Transformer Protection
Transformer Protection Outline

- Fuses
- Protection Example
- Overcurrent Protection
- Differential Relaying
  - Current Matching
  - Phase Shift Compensation
  - Tap Changing Under Load
  - Magnetizing Inrush
  - Overexcitation
  - Connection Examples
  - Ground Differential
- Sudden-Pressure Relays (63)
### Power Transformer Failure Statistics

**1955 - 2002 (3,112 failures)**

<table>
<thead>
<tr>
<th>Failure Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding failures</td>
<td>31%</td>
</tr>
<tr>
<td>Tap changer failures</td>
<td>26%</td>
</tr>
<tr>
<td>Bushing failures</td>
<td>12%</td>
</tr>
<tr>
<td>Cooling equipment failures</td>
<td>3%</td>
</tr>
<tr>
<td>Auxiliary equipment failures</td>
<td>3%</td>
</tr>
<tr>
<td>Core failures</td>
<td>1%</td>
</tr>
<tr>
<td>Leads failures</td>
<td>1%</td>
</tr>
<tr>
<td>Other failures</td>
<td>23%</td>
</tr>
</tbody>
</table>

Source: IEEE C37.91-2000
Transformer Fusing

- Normally used at 10MVA and below
- Reference transformer damage curves
  IEEE C37.91
- Selected to fit below damage curve
- Fuses must be coordinated with relays
- Economical
Fuse Characteristics

Operate Time vs. Current Graph

- 200 A-AF
- 100 A-AF
- Maximum Clear
- Minimum Melt

- 0.15 Sec
- 0.1 Sec

- 0.01 to 1000 on the Y-axis
- 0.5 to 10,000 on the X-axis
Example: Large Industrial Load

XX Primary Protection
Transformer Overcurrent Protection

High side overcurrent will not see low side ground faults.
High Side Overcurrent

- Coordinate with upstream devices
- Backup transformer differential / sudden pressure
- Thermal overload
- Set above Inrush, 2-8 X Load
Low Side Overcurrent

- Coordinate with downstream devices (radial)
- Bus backup scheme
- Thermal overload
“Frequent” and “Infrequent” Operating Limits

THROUGH-FAULT PROTECTION ON CURVE FOR FAULTS WHICH WILL OCCUR FREQUENTLY (TYPICALLY MORE THAN 5 IN A TRANSFORMER LIFETIME).

THROUGH-FAULT PROTECTION ON CURVE FOR FAULTS WHICH WILL OCCUR INFREQUENTLY (TYPICALLY NOT MORE THAN 5 IN A TRANSFORMER LIFETIME).

This curve may also be used for backup protection where the transformer is exposed to frequent faults normally caused by high-speed relaying.

For fault current from 50% to 100% maximum possible: $I_2t = K$

Where $I = \text{symmetrical fault current in times normal base current (ANSI/IEEE C57.12.00-1980)}$

$K = \text{constant determined at maximum } I \text{ with } t = 2 \text{ s}$

Note: Sample $I_2t = K$ curves have been plotted for

% of transformer impedance

Times normal base current

Time (seconds)
Transformer Monitor (51TF)

Get TF(M) from curve

\[ \int \frac{1}{TF(M)} dt \]

Start Integration

Reset Integration

Pickup Counter + 1

Alarm

Alarm Counts

TF Counter + 1
Transformer Monitor (51TF)
Transformer Differential Relays

- Faster
- More sensitive
- Eliminates single phasing problem
- More selective
Percentage Differential

PROTECTED ZONE (PHASE A)

R1

87T

OP

R2
External Fault

PROTECTED ZONE (PHASE A)

R1

OP

R2

87T
Internal Fault

PROTECTED ZONE (PHASE A)

R1

OP

R2

87T
Percentage Differential Characteristic

Operational Current (in multiples of TAP)

Maximum Restraint Current (in multiples of TAP)

Operating Zone

Thru-Current Restraint Setting

Values:
- Operating Current: 2.33
- Thru-Current Restraint Setting: 60%
Transformer Differential Limitations

