Which vectors are used
  - Where the 1.73 factor (√3) is applied
    - When examining line to line quantities on delta connected transformer windings and CT windings
- Zero-sequence current filtering for wye windings so the differential quantities do not occur from external ground faults

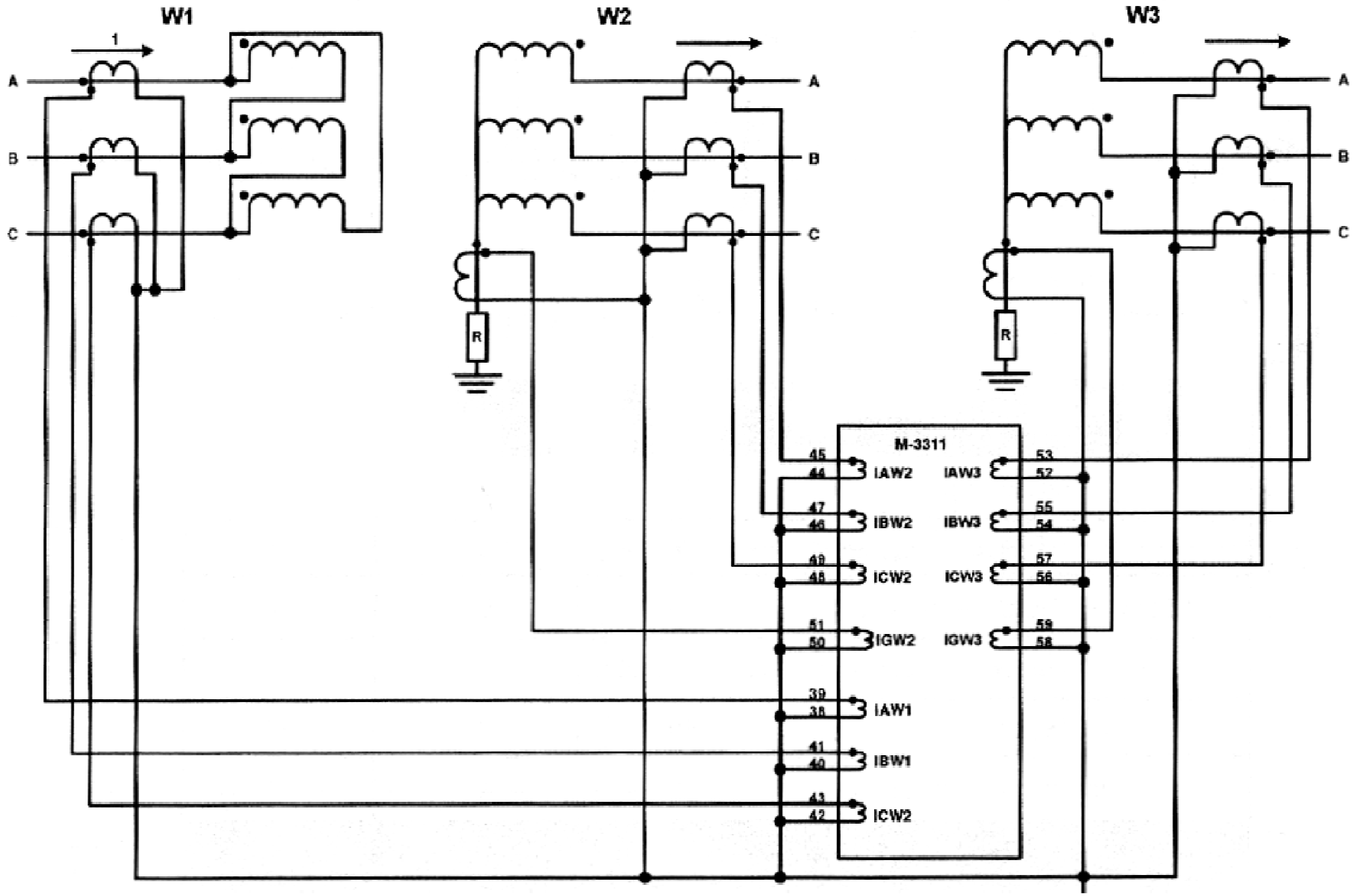


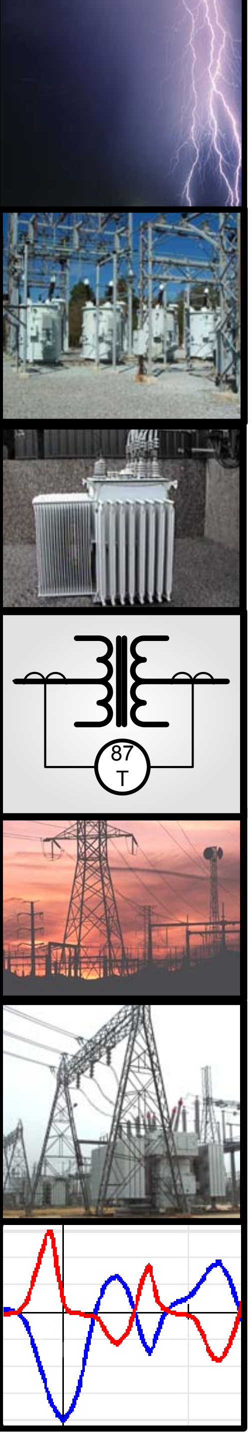




Digital Relay Application

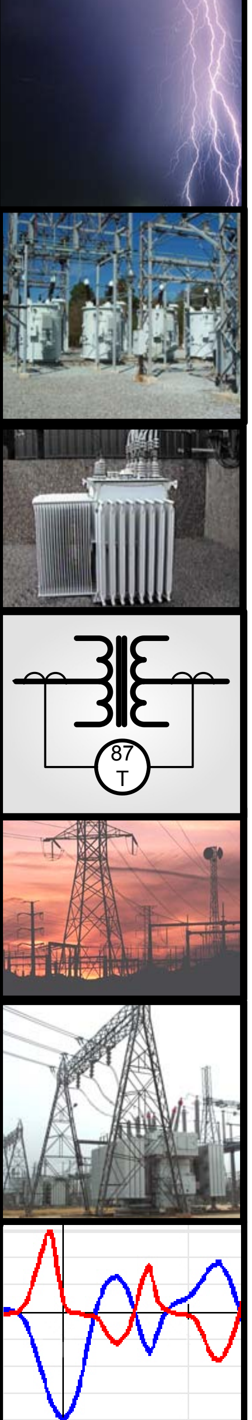


All wye CTs shown, can retrofit legacy delta CT applications

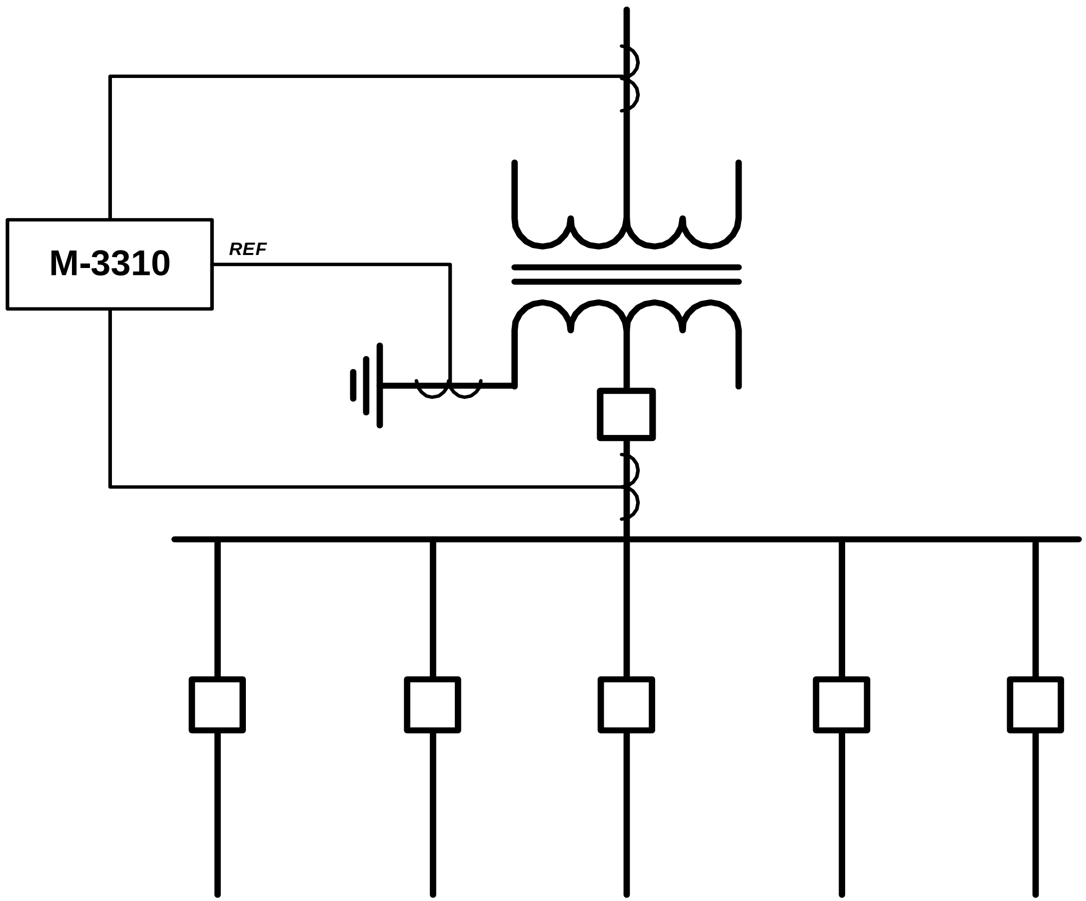


Benefits of Wye CTs

- Phase segregated line currents
  - Individual line current oscillography
  - Currents may be easily used for overcurrent protection and metering
  - Easier to commission and troubleshoot
  - Zero sequence elimination performed by calculation
  - BUT IS IT WORTH ALL THE RE-WIRING IN RETRO-FIT APPICATIONS ?

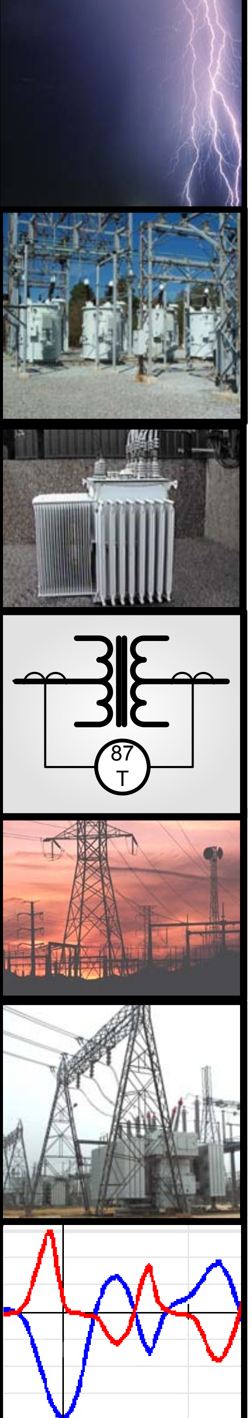


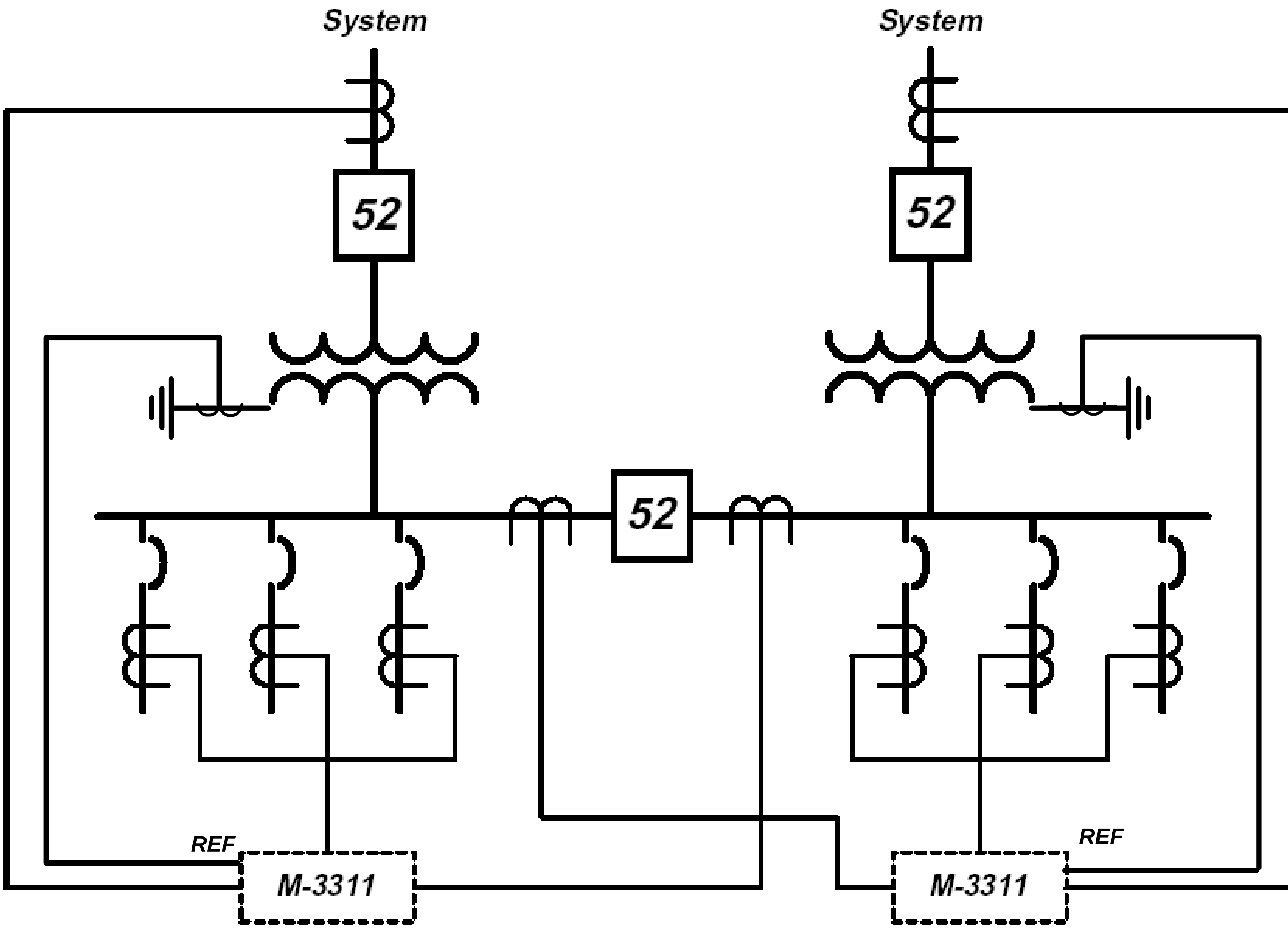
Typical Applications



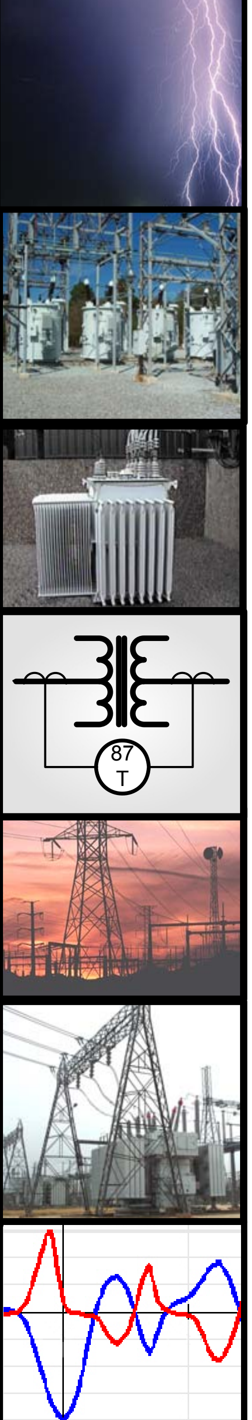
- Two winding transformer, with Neutral Input

