PROTECTION OF MV TRANSFORMERS AT UTILITY AND INDUSTRIAL FACILITIES

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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 DIFFERENTIAL
  + Phase (87T)
  + Gnd (87GD)
• OVEREXCITATION PROTECTION
• DIGITAL TRANSFORMER RELAYS
IEEE Standards

• Latest developments reflected in:
  
  – Std. 242: Buff Book Transformer Protection Chapter 11
  
  – ANSI / IEEE C37.91 “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.

<table>
<thead>
<tr>
<th>Cause</th>
<th>% of Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Failure</td>
<td>26%</td>
</tr>
<tr>
<td>Manufacturing Problems</td>
<td>24%</td>
</tr>
<tr>
<td>Unknown</td>
<td>16%</td>
</tr>
<tr>
<td>Loose Connections</td>
<td>7%</td>
</tr>
<tr>
<td>Through Faults</td>
<td>5%</td>
</tr>
<tr>
<td>Improper Maintenance</td>
<td>5%</td>
</tr>
<tr>
<td>Oil Contamination</td>
<td>4%</td>
</tr>
<tr>
<td>Overloading</td>
<td>4%</td>
</tr>
<tr>
<td>Fire/Explosions</td>
<td>3%</td>
</tr>
<tr>
<td>Lighting</td>
<td>3%</td>
</tr>
<tr>
<td>Floods</td>
<td>2%</td>
</tr>
<tr>
<td>Moisture</td>
<td>1%</td>
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</tbody>
</table>
Through Fault
Category 3
5-30 MVA
Through Fault Category 4 Larger than 30 MVA
TRANSFORMER PROTECTION BASICS
Transformer Formulas

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

I_1 = 5

I_2 = 10

N_1 = 100

N_2 = 50

V_1 = 100

V_2 = 50

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 than dry insulation
  - Vast majority of power transformers use wet (oil) insulation.
Basic Transformer Designs
Gas-Oil Sealed Transformers

Transformer Ratings
OA/FA/FA/FA

Gas Regulator
NI Gas Tank
Fans
Regulating Valve
Pressure Relief
NI GAS
OIL
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

Diagram of a grounded transformer with labels for High Side and Low Side.
Basic Industrial Transformer Protection

- High Side
- Low Side
- RESISTOR 200-400 A
- Aux. CT
- GD
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

- Mounting Boss (Part of Tank Well)
- Equalizer
- Bellows
- Micro-Switch
- Test Plug
- Press Tight Connector

Sudden Pressure Relay

Transformer

NI GAS

OIL
Transformer Thermal Monitoring

Transformer diagram with labels:
- Top Oil Temp.
- Winding Hot Spot
- OIL
- NI GAS
- 49W
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

$I_{FL} = \frac{10,000}{1.73} \times 138 = 42A$

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

Transformer

H1 → X1
H2 → X2
H3 → X3

- 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

- 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

**EXAMPLES**

**For Delta Primary Transformers:**
1 = Dy1 = X lags H by 30°
3 = Dy3 = X lags H by 90°
7 = Dy 7 = X lags H by 210°

**For Wye Primary Transformers:**
1 = Yd1 = X lags H by 30°
3 = Yd3 = X lags H by 90°
7 = Yd7 = X lags H by 210°
Transformer Phasing
Communicating Phasing To Digital Relays

- Major Source of Setting Error
- IEEE-ANSI – Can use $\Delta$ AB or $\Delta$ AC
- IEC – Need to Use 30° Clock
- CT’s Can be $\Delta$ or Y
- Solution: Let the Software Decide
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!

<table>
<thead>
<tr>
<th>IEC Connection Description</th>
<th>Beckwith Standard Connection Description</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yy0</td>
<td>YY</td>
<td>*1</td>
</tr>
<tr>
<td>Dd0</td>
<td>Dac Dac</td>
<td>*1</td>
</tr>
<tr>
<td>Yd1</td>
<td>Y Dac</td>
<td>*2</td>
</tr>
<tr>
<td>Yd11</td>
<td>Y Dab</td>
<td>*2</td>
</tr>
<tr>
<td>Dy1</td>
<td>Dab Y</td>
<td></td>
</tr>
<tr>
<td>Dy11</td>
<td>Dac Y</td>
<td></td>
</tr>
<tr>
<td>Yd6</td>
<td>Y Inverse Dab</td>
<td></td>
</tr>
<tr>
<td>Dy5</td>
<td>Dac Inverse Y</td>
<td></td>
</tr>
<tr>
<td>Dd110</td>
<td>Dac Dab</td>
<td></td>
</tr>
<tr>
<td>Dz2</td>
<td>Dab Custom</td>
<td></td>
</tr>
</tbody>
</table>