- Unequal secondary currents, because of the different turns ratios of the power transformer windings and the CTs
- Phase shift of wye-delta banks
- Tap changing under load
- Magnetizing inrush
Current Matching

RESTRAINT COILS

OPERATING COIL

R1

R2

10

5

5

5

Basler
Current Matching

Electronics

Relay

Input

CTS

Matching

Taps

Operating

Restraint

Comparator
Phase Shift Compensation
Phase Shift Compensation / Zero Sequence Trap
Two Kinds of Delta Connections

\[ I_A \cdot I_B \]
\[ I_B \cdot I_C \]
\[ I_C \cdot I_A \]

\[ I_A \cdot I_C \]
\[ I_B \cdot I_A \]
\[ I_C \cdot I_B \]
Percentage Differential Characteristic

Maximum Restraint Current (in multiples of tap)

Operating Current (in multiples of tap)

Thru-Current Restraint Setting

IOP 60° Difference

IOP 30° Difference

Operating Current: 2.33

Maximum Restraint Current: 60%

Thru-Current Restraint Setting: 60%, 40%, 15%
Tap Changing Under Load

\[ I_{OP} \text{ (MULT. OF TAP)} \]

\[ MARGIN \]

\[ XMFR \text{ EXCITING CURRENT} \]

\[ MAXIMUM I_R \text{ (MULT. OF TAP)} \]

\[ \text{TOTAL MISMATCH DUE TO LTC} \]

60%

15%
Magnetizing Inrush

Transformer Deenergized at This Point
Transformer Reenergized at This Point
Magnetizing Inrush

Transformer Deenergized at This Point

Transformer Reenergized at This Point
Inrush Waveform

DEAD SPOT
Unbalanced Inrush

Transformer Energization
Circuit 1 Currents vs Time

Time (mS)  IA1  IB1  IC1
Differential Setting Review

• If the transformer connection is a delta-wye the angles of the two currents will not be 180 degrees apart, and must be compensated by 30 degrees

• To compensate with the CT connection, reverse the connection; for delta-wye transformers connect the CT’s wye-delta

• Digital relays can be connected wye-wye and set the compensation inside the relay
Differential Setting Review

Ratio of taps = Ratio of currents
Differential Setting Review

- Set slope low for low mismatch and high quality CTs
- Increase slope setting for tap changer transformers, poor quality CTs or poorly matched CTs
- Use of transient monitor to detect the effect of CT saturation during through-fault => enhance security
Differential Setting Review

- Use of 2\textsuperscript{nd} harmonic sharing for 2\textsuperscript{nd} harmonic inhibit \implies Superior method to enhance security
Overexcitation

A) G

B) S

S - POWER SYSTEM
Relay restrains over the voltage range of 104-138% of rated excitation

![Graph showing the relationship between magnetizing current and harmonic components at different voltages.

- $I_1$ (% of $I_m$)
- $I_3$ (% of $I_1$)
- $I_M$ (% of $I_n$)
- $I_5$ (% of $I_1$)
- $I_7$ (% of $I_1$)

Voltage in percent of nominal voltage vs. magnetizing current and harmonic components.}
Bus/Transformer Application
Bus/Transformer Application
CT Error Produces Incorrect Operation

OPERATING

OPERATING ZONE

SINGLE-FEED LINE

OPERATING POINT

MAXIMUM RESTRAINT

20A

20A
Ground Differential

87N
Neutral Overcurrent
Sudden Pressure Protection

- Operates on rate of change in gas or oil pressure
- Detects incipient low magnitude faults
- Protects for faults differential may not see
- Backs up differential for high magnitude internal faults
- Users are split between using sudden pressure for trip or alarm
Sudden Pressure Relay Mounted in Gas Space

1 SUDDEN PRESSURE RELAY
2 TRANSFORMER TANK
3 INSULATING OIL LEVEL
4 MAIN PORT
5 BELLOWS
6 GAS CUSHION
7 SNAP SWITCH
8 EQUALIZER PORT
Thank You