Typical Applications



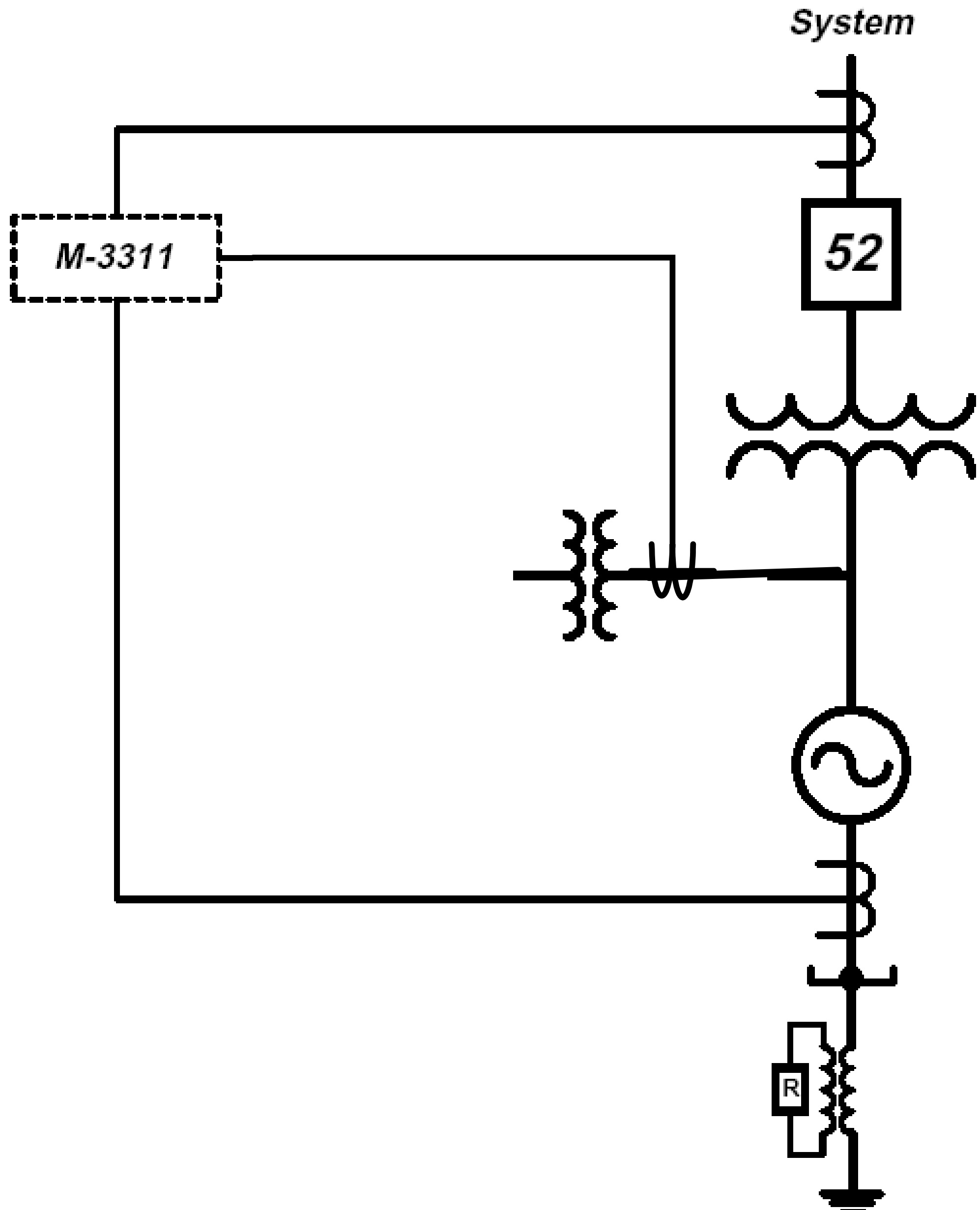


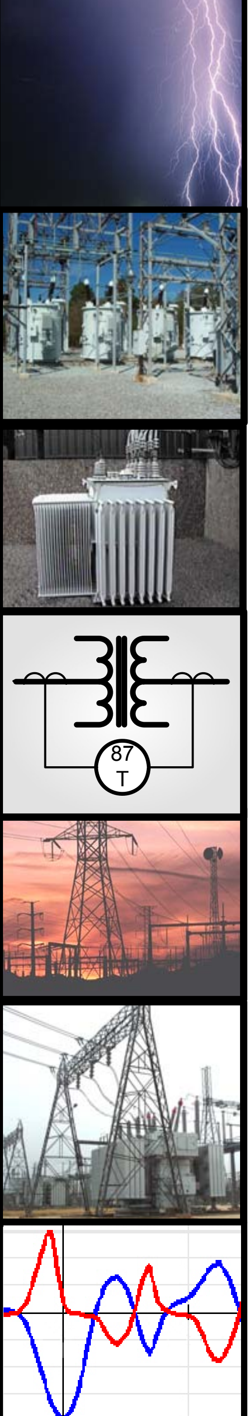
- Main-Tie-Main Substation



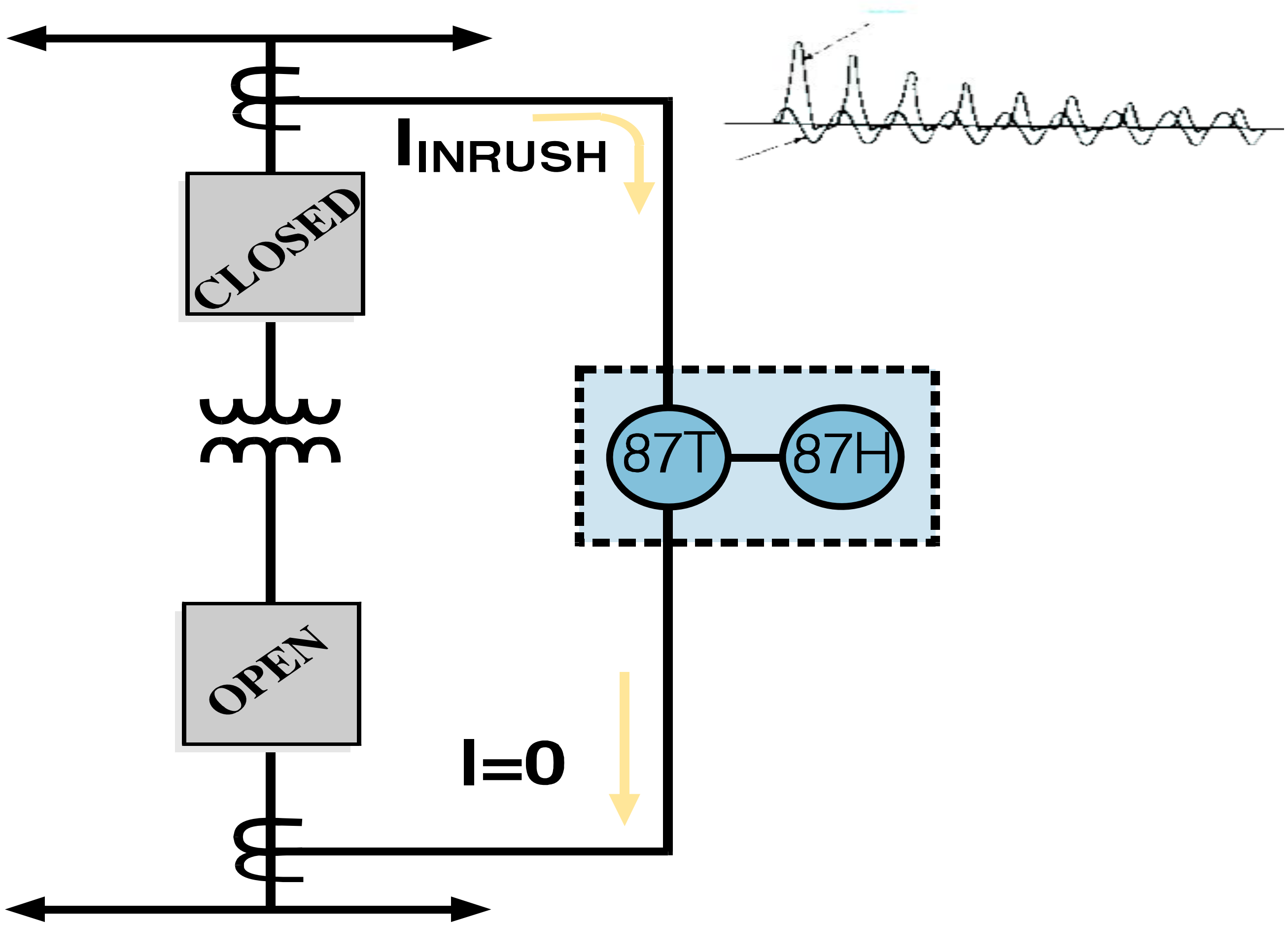
Typical Applications

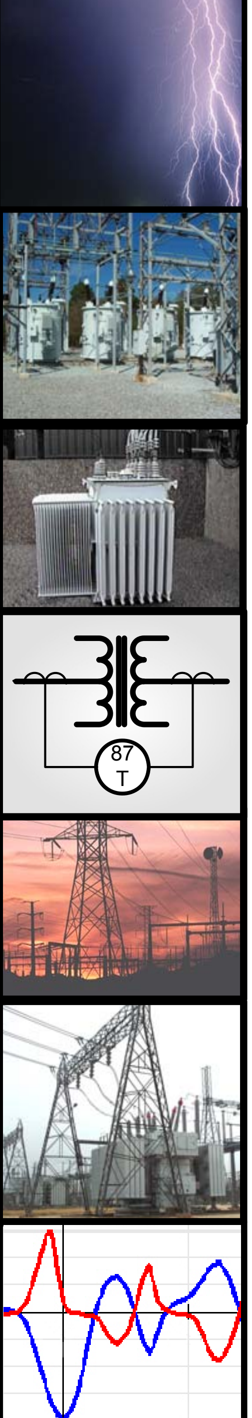
- Generator unit differential wrap





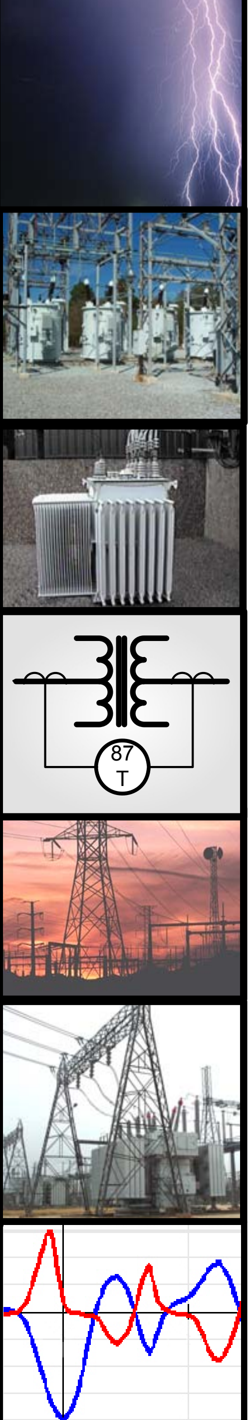
Inrush Restraint





Advanced Element Design: 87T

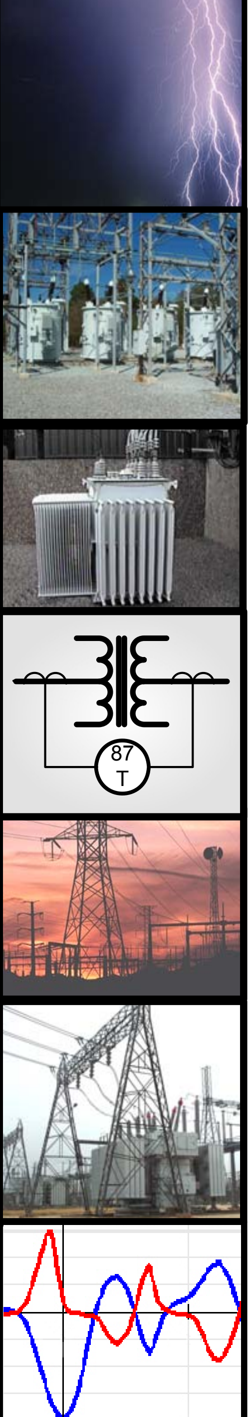
- Inrush Detection and Restraint
  - 2nd harmonic restraint has been employed for years
  - "Gap" detection has also been employed
  - As transformers are designed to closer tolerances, both 2nd harmonic and low current gaps in waveform have decreased
  - If 2nd harmonic restraint level is set too low, differential element may be blocked for internal faults with CT saturation (with associated harmonics generated)

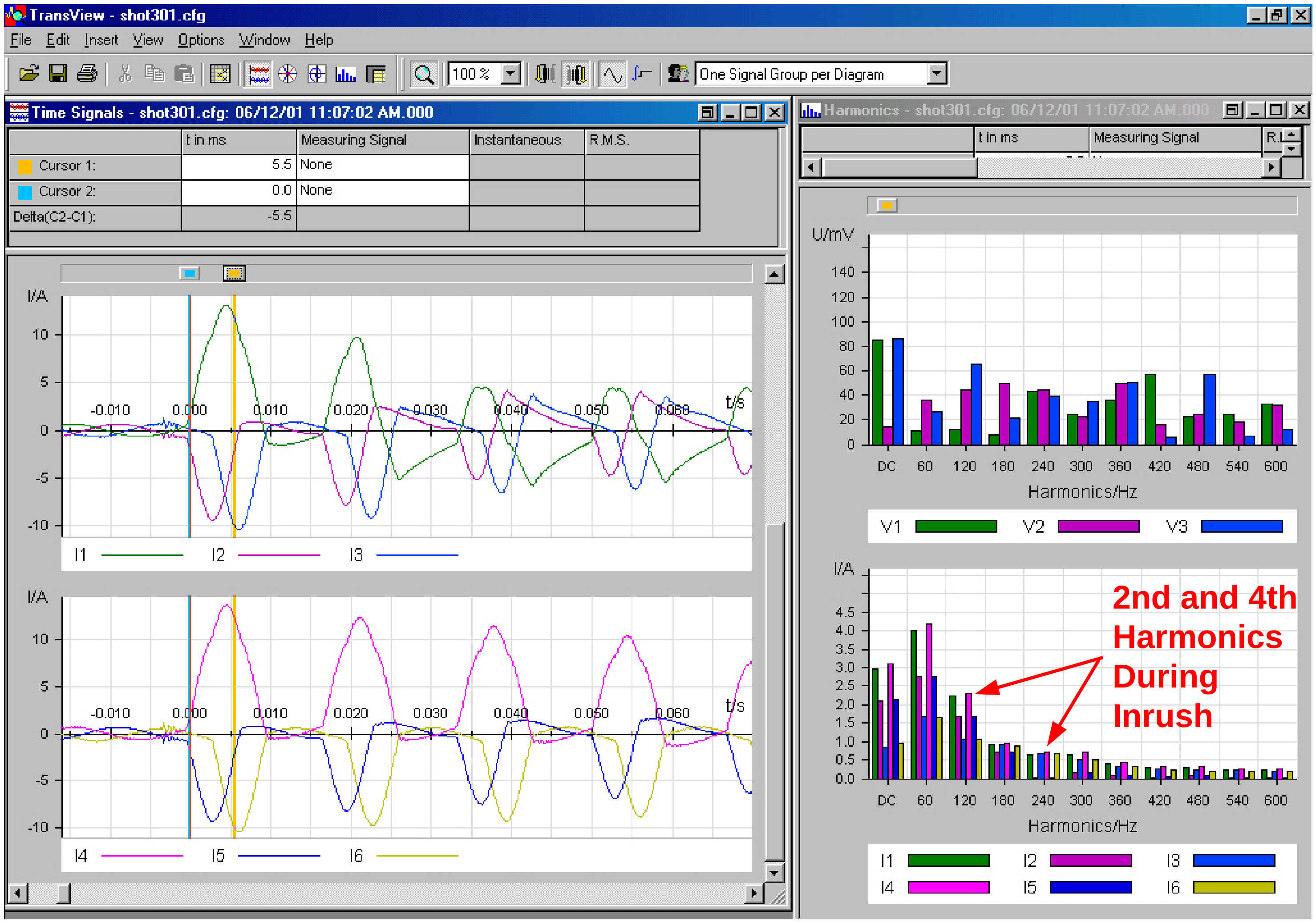


Advanced Element Design: 87T

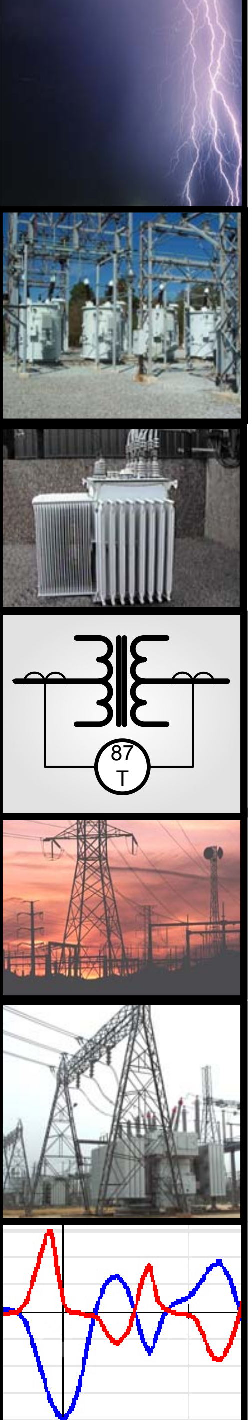
- Inrush Detection and Restraint
  - 4th harmonic is also generated during inrush
  - Odd harmonics are not as prevalent as Even harmonics during inrush
  - Odd harmonics more prevalent during CT saturation
  - Use 4th harmonic and 2nd harmonic together
  - M-3310/M-3311 relays use RMS sum of the 2nd and 4th harmonic as inrush restraint
  - Result: Improved security while not sacrificing reliability

Advanced Element Design: 87T





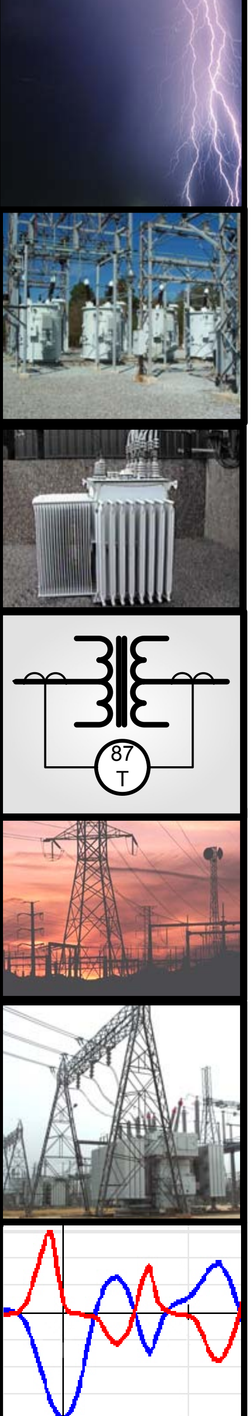
Typical Transformer Inrush Waveform



Cross Phase Averaging

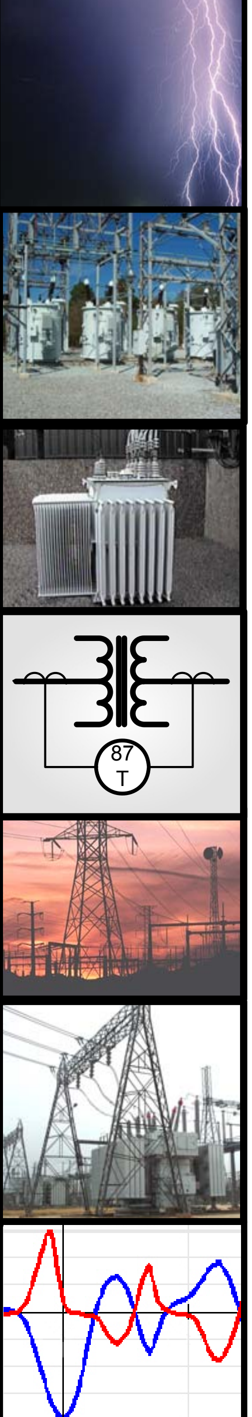
$$I_{dc_{PA\,24}} = \sqrt{IA_{d24}^2 + IB_{d24}^2 + IC_{d24}^2}$$

- Provides security if any phase has low harmonic content during inrush or overexcitation
- This can occur depending on the voltage point-on-wave when the transformer is energized for a given phase
- Cross phase averaging uses the average of harmonics on all three phases to determine level



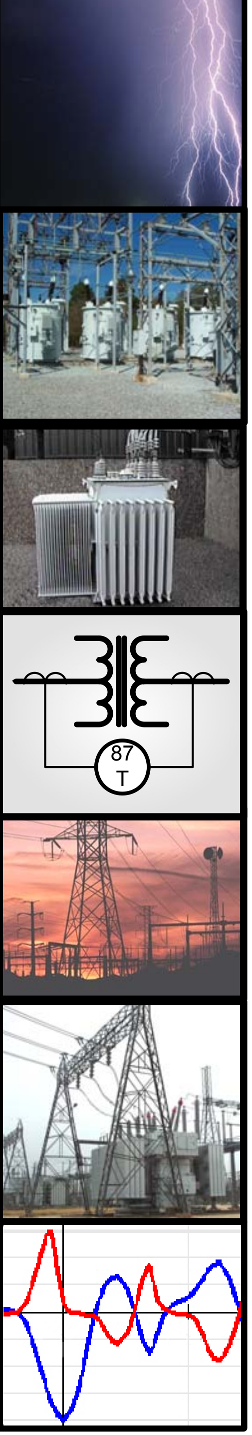
Advanced Element Design: 87T

- Overexcitation Restraint
  - Overexcitation occurs when volts per hertz level rises (V/Hz)
  - This typically occurs from load rejection and malfunctioning generation AVRs
  - The voltage rise at nominal frequency causes the V/Hz to rise
  - This causes 5th harmonics to be generated in the transformer as it begins to go into saturation
  - The current entering the transformer is more than the current leaving due to this increase in magnetizing current
  - This causes the differential element to pick-up
  - Use 5th harmonic level to detect overexcitation

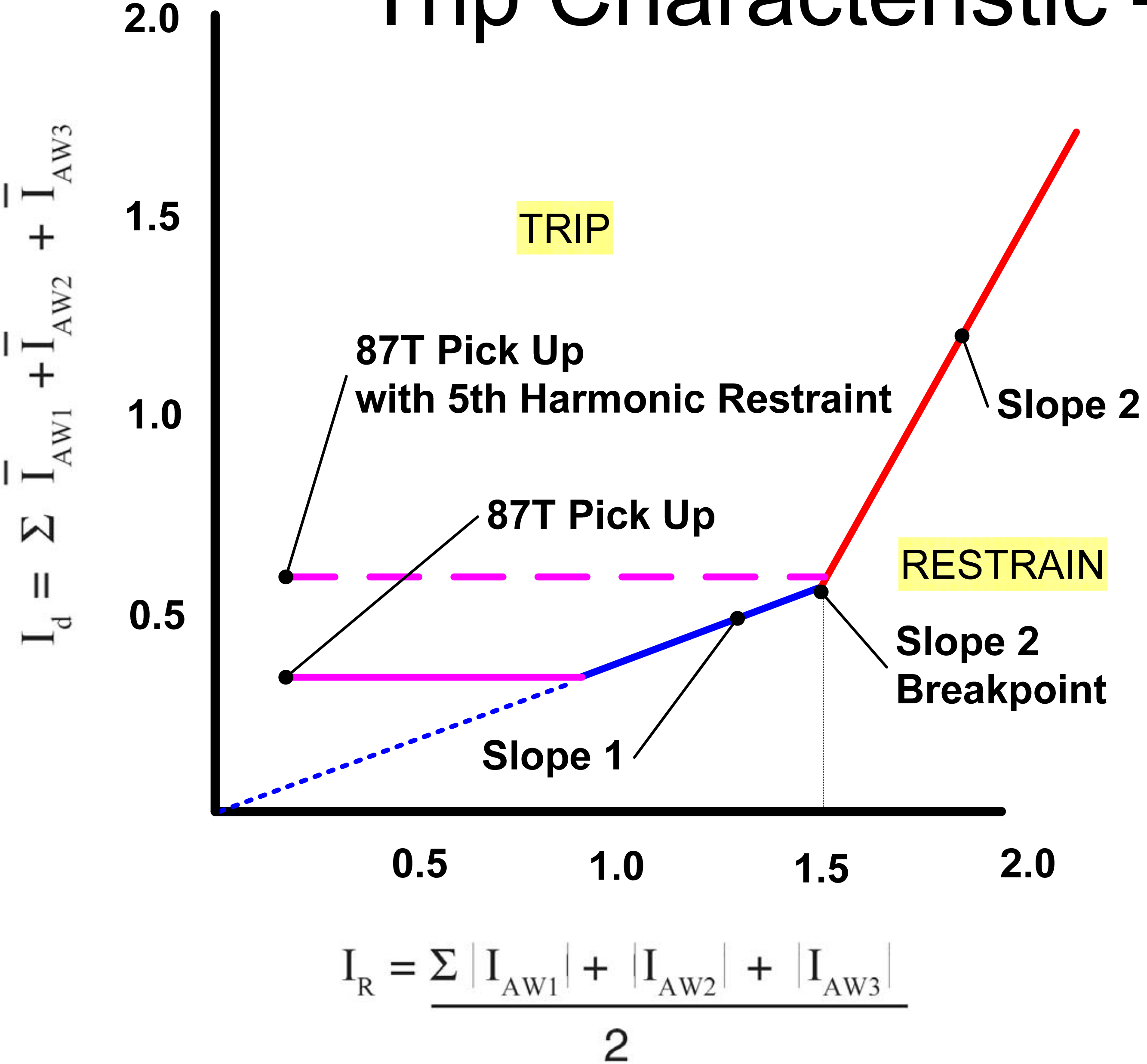


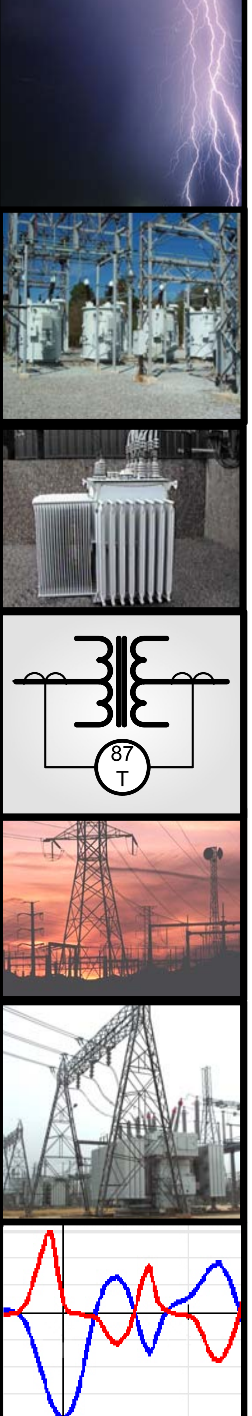
Advanced Element Design: 87T

- Overexcitation Restraint
  - Most other relays block the differential element from functioning during transformer overexcitation
  - M-3310/M-3311 do not block it, but rather raise the pick up level to accommodate the difference currents caused by the transformer saturation
  - This allows the differential element to trip if an internal fault occurs during the overexcitation period due to increased stress level on the insulation
  - Result: Improved reliability while not sacrificing security