*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

TRANSFORMER

TAP W-1

Restraint W-1

Operate

Restraint W-2

TAP W-2
Basic Differential Relay
External Fault

TRANSFORMER

Operate = 0

TAP W-1
Restraint W-1

TAP W-2
Restraint W-2

RELAY
Basic Differential Relay

Internal Fault

TRANSFORMER

TAP W-1

TAP W-2

Restraint W-1

Restraint W-2

RELAY

Operate
Typical Phase Differential Characteristic – Percentage Slope Concept

\[ I_d = \sum I_{\text{AW1}} + I_{\text{AW2}} + I_{\text{AW3}} \]

\[ I_R = \frac{\sum |I_{\text{AW1}}| + |I_{\text{AW2}}| + |I_{\text{AW3}}|}{2} \]
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

PRI. (H)  SEC. (X)
Digital Relay Application
Compensation in Digital Relays

• Transformer ratio
• CT ratio
• Vector quantities
  – Which vectors are used
  – Where the 1.73 factor (\(\sqrt{3}\)) 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 APPLICATIONS?**
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
  - 2\textsuperscript{nd} harmonic restraint has been employed for years
  - “Gap” detection has also been employed
  - As transformers are designed to closer tolerances, both 2\textsuperscript{nd} harmonic and low current gaps in waveform have decreased
  - If 2\textsuperscript{nd} 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

2nd and 4th Harmonics During Inrush
Cross Phase Averaging

\[ \text{Idc}_{PA24} = \sqrt{I_{A_{d24}}^2 + I_{B_{d24}}^2 + I_{C_{d24}}^2} \]

- 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

\[ I_d = \sum |I_{AW1}| + |I_{AW2}| + |I_{AW3}| \]
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 (2\textsuperscript{nd} and 4\textsuperscript{th} harmonic)
  – Typically set from 10-15%
  – Employ cross phase averaging blocking for security – Blocks tripping for 10 cycles

• Overexcitation Restraint (5\textsuperscript{th} 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

- **Remnance**: Residual magnetism that causes dc saturation of the CTs
- **Saturation**: Error signal resulting from too high a primary current combined with a large burden
- **Tolerance**: 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

• CT Burden Check– want to operate below the knee-point voltage \((V_k)\) for worst-case fault external to diff. Zone.

\[
V_S = \frac{I_P}{N} \left[ R_{CT} + R_W + R_R \right]
\]

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 no 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

![Graph showing the relationship between distance of fault from neutral and currents (phase and neutral)]
Improved Ground Fault Sensitivity

Typical Pickup of 87T:
- 0.3 pu pickup
- Relay Tap set at Trans. Rating (45MVA)
  \[ I_{FL138KV} = 4.71 \text{ Amps} \]
  \[ PU = 4.71 \times 0.3 = 1.41 \text{A} \]

- 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,

\[ I_{op} = 3I_0 \cdot R_{ct} I_N \]

**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.

\[-3I_o \times I_G \cos (180) = 3I_o I_G\]
Residual current calculated from individual phase currents. Paralleled CTs shown to illustrate principle.

\[-3I_o \times I_G \cos (\theta) = -3I_o I_G\]
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

Power System
High Voltage During Major System Disturbance

Transformers Still Connected to Power System Even After Load Transfered onto Plant Generation

Plant Separated onto Local Plant Gen.
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

Open Generator Breaker

GSU

Unit Auxiliary

AVR

 VT

Open VT

VT

$V_A$ & $I_A$
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
M-3310 Transformer Protection Relay

- This function is available as a standard protective function.
- This function is available as an optional protective function.

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)
This function is available as a standard protective function.

This function is available as an optional protective function.

### M-3311

<table>
<thead>
<tr>
<th>Targets (Optional)</th>
<th>Integral HMI (Optional)</th>
<th>Metering</th>
<th>Sequence Of Events</th>
<th>Waveform Capture</th>
<th>IRIG-B</th>
<th>Front RS-232 Communication</th>
<th>Rear MODBUS or DNP Communication</th>
<th>Multiple Setting Groups</th>
<th>Programmable I/O</th>
<th>Self Diagnostics</th>
<th>Dual Power Supply (Optional)</th>
<th>Breaker Monitoring</th>
</tr>
</thead>
</table>

#### Winding 1 (W1)

#### Winding 2 (W2)

#### Winding 3 (W3)
Hardware Block Diagram

- CTs
- VTs & CTs
- RAM
- Flash-Programmable ROM
- Host Processor
- EEPROM
- Clock with battery backup
- Power Supply
- Character Liquid Crystal Display
- RAM
- Analog-to-Digital Converter
- Digital Signal Processor (DSP)
- Dual-Ported RAM
- Address/Data Bus
- RS232 and RS485 Communication ports
- IRIG-B Time Code input
- Relay Outputs
- Contact Inputs
- MMI Module
- Target Module
- Anti-Aliasing Low-Pass Filters (LPF)
- Analog Multiplexer
- Programmable Gain Amplifier
- Power Supply
Transformer Protection

TYPICAL PROTECTION WITH DUAL DIGITAL RELAYS
Traditional Approach
Tripping Redundancy

Diagram: A to B with a transformer and multifunction digital transformer relay.
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
??
FINALQUESTIONS
??