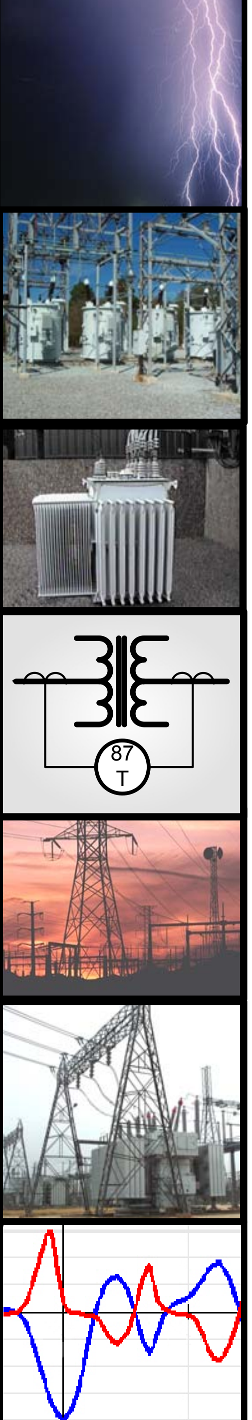
Trip Characteristic – 87T





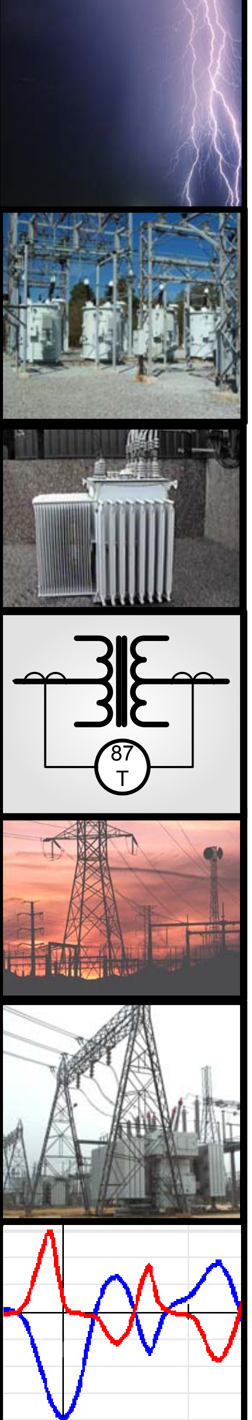
Trip Characteristic – 87T

- 87T Pick Up
  - Class C CTs, use 10%
  - 5% Margin
  - LTC, add 10%
  - Magnetizing losses, add 1%
  - 0.15 to 0.3 pu typically setting
- Slope 1
  - Used for low level currents
  - Can be set as low as 15%
  - With LTC 25-30%
- Slope 2 “breakpoint”
  - Typically set at 2X rated current
  - This setting assumes that any current over 2X rated is a through fault or internal fault, and is used to desensitize the element against unfaithful replication



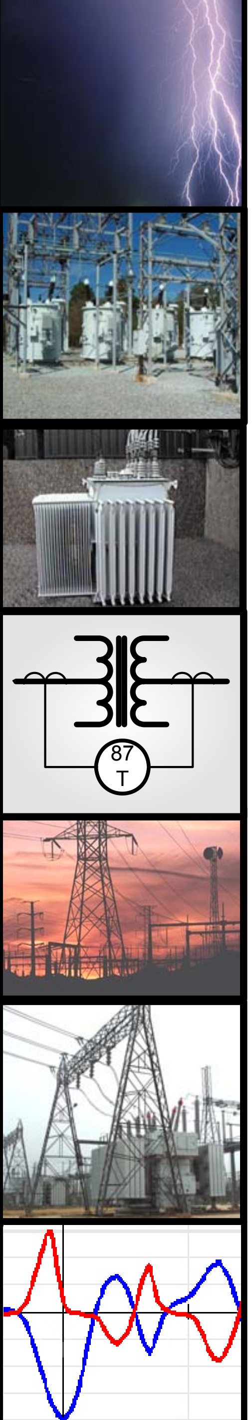
Trip Characteristic – 87T

- Slope 2
  - Typically set at 60% (double slope 1)
- Inrush Restraint (2nd and 4th harmonic)
  - Typically set from 10-15%
  - Employ cross phase averaging blocking for security– Blocks tripping for 10 cycles
- Overexcitation Restraint (5th harmonic)
  - Typically set at 30%
  - Raise 87T pick up by 200% or 0.60 pu during overexcitation
  - No cross phase averaging needed, as overexcitation is symmetric on the phases



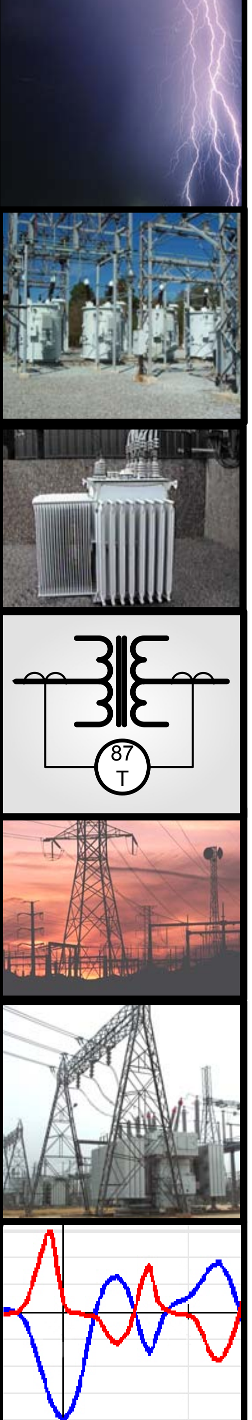
Trip Characteristic – 87H

- 87H Pick Up
  - Typically set at 10pu rated current
  - This value should be above maximum possible inrush current and lower than the CT saturation current
  - C37.91, section 5.2.3, states 10pu an acceptable value
  - Can use data captured from energizations to fine tune the setting



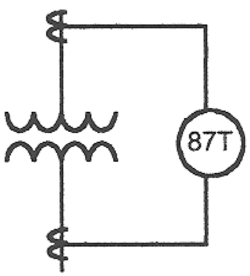
CT Issues

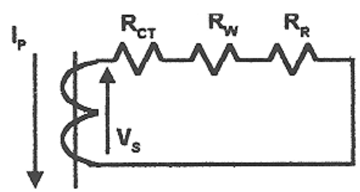
- **<u>Remnance</u>**: Residual magnetism that causes dc saturation of the CTs
- **<u>Saturation</u>**: Error signal resulting from too high a primary current combined with a large burden
- **<u>Tolerance</u>**: Class “C” CTs are rated 10% for currents x20 of nominal
  - Thru-faults and internal faults may reach those levels depending on ratio selected



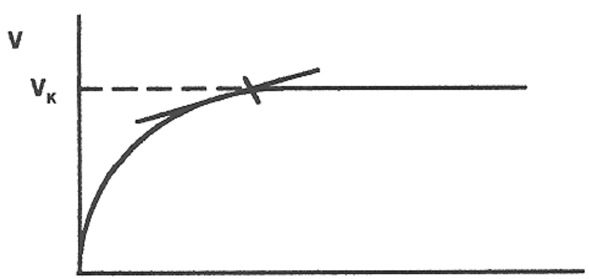
IS THE CT GOOD ENOUGH ?

- **Provides security for high fault current levels outside the differential zone where CT inputs can saturate.**
- **Factors effecting CT saturation**
  - **- Residual magnetism in CT core**
  - **- CT characteristic mismatch**
  - **- CT circuit burden**
- **<u>CT Burden Check</u>– want to operate below the knee-point voltage (V_k) for worst-case fault external to diff. Zone.**

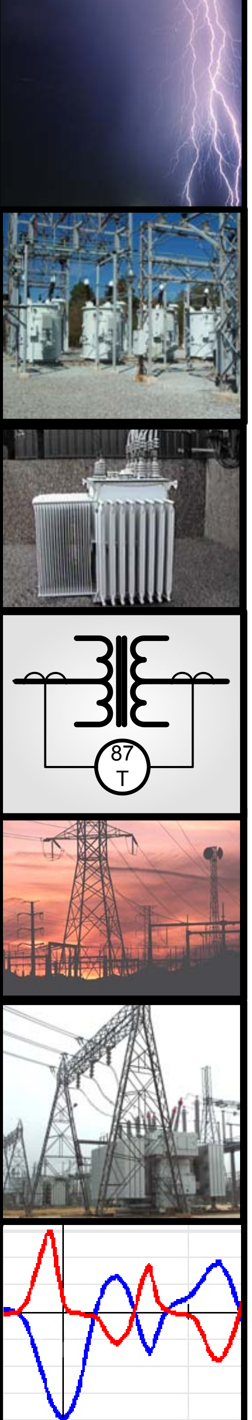




$$V_S = \frac{I_P}{N}\,[R_{CT} + R_W + R_R]$$



Where I_P is the maximum external fault current

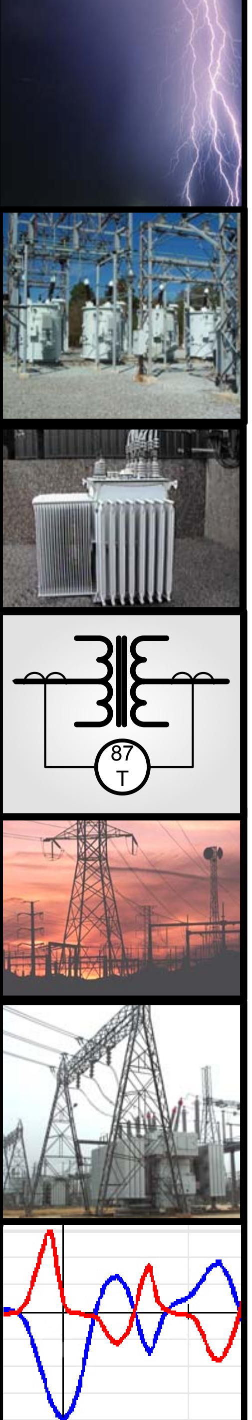


CT Issues

- Best defense is to use high "Class C" voltage levels
  - C200,C400, C800
  - These have superior characteristics against saturation and relay/wiring burden
- Use low burden relays
  - Digital systems are typically 0.020 ohms
- Use a variable percentage slope characteristic to desensitize the differential element when challenged by high currents that may cause replication errors

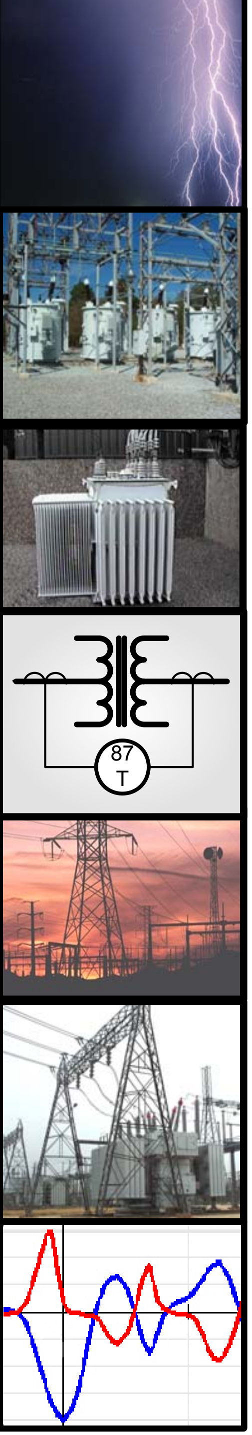
Improved Ground Fault Sensitivity

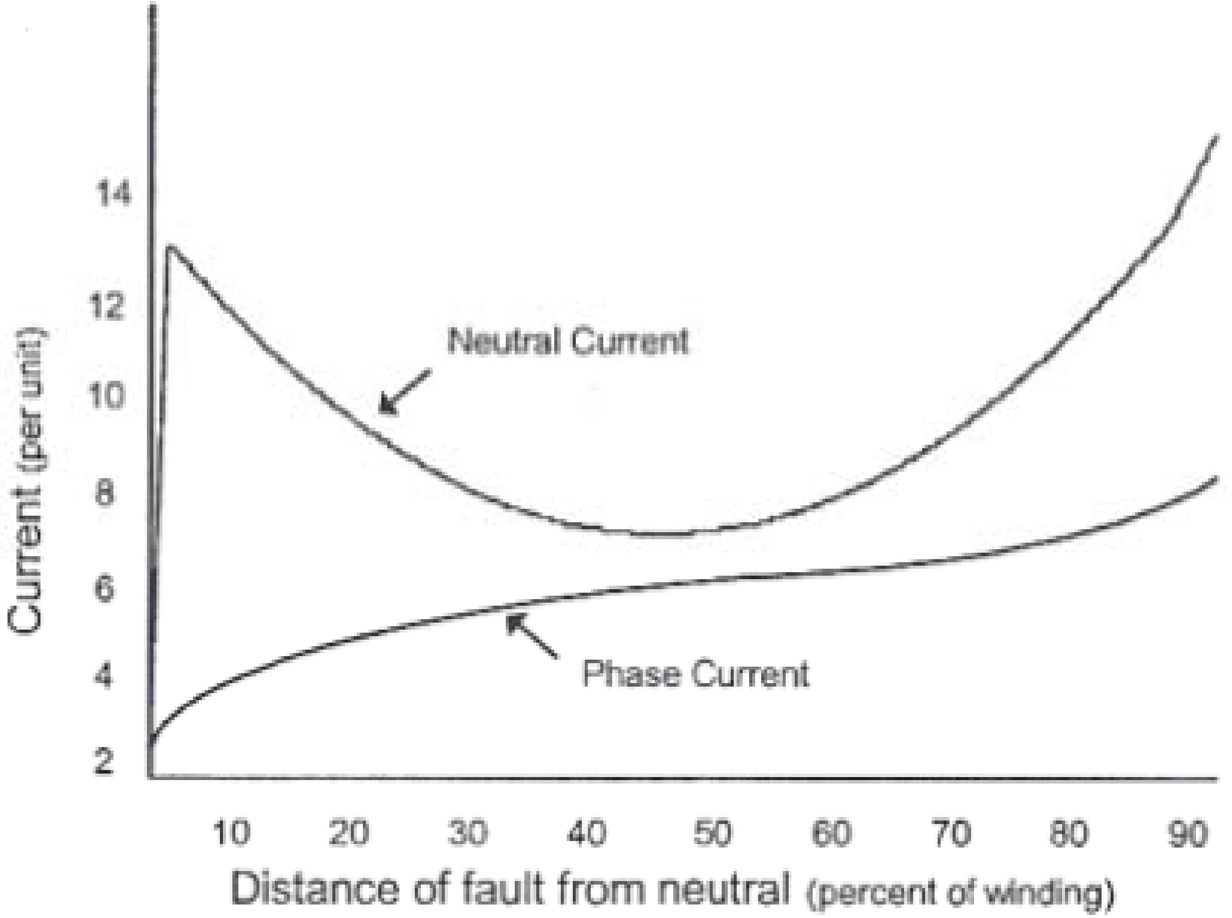
Ground Differential Protection (87GD)

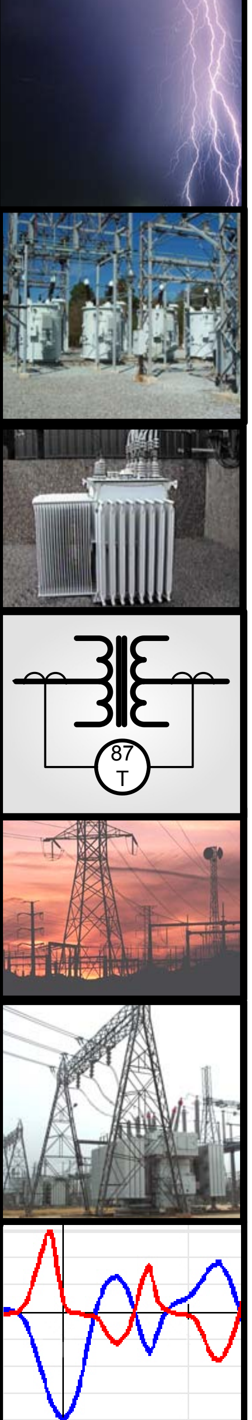


- 87T element is typically set with 15-30% pick up -
- This is to accommodate Class “C” CT accuracy during a fault plus the effects of LTCs
- That leaves 10-15% of the winding not covered for a ground fault (Solidly Grounded Winding)
- When a neutral resistor limits ground current to 200-400A <u>no</u> ground fault protection is provided for that winding by the 87T element.
- Employ a ground differential element to improve sensitivity (87GD)

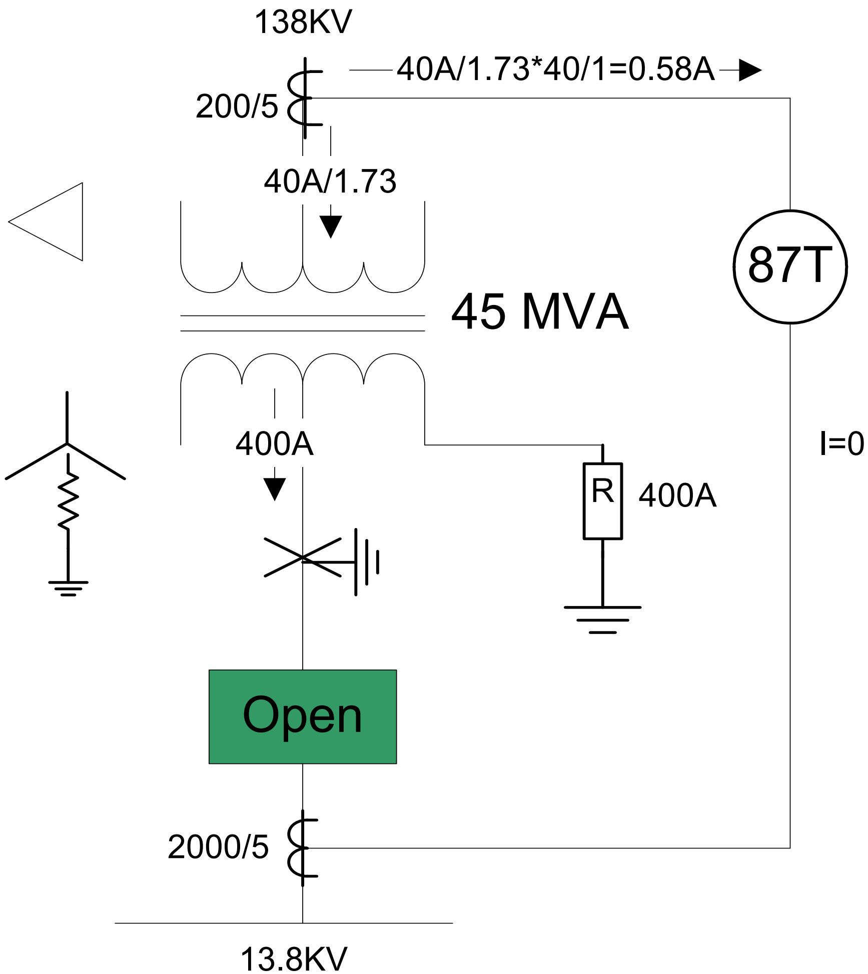
Differential Sensitivity Reduced for Ground Fault Near the Neutral







Improved Ground Fault Sensitivity

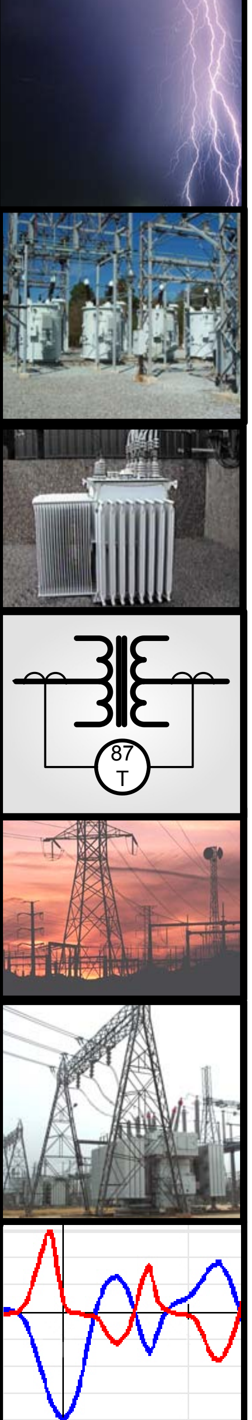


Typical Pickup of 87T:

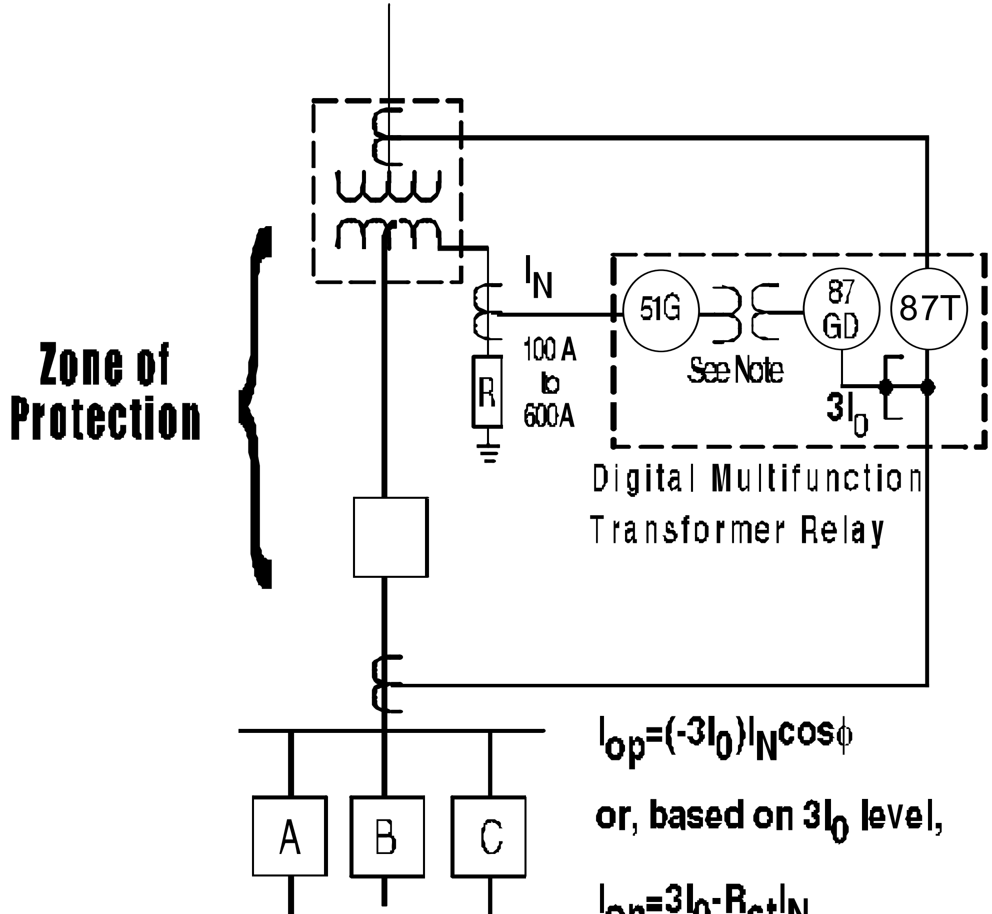
- **O.3 pu pickup**
- **Relay Tap set at Trans. Rating (45MVA)**

  $I_{FL138KV}$ = 4.71 Amps
- **PU = 4.71A x 0.3 = 1.41A**

- WITHOUT GROUND DIFF. (87GD) THERE IS NO HIGHSPEED PROTECTION FOR SEC. GND FAULTS



Improved Ground Fault Sensitivity

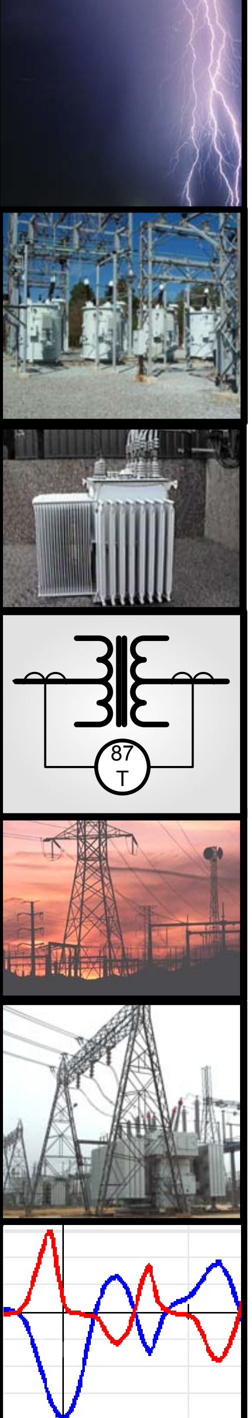


$I_{op}=(-3I_0)I_N\cos\phi$

or, based on $3I_0$ level,

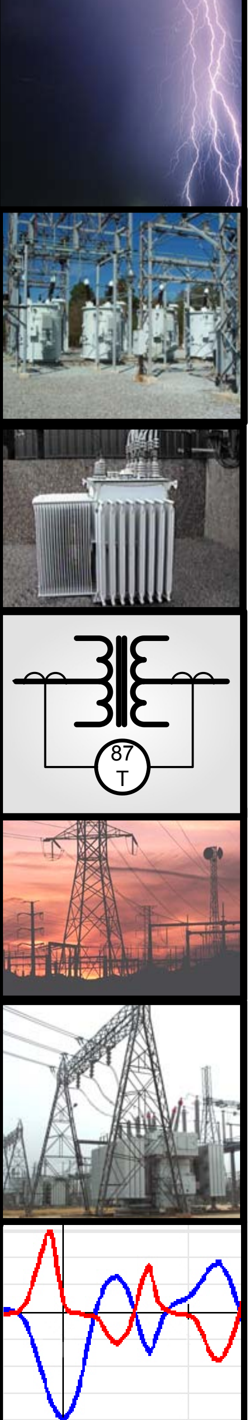
$I_{op}=3I_0-R_{ct}I_N$

- NOTE: R_{ct} is the ratio-matching auxiliary ct implemented through software

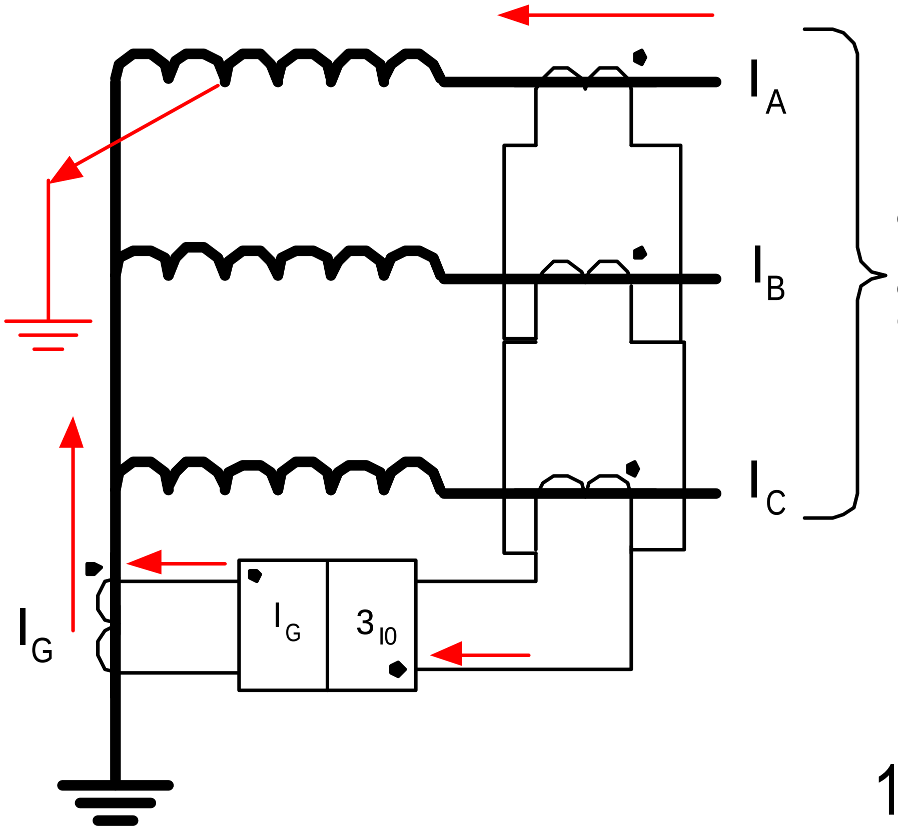


Trip Characteristic – 87GD

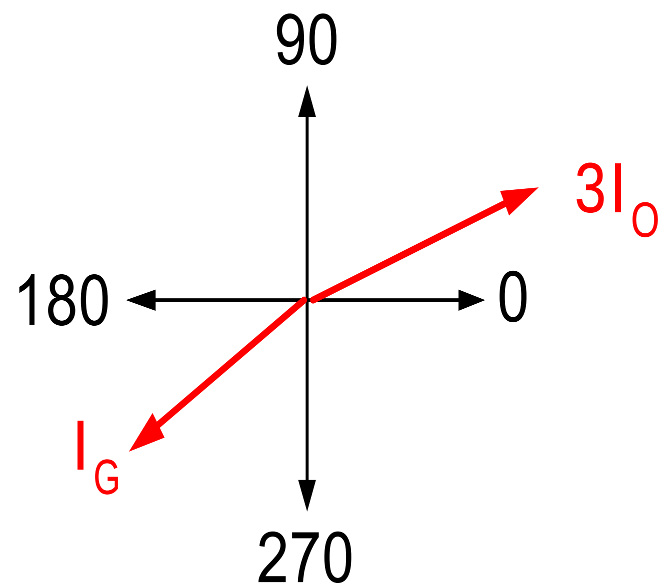
- 87GD Pick Up
  - Element normally uses directional comparison between phase residual current ($3I_0$) and measured ground current (I_G)
    - No user setting
  - Pick up only applicable when $3I_0$ current is below 140mA (5A nom.)
    - Pick up = $3I_0 - I_G$
  - If $3I_0$ greater than 140mA, element uses:
    - $-3I_0 * I_G * \cos\theta$. It will trip only when the directions of the currents is opposite, indicating an internal fault
    - Using direction comparison mitigates the effects of saturation on the phase and ground CTs



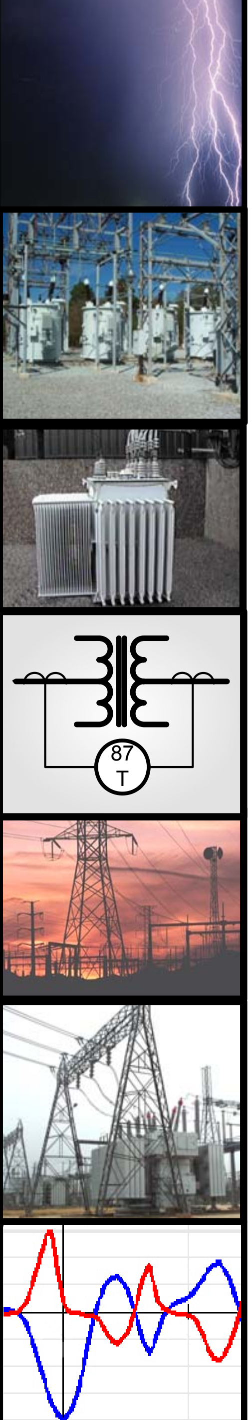
Trip Characteristic – 87GD



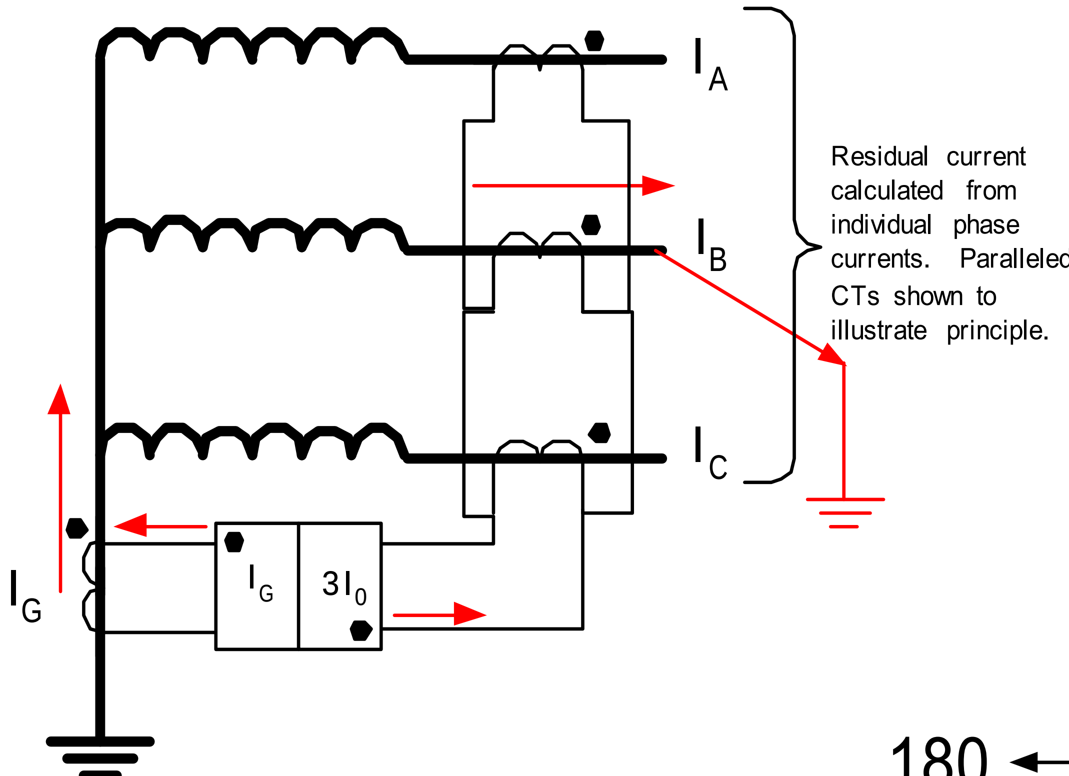
Residual current calculated from individual phase currents. Paralleled CTs shown to illustrate principle.

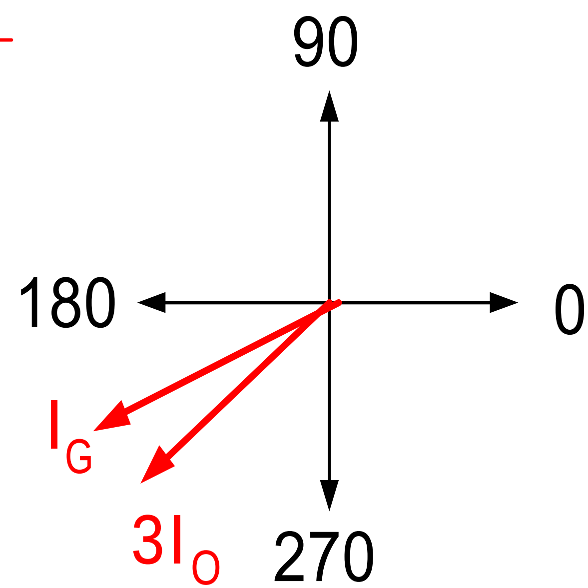


$$-3I_o \times I_G \cos(180) = 3I_oI_G$$

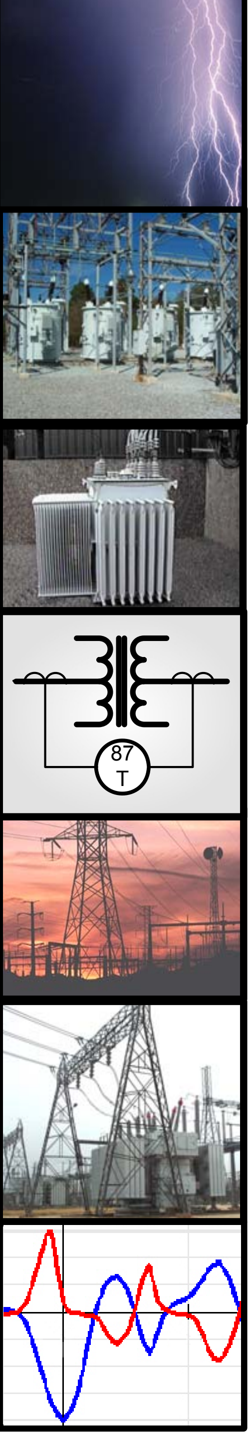


Trip Characteristic – 87GD

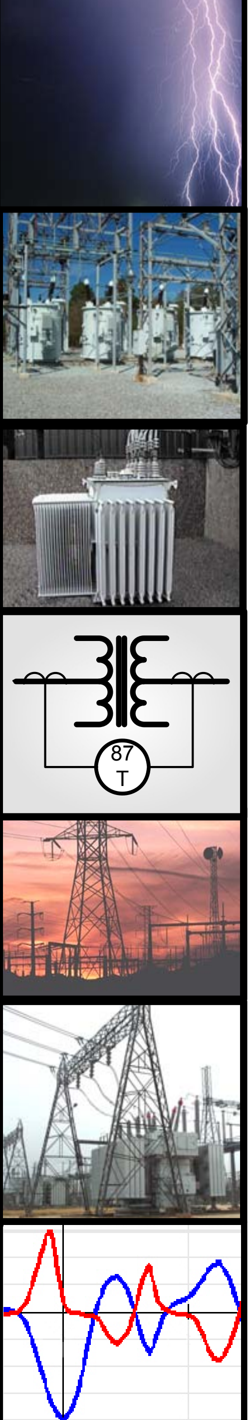




$$-3I_o \times I_G \cos(0) = -3I_oI_G$$

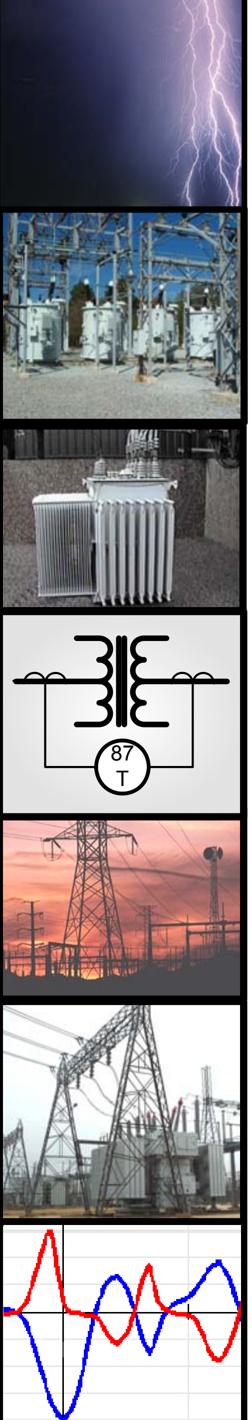


TRANSFORMER OVEREXCITATION PROTECTION

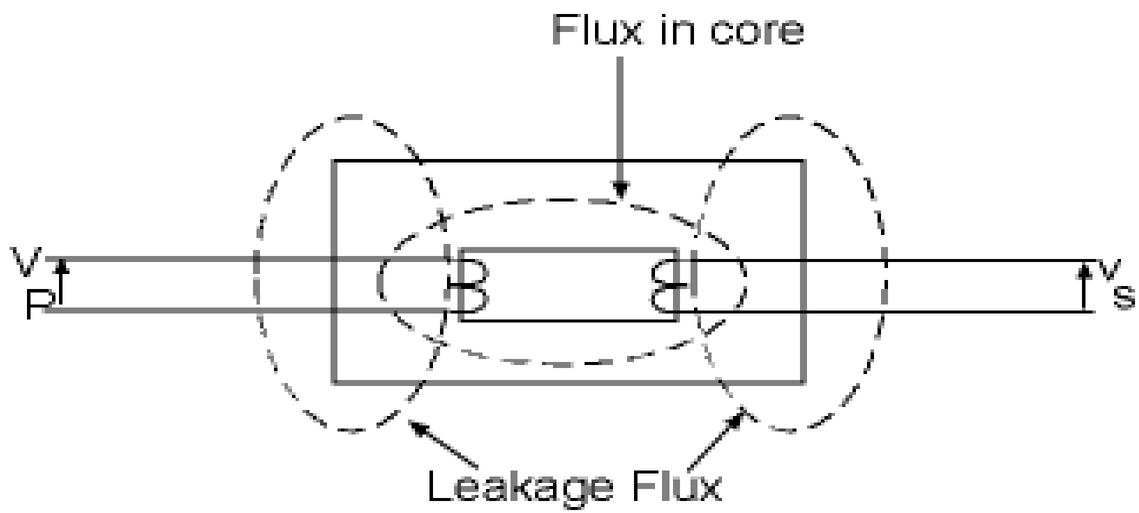


Transformer Limits

- Overexcitation
  - Responds to overfluxing; excessive V/Hz
  - Continuous operational limits
    - ANSI C37.91 & C57.12
      - 1.05 loaded, 1.10 unloaded
      - Measured at the transformer output
    - Inverse curves typically available for values over the continuous allowable maximum
    - Protection required application of V/Hz (24) protection



Overexcitation/ Volts per Hertz (24)

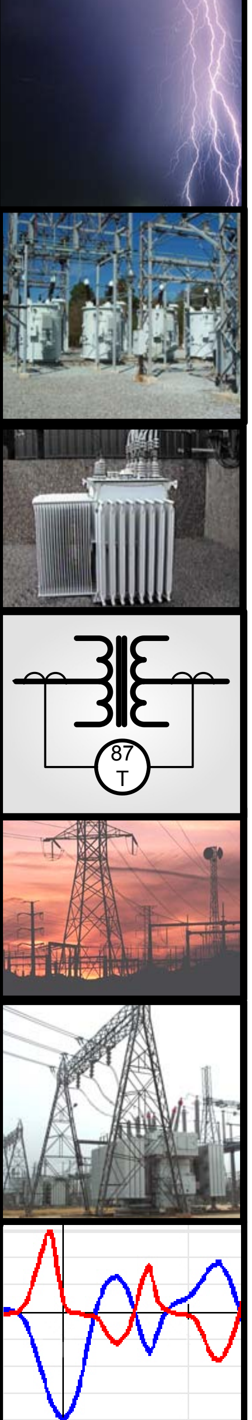


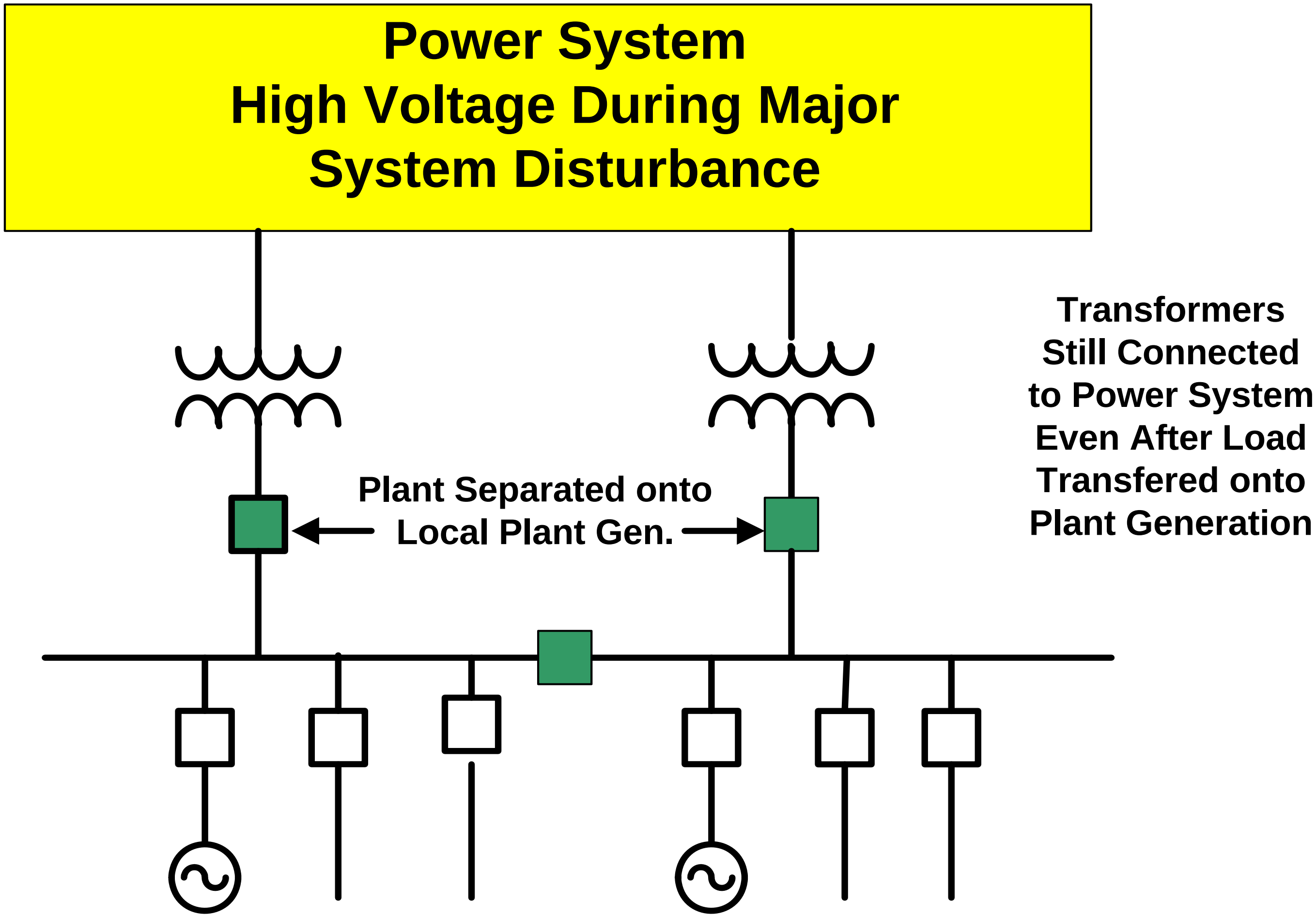
PHYSICAL INSIGHTS

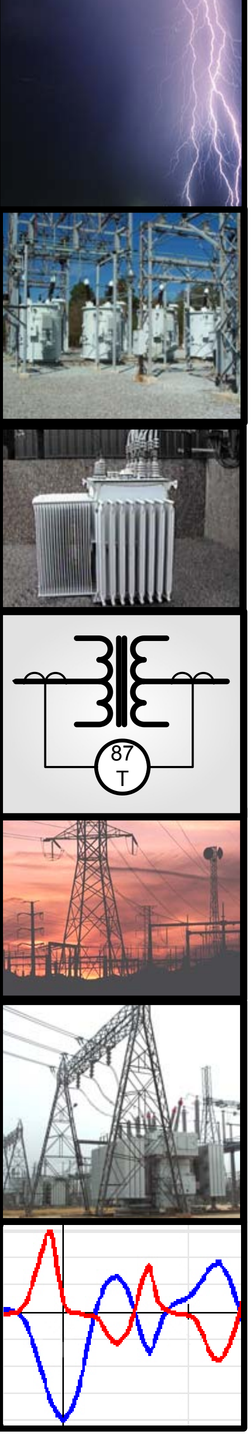
- As voltage rises above rating leakage flux increases

- Leakage flux induces current in transformer support structure causing rapid localized heating

Industrial System Overexcitation







Overexcitation Event on EHV Transmission System

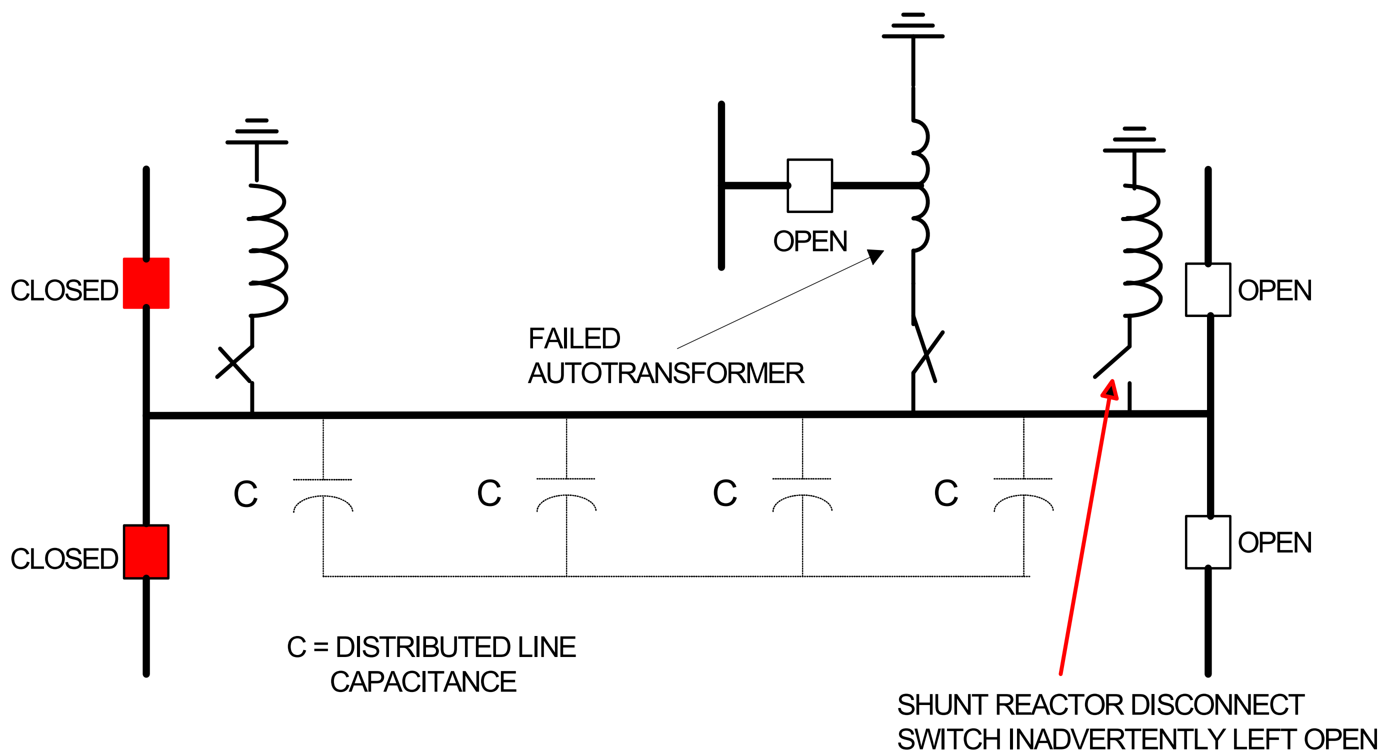
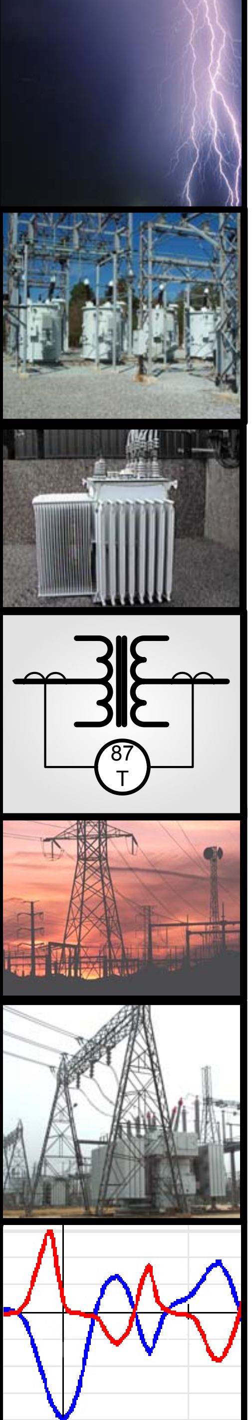
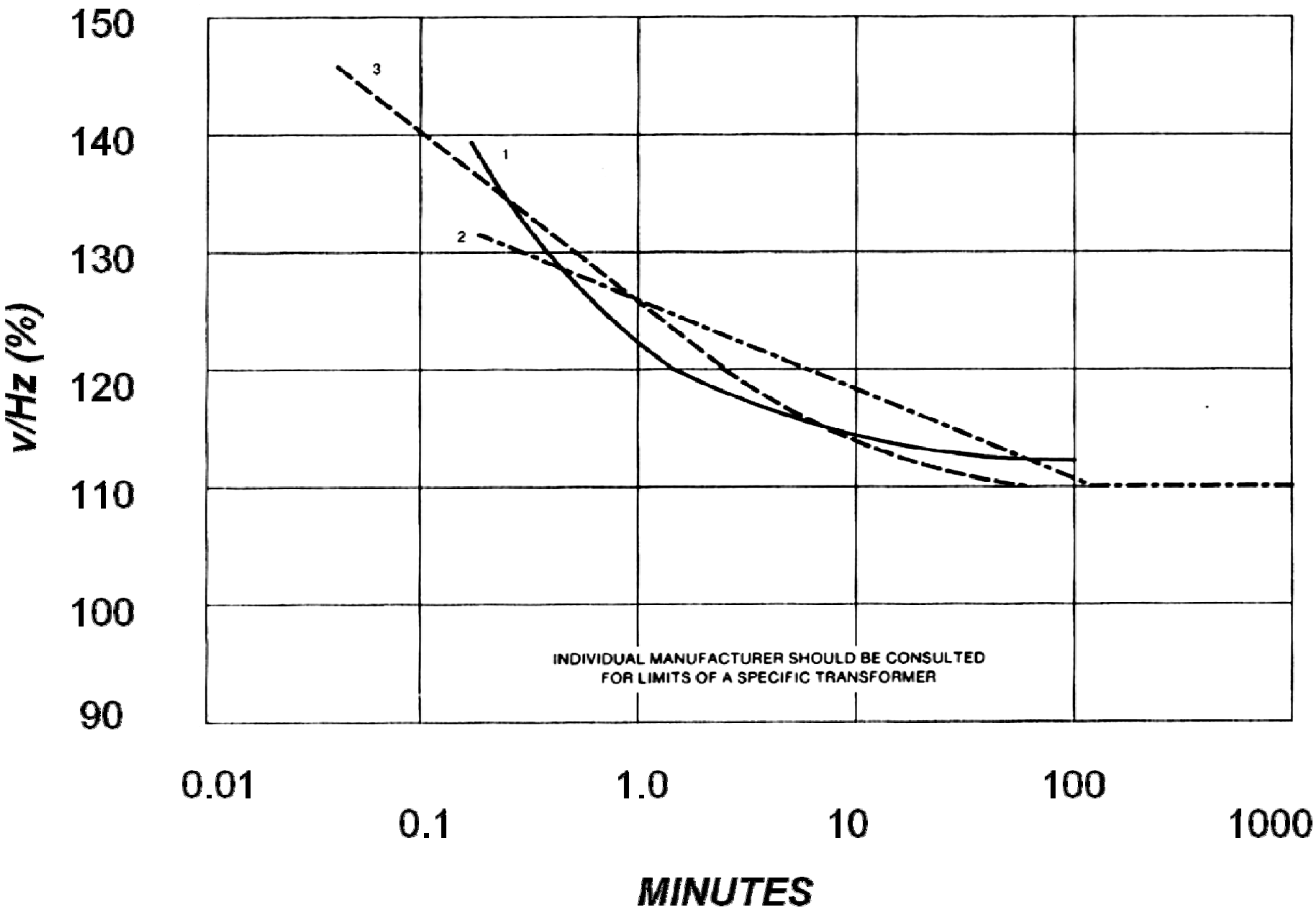


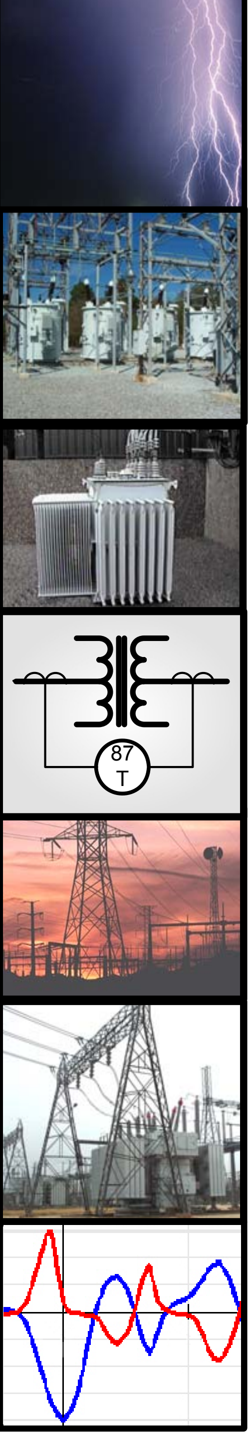
Fig. 11 Overexcitation Failure of an EHV Autotransformer



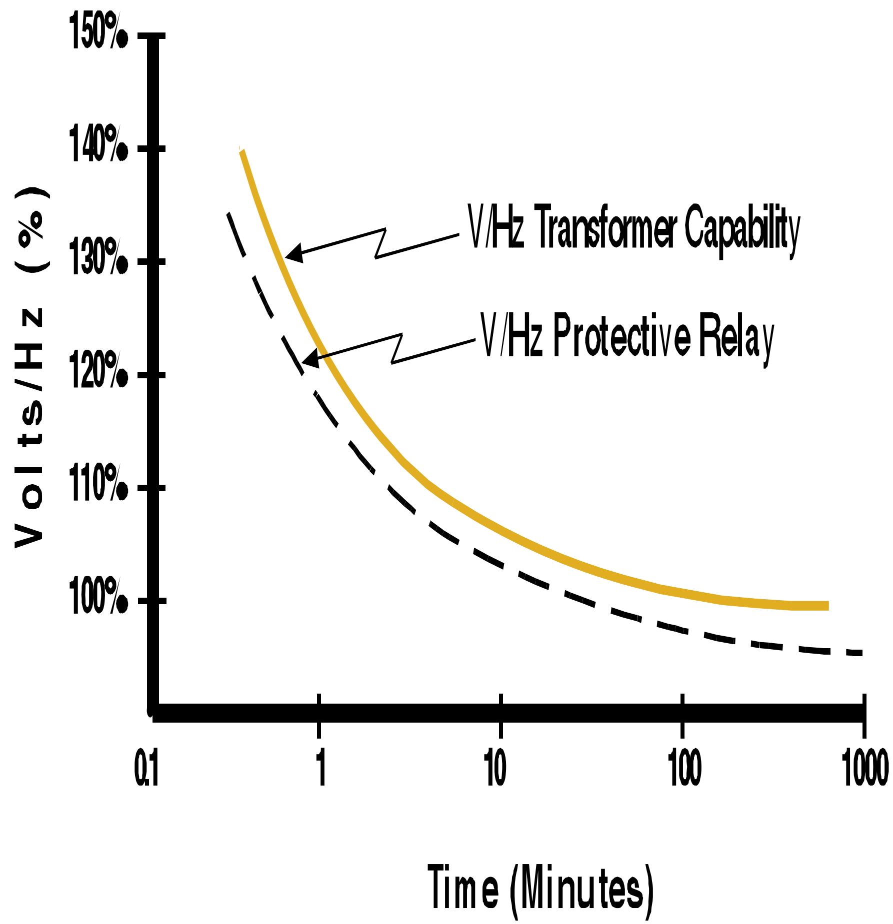
Overexcitation Curve

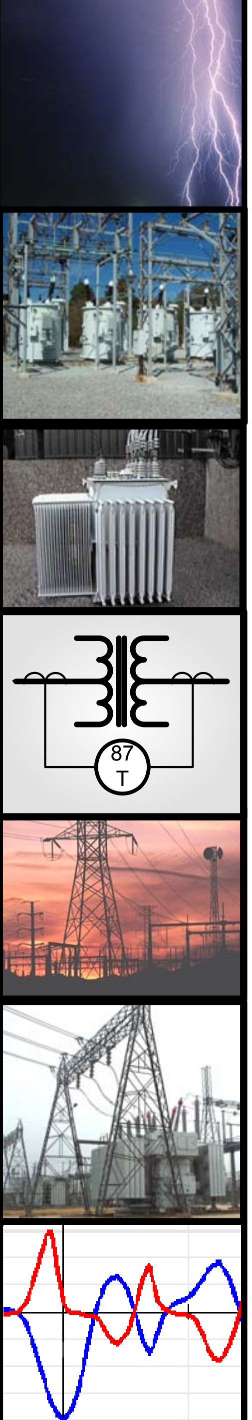


This is typically how the apparatus manufacturer specs it

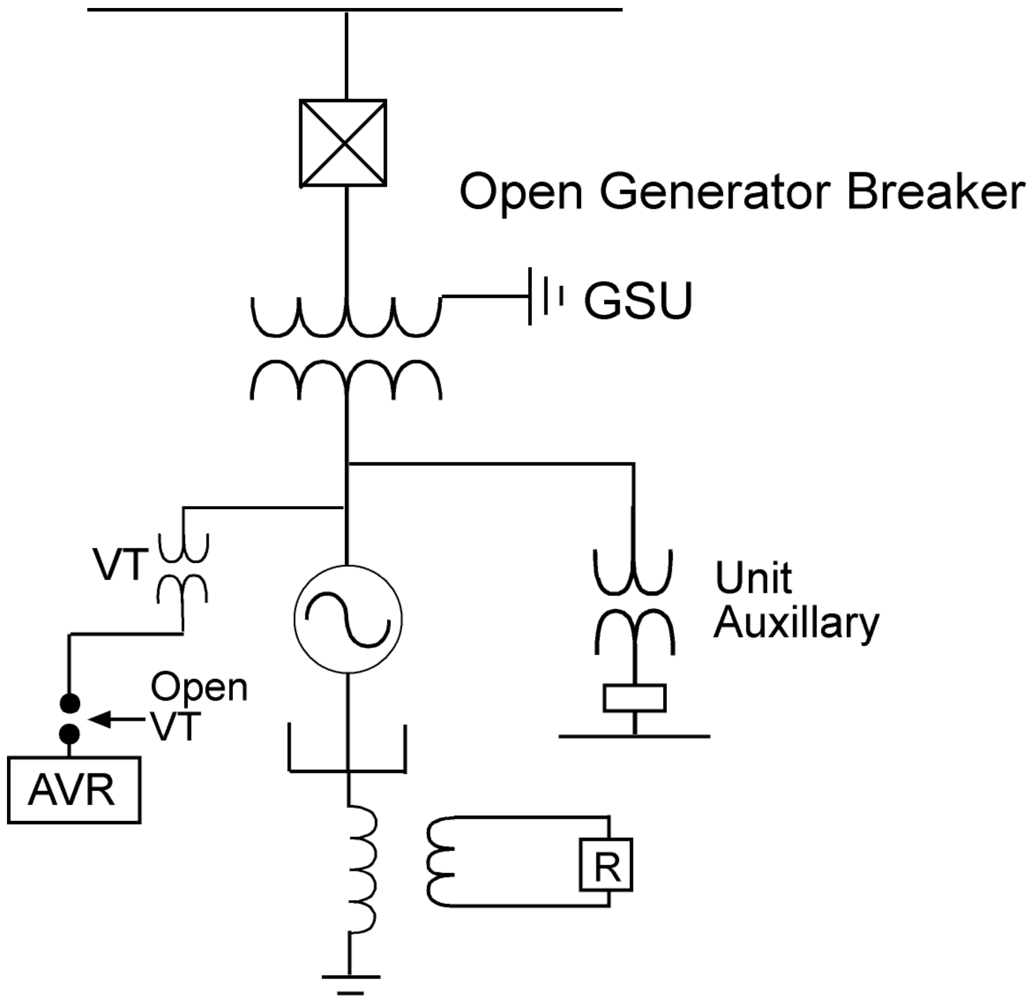


Overexcitation Digital Relay Curve

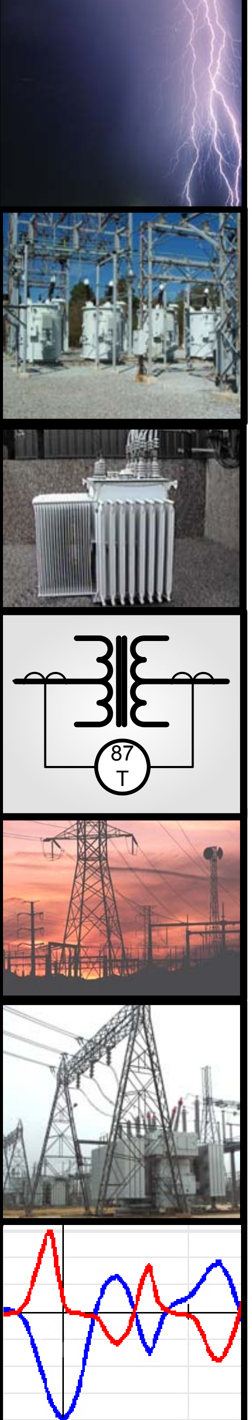


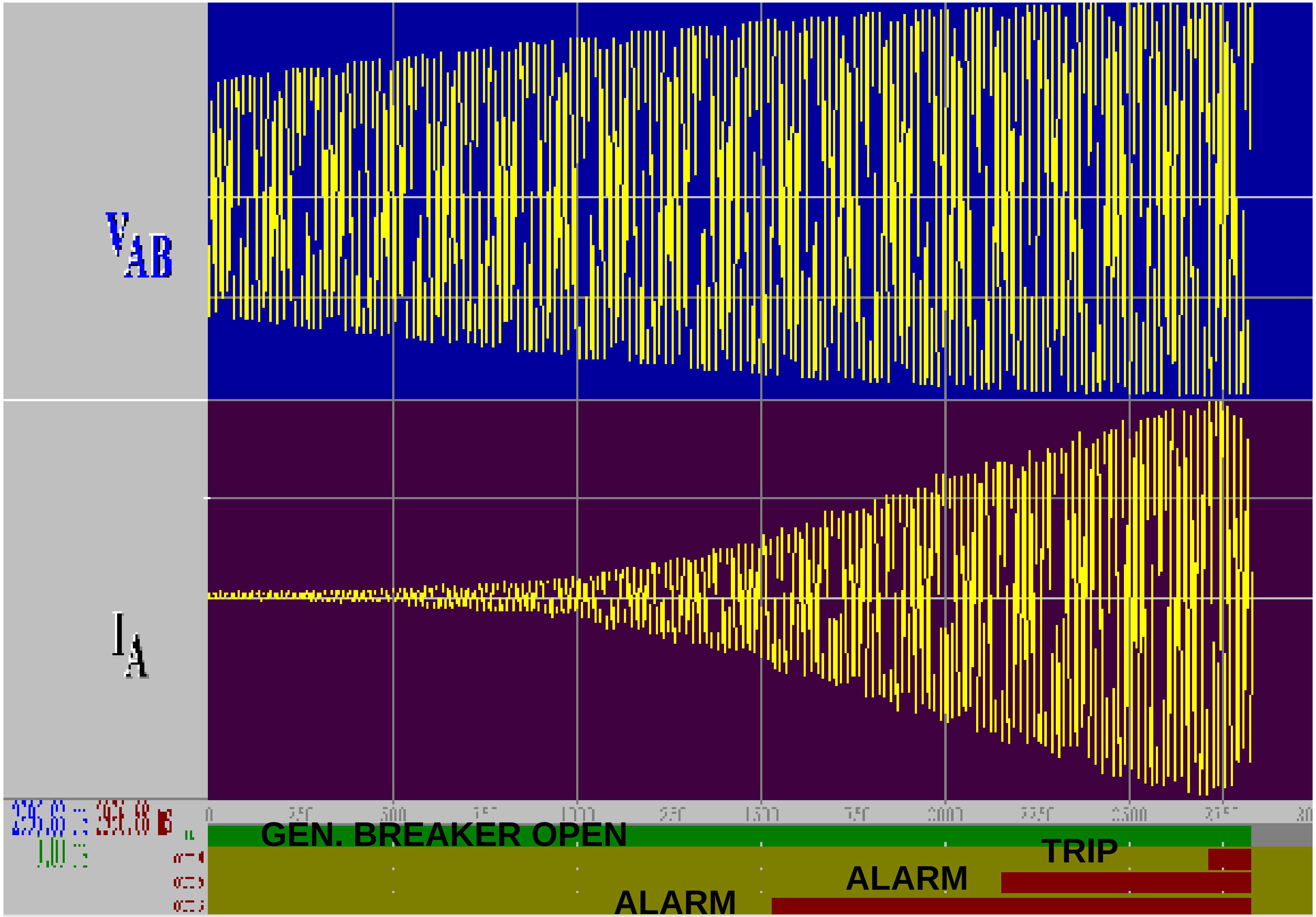


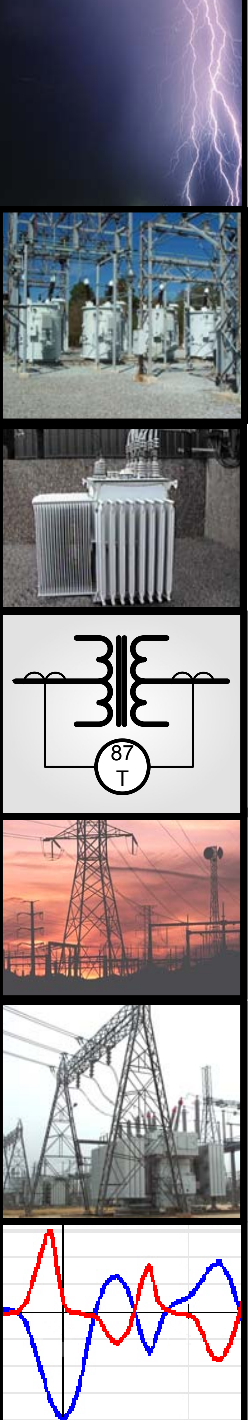
V/Hz Event



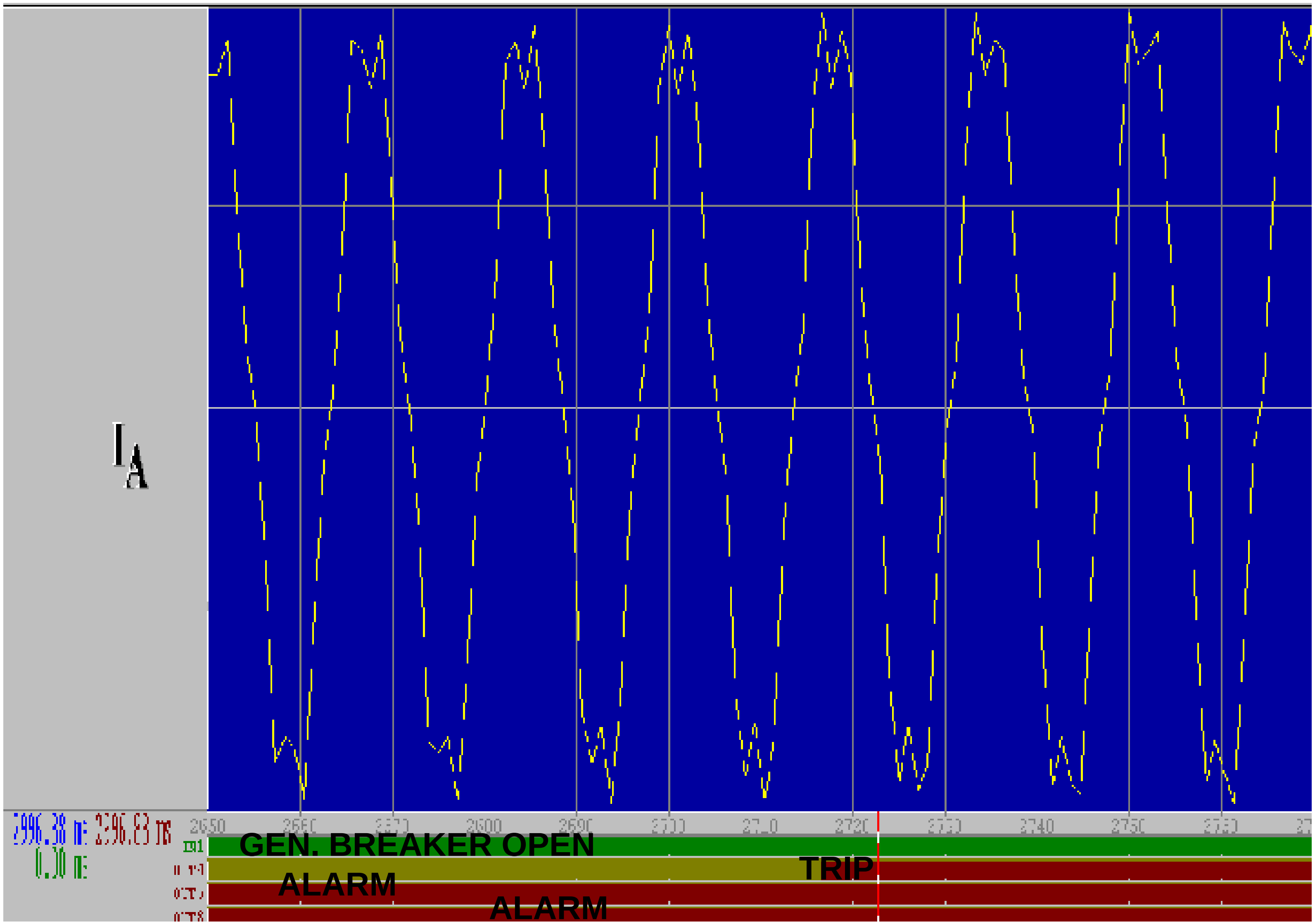
V_A & I_A

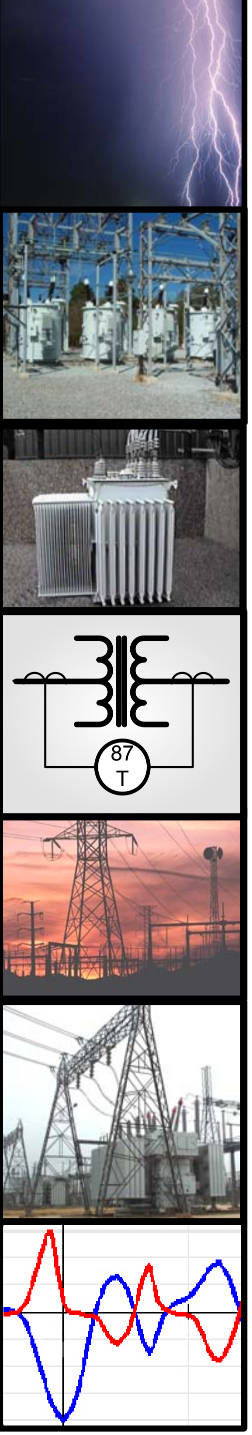




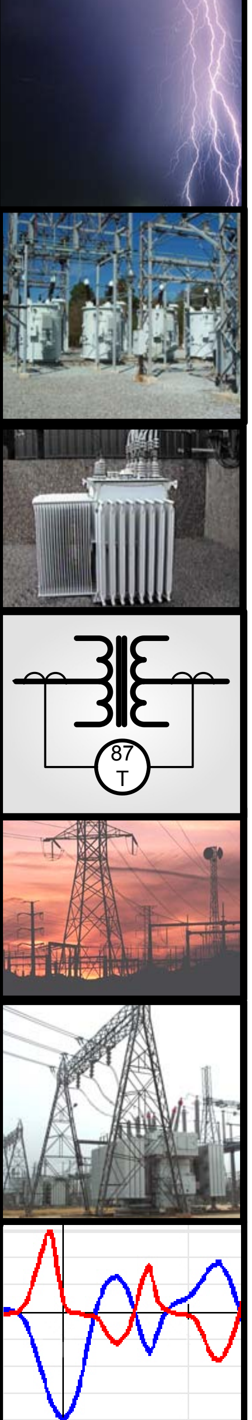


I_A



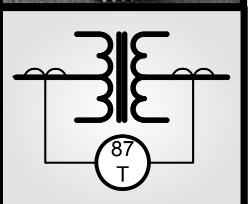


DIGITAL RELAY TRANSFORMER PROTECTION

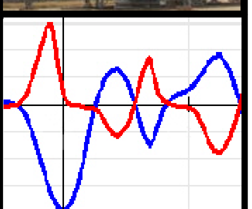


Digital Transformer Relays



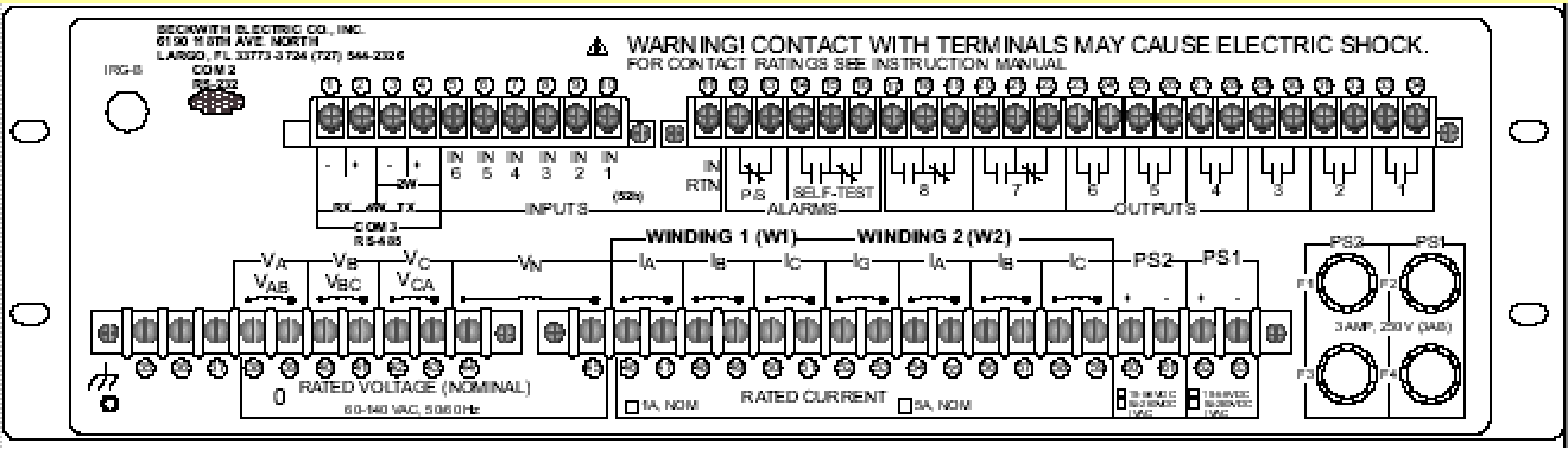




Digital Relay Features

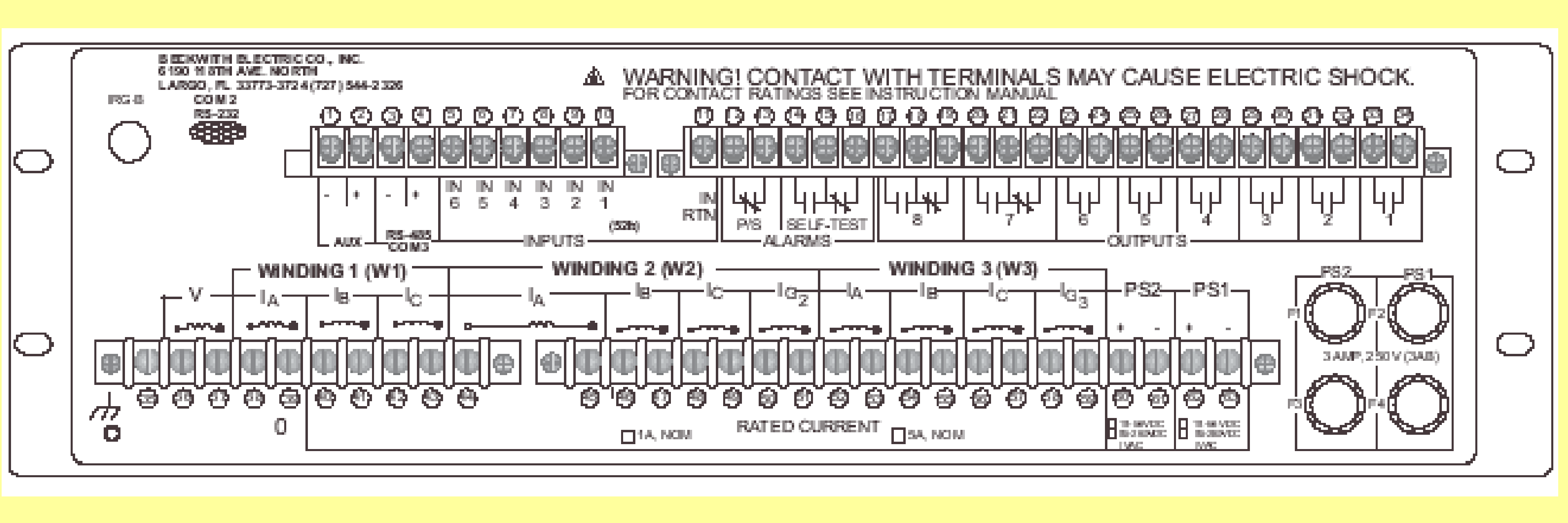
- + Self-Monitoring and Diagnostics.
- + Some Monitoring of VT and CT Inputs.
- + Multiple Input and Output Contacts
- + Multiple Setting Groups
- + Programmable Logic
- + Metering of all Inputs
- + Oscillography and Event Recording
- + Communications

Two Winding Transformer Relay-- External Connections



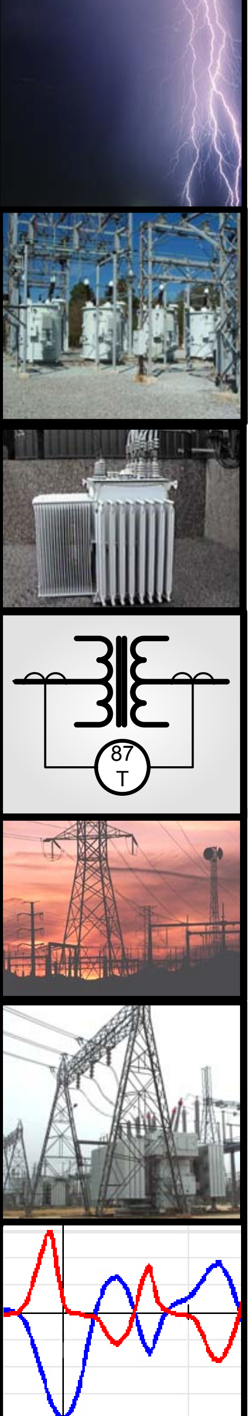
- •2 Three Phase Current, plus 1 Ground Current Input
- •3 Phase and One Ground Voltage Input

Three Winding Transformer Relay-- External Connections

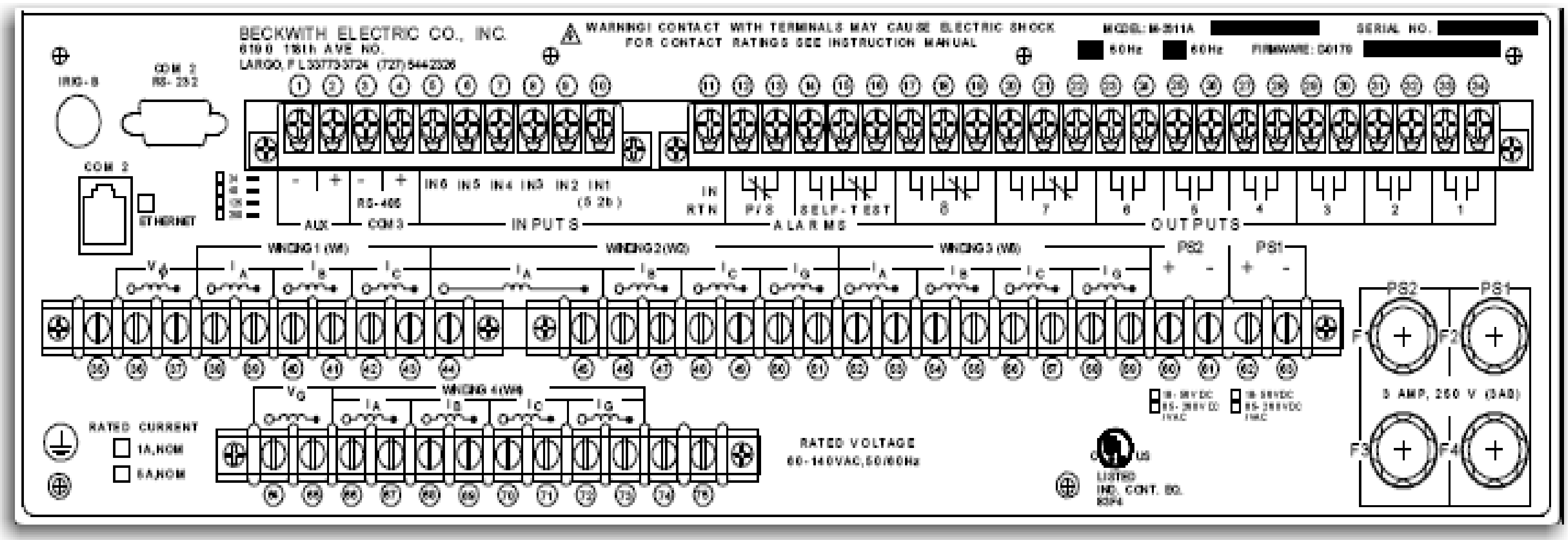


•3 Three Phase Current, plus Two Ground Current Inputs!

•One Voltage Input

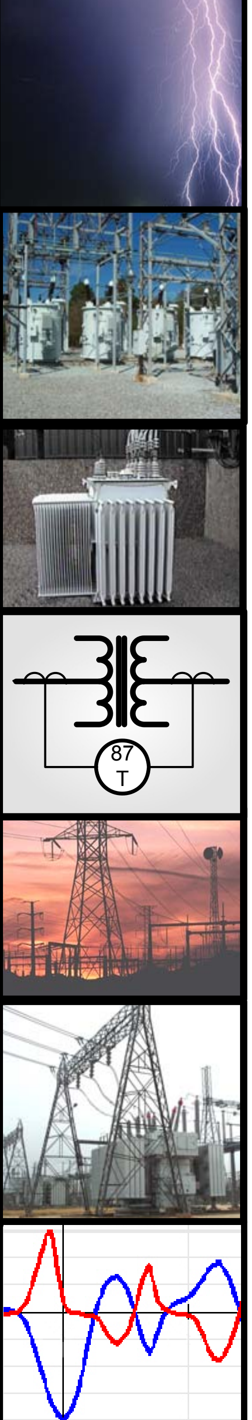


Four Winding Transformer Relay-- External Connections



•4 Three Phase Current, plus 3 Ground Current Inputs!

• Two Voltage Input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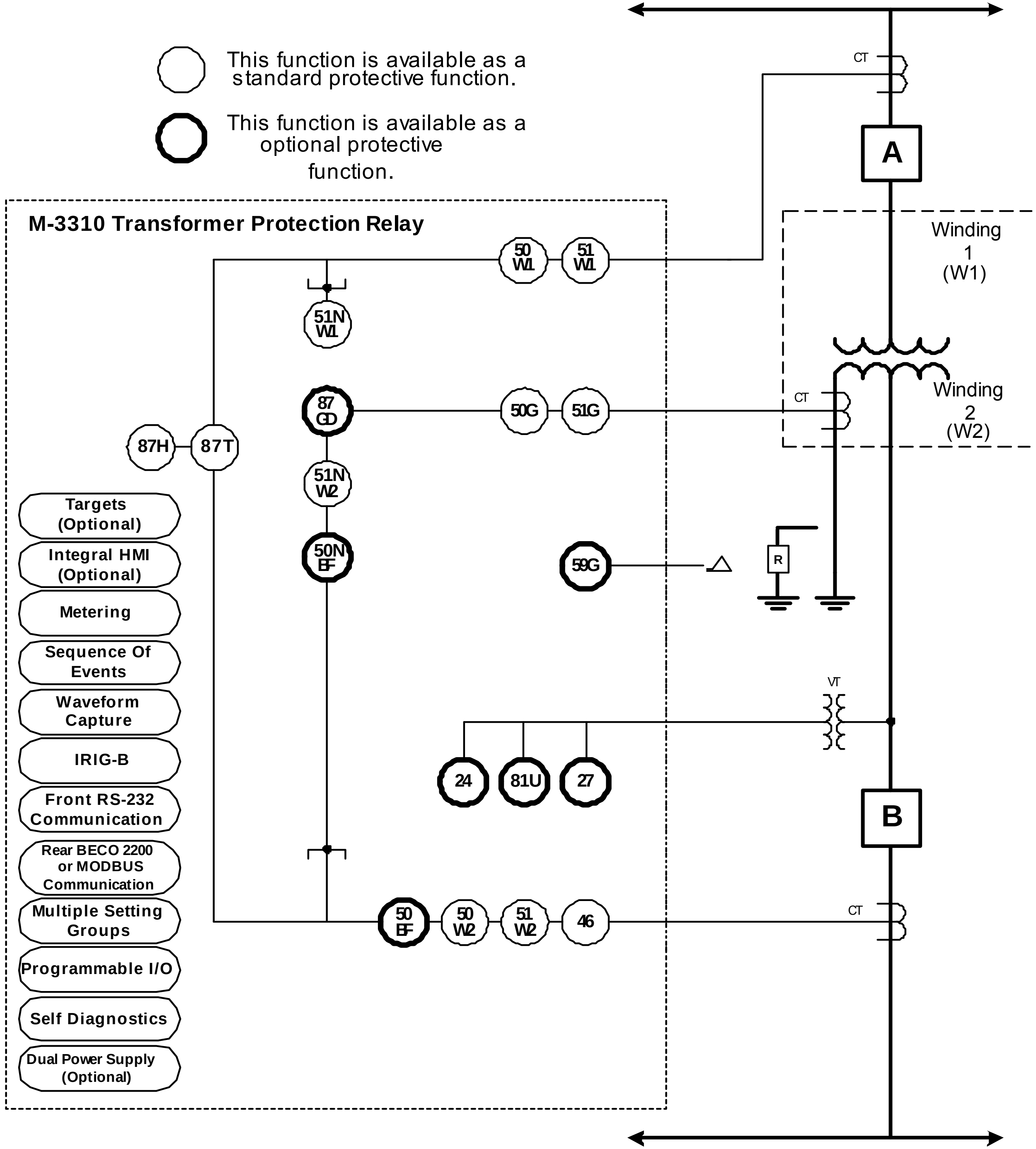
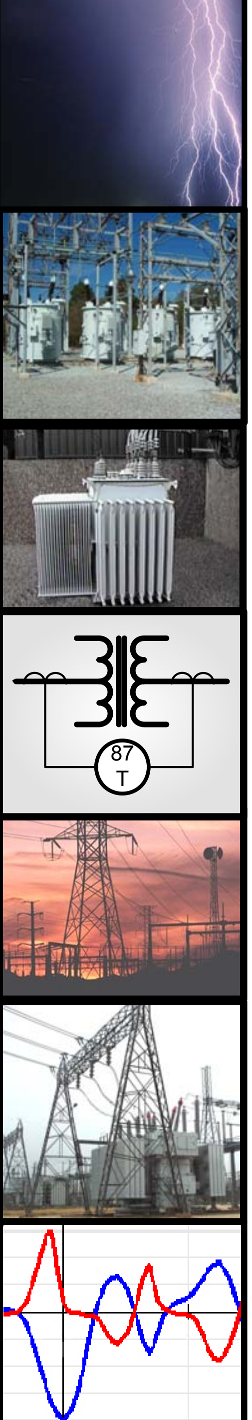

This function is available as a standard protective function.
This function is available as a optional protective function.
M-3310 Transformer Protection Relay
50 W1
51 W1
51N W1
87 GD
50G
51G
87H
87T
51N W2
50N BF
59G
24
81U
27
50 BF
50 W2
51 W2
46
Targets (Optional)
Integral HMI (Optional)
Metering
Sequence Of Events
Waveform Capture
IRIG-B
Front RS-232 Communication
Rear BECO 2200 or MODBUS Communication
Multiple Setting Groups
Programmable I/O
Self Diagnostics
Dual Power Supply (Optional)
CT
A
Winding 1 (W1)
Winding 2 (W2)
CT
R
VT
B
CT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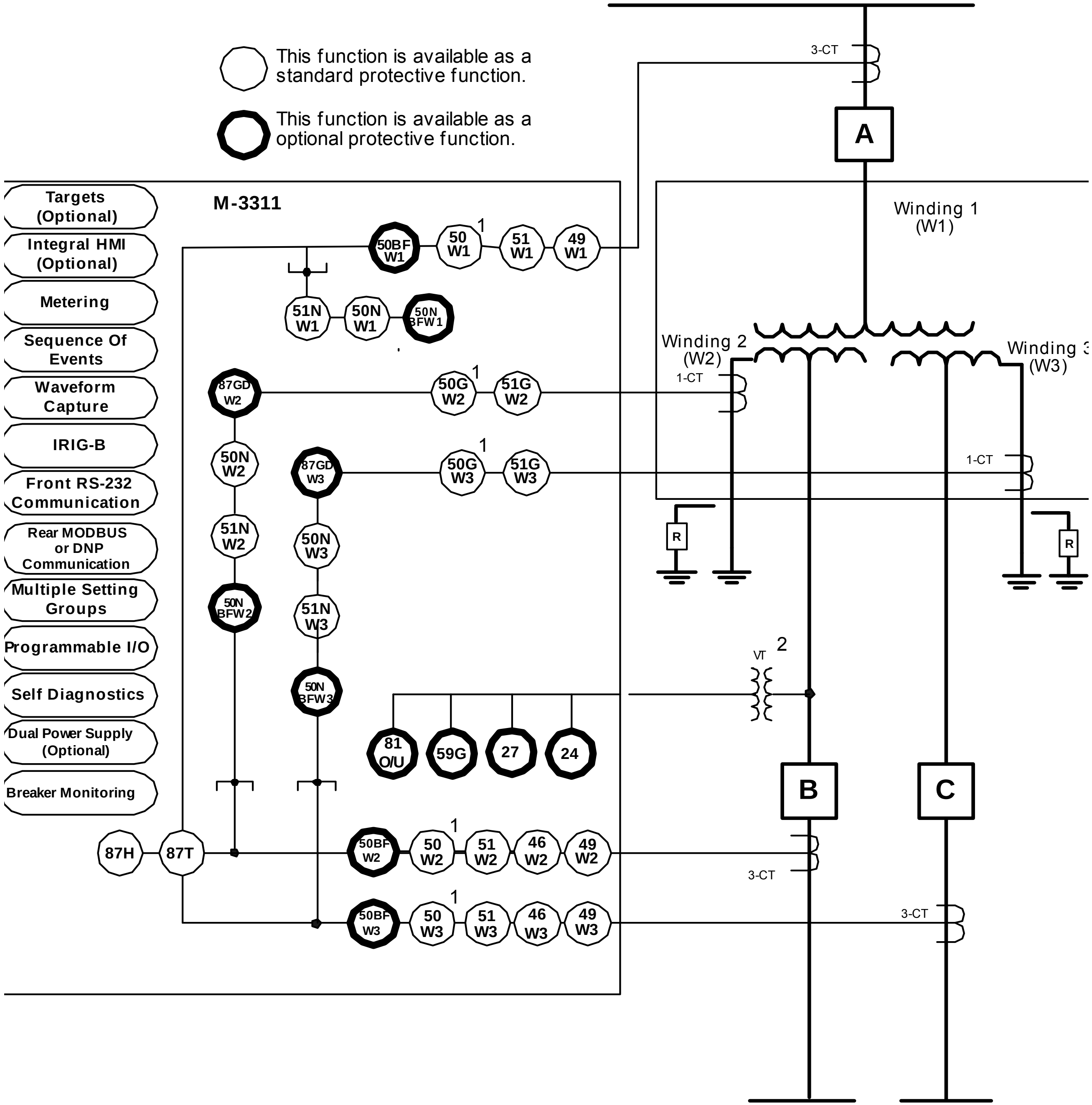
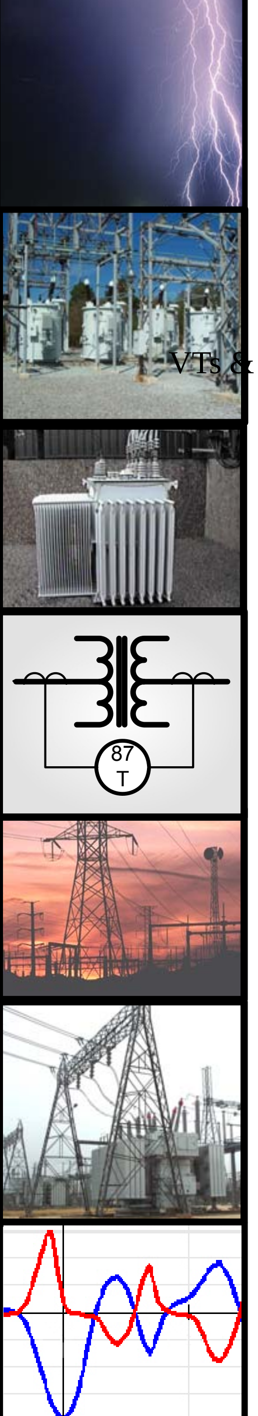
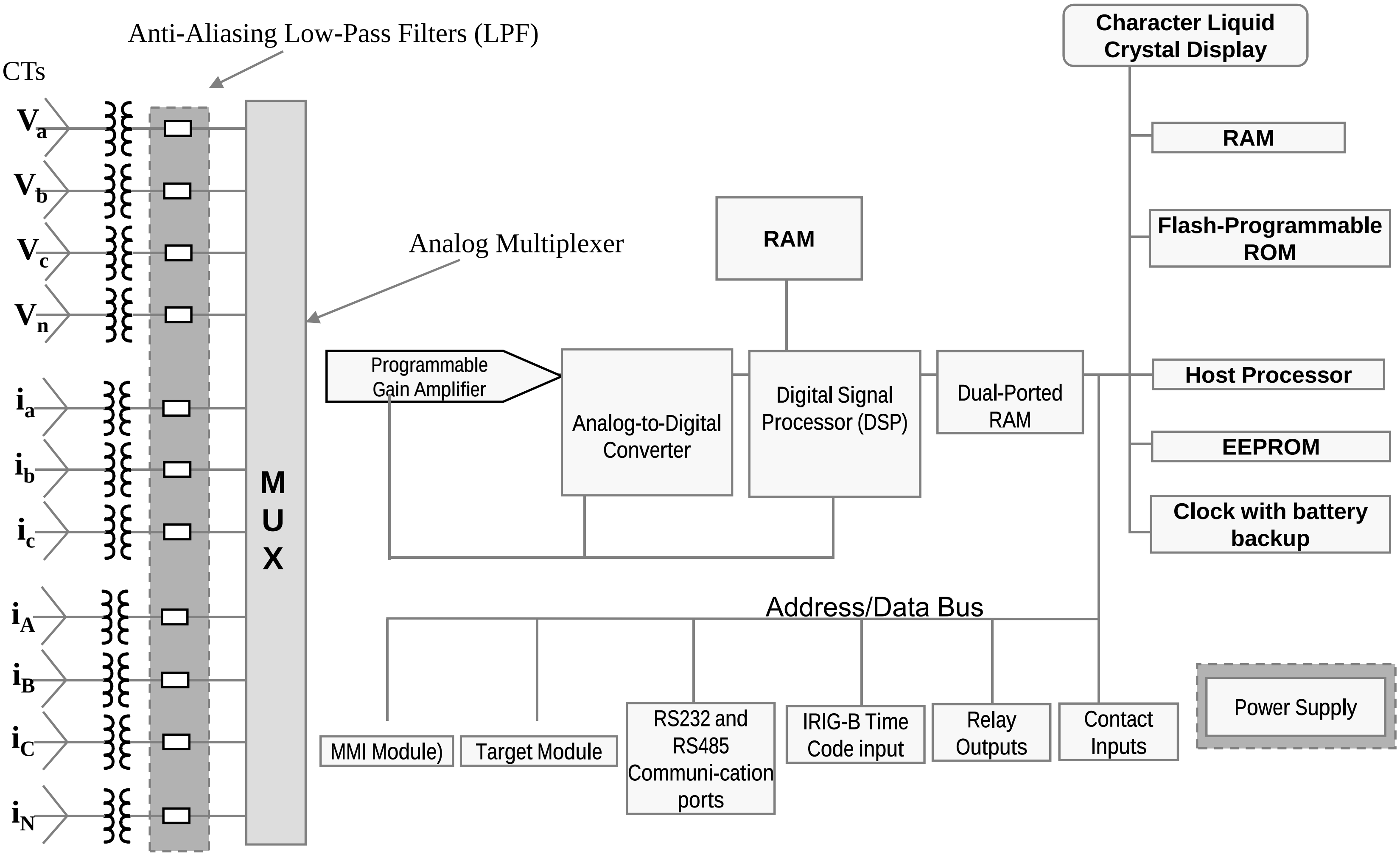
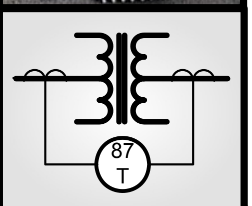
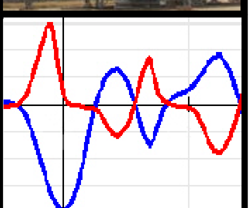

This function is available as a standard protective function.
This function is available as a optional protective function.
M-3311
Targets (Optional)
Integral HMI (Optional)
Metering
Sequence Of Events
Waveform Capture
IRIG-B
Front RS-232 Communication
Rear MODBUS or DNP Communication
Multiple Setting Groups
Programmable I/O
Self Diagnostics
Dual Power Supply (Optional)
Breaker Monitoring
50BF W1
50 W1
51 W1
49 W1
51N W1
50N W1
50N BFW1
87GD W2
50G W2
51G W2
50N W2
51N W2
50N BFW2
87GD W3
50G W3
51G W3
50N W3
51N W3
50N BFW3
81 O/U
59G
27
24
87H
87T
50BF W2
50 W2
51 W2
46 W2
49 W2
50BF W3
50 W3
51 W3
46 W3
49 W3
3-CT
A
Winding 1 (W1)
Winding 2 (W2)
Winding 3 (W3)
1-CT
R
VT
B
C

Hardware Block Diagram



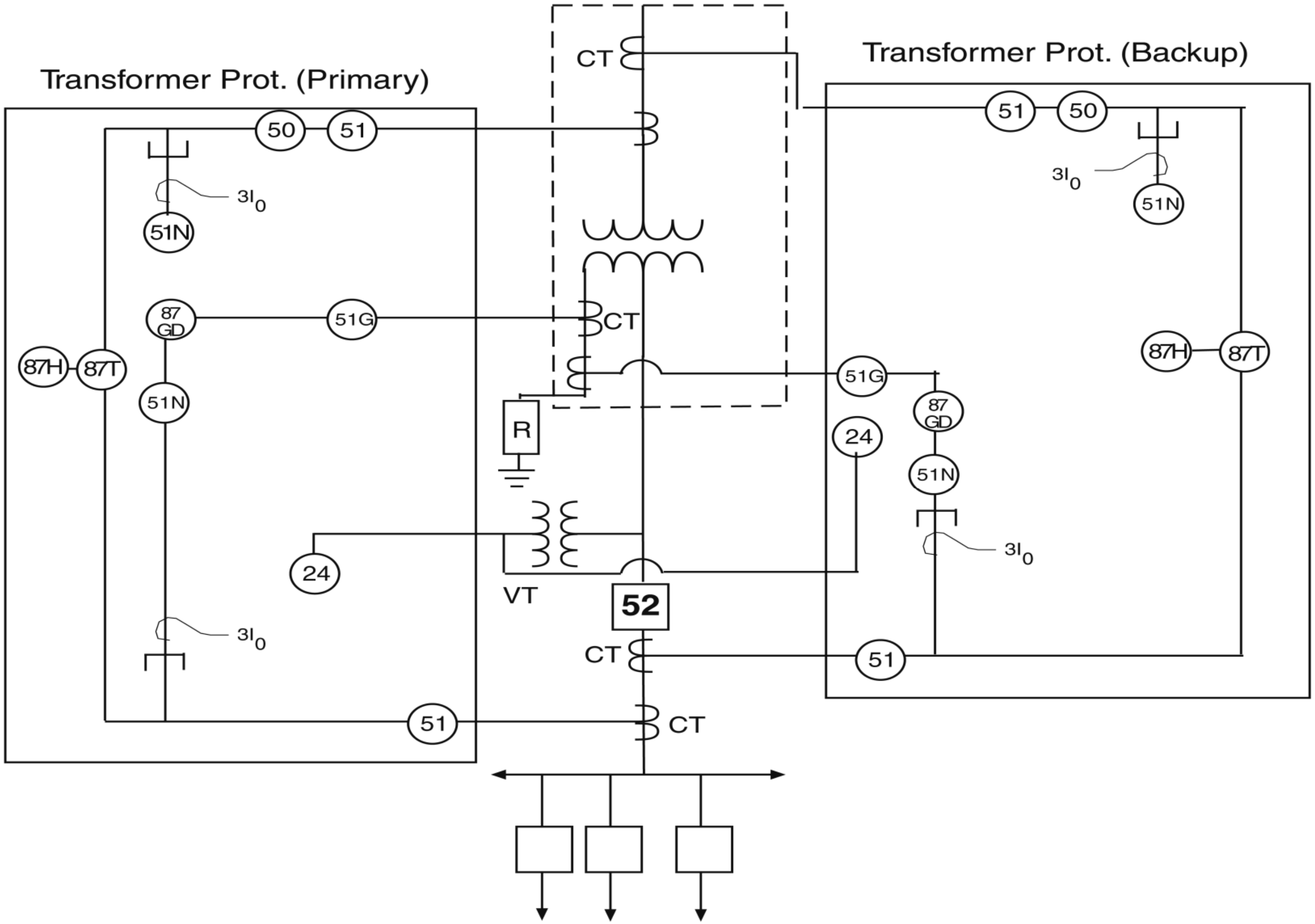






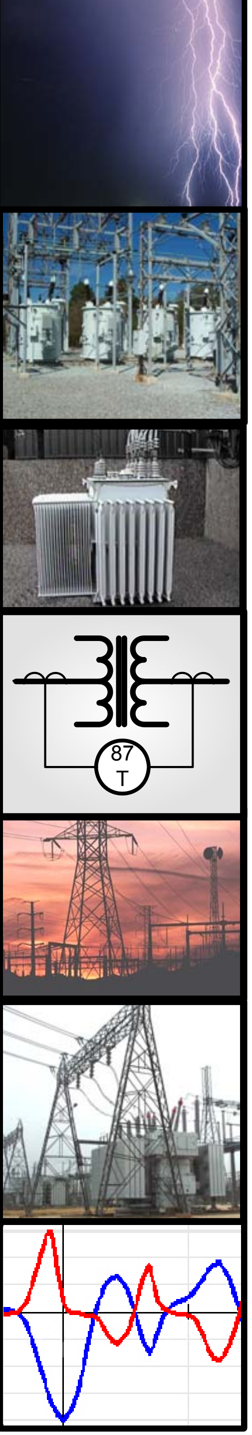
Transformer Protection

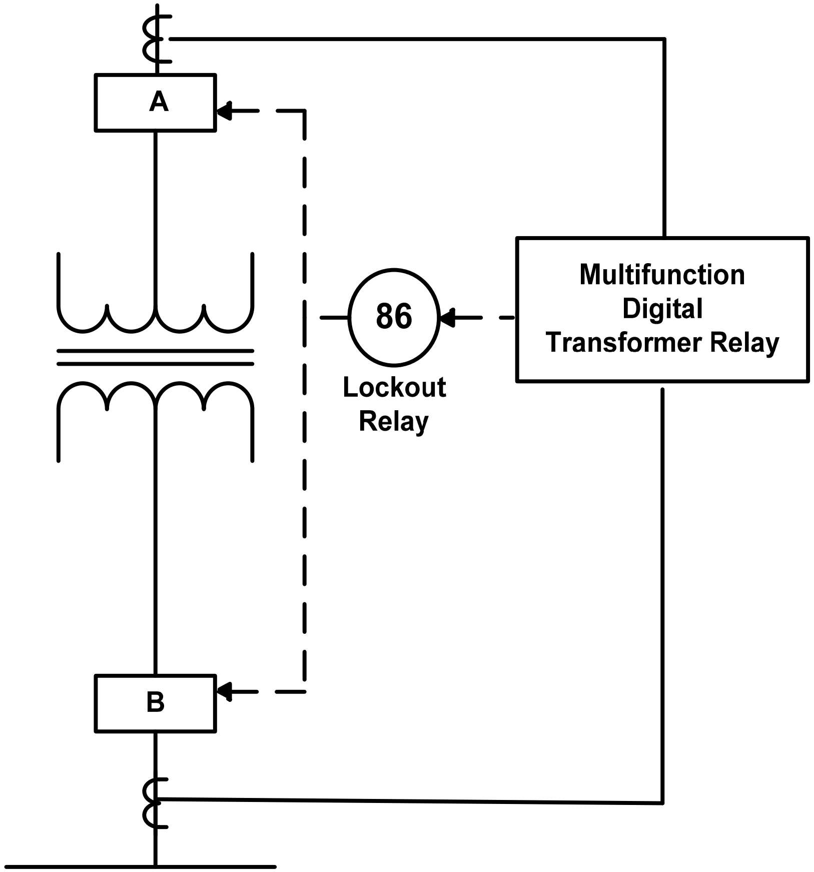
TYPICAL PROTECTION WITH DUAL DIGITAL RELAYS



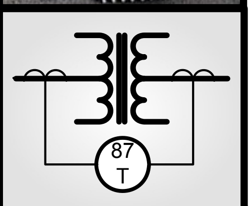
Traditional Approach

Tripping Redundancy

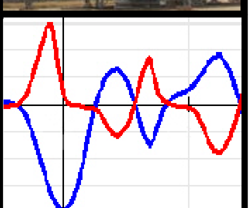






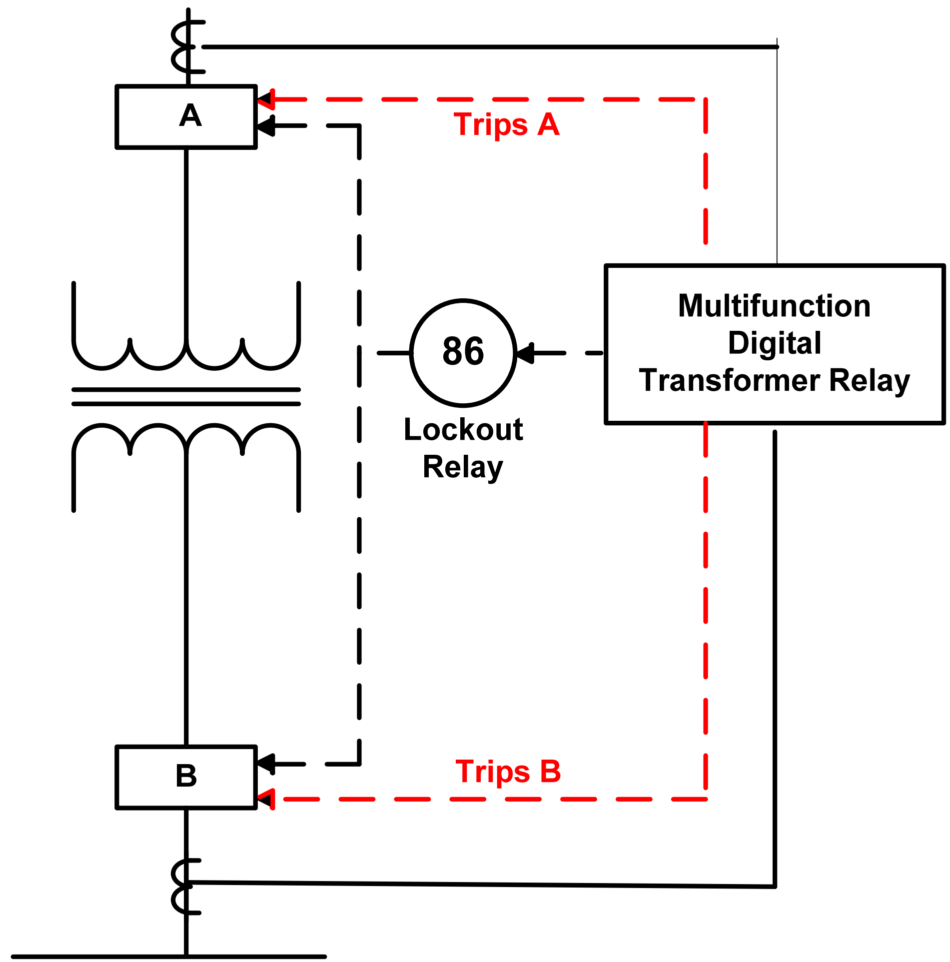



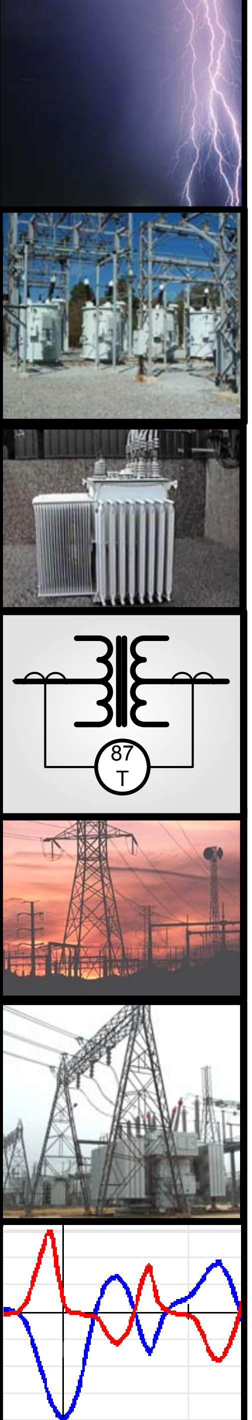




New Approach

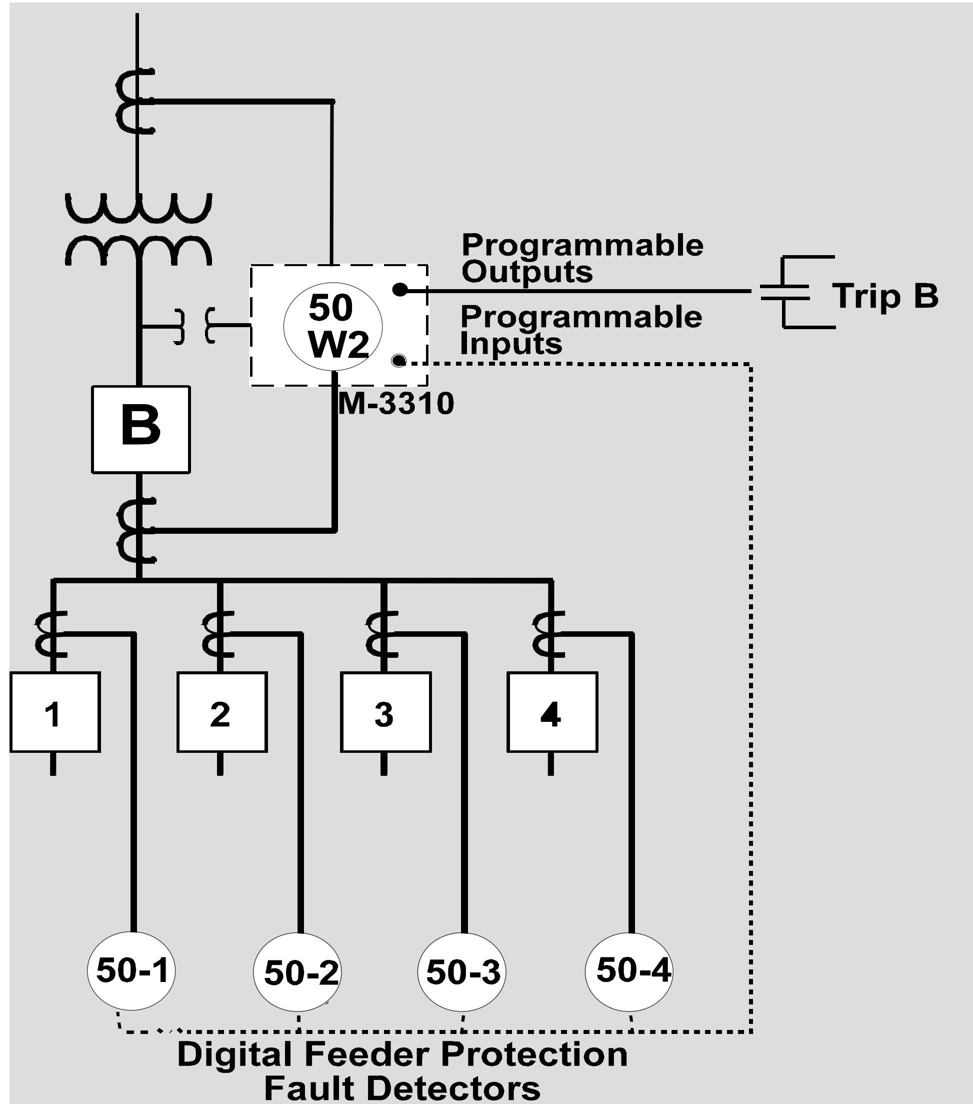
Tripping Redundancy Improvement

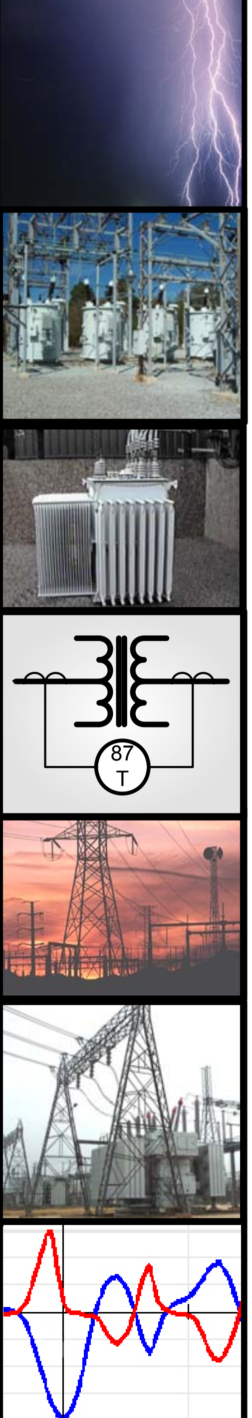




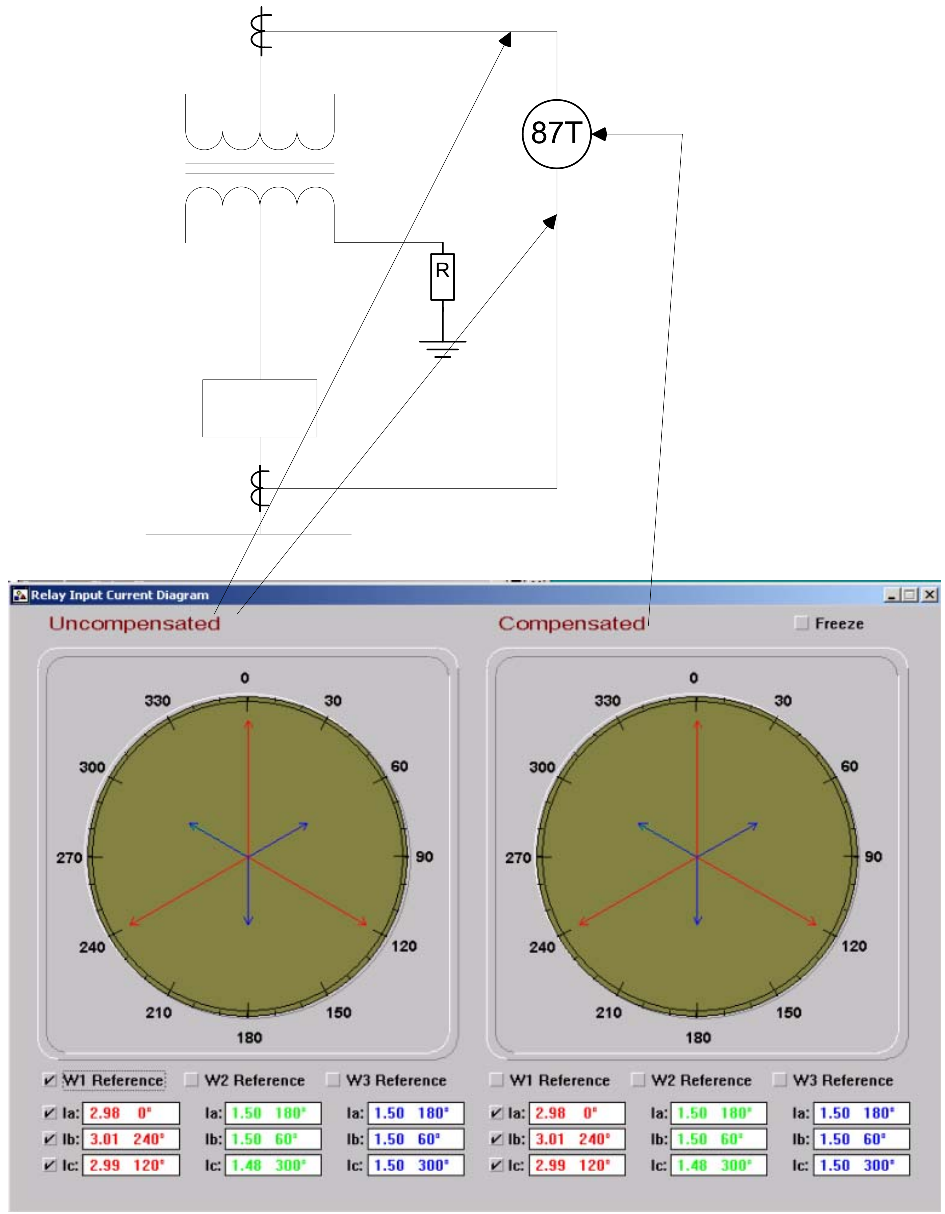
Schemes - Bus Fault Protection

- Use interlocked overcurrent to avoid long time delays
- Inexpensive solution for lower voltage distribution buses

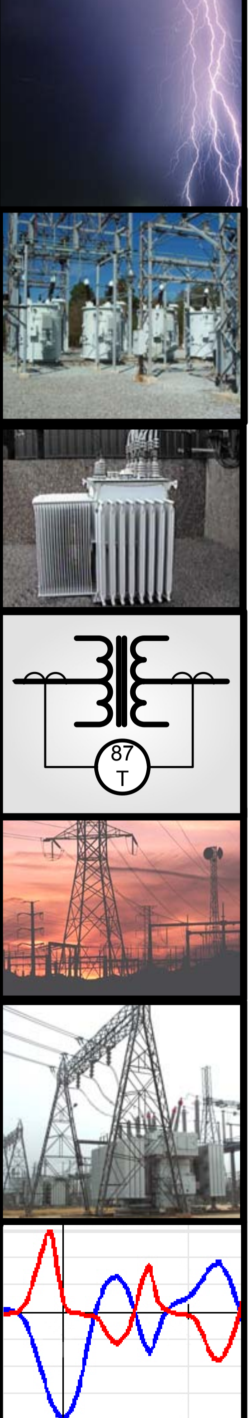


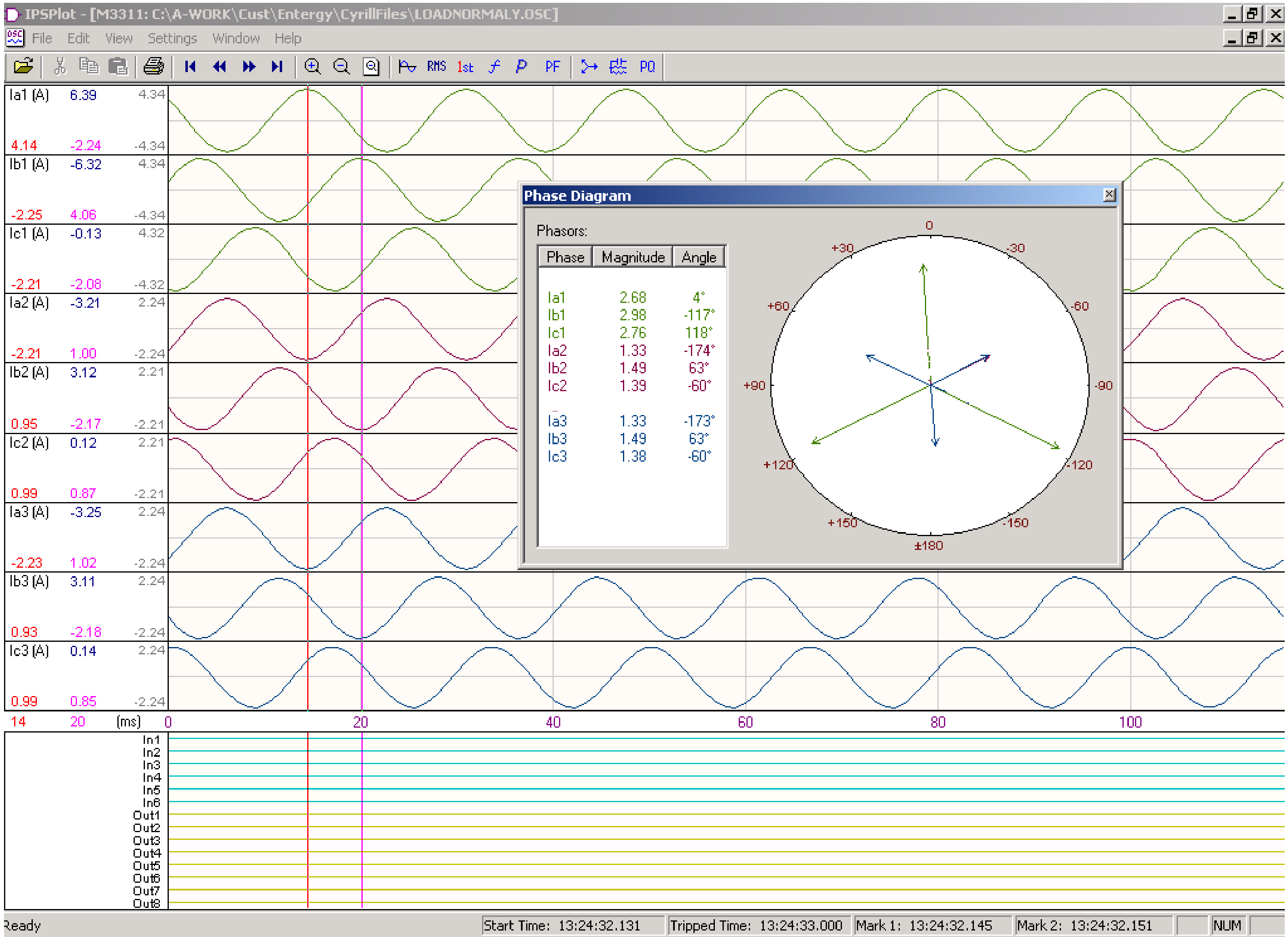


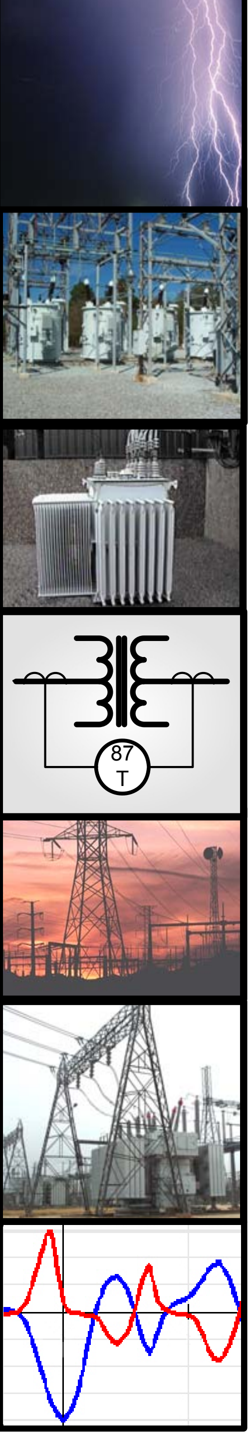
Vector Display, 87



Waveform Capture







THE END

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FINALQUESTIIONS

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