Transformer Auxiliary Protective Devices

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Agenda

Intro:
- Common Relay Protection (87, 50/51)
- Other Relay Protection (24, REF, 87Q)

Blind Spots in Transformer Protection

Auxiliary Protection:
- Oil Level Gauges (71)
- Thermal Protection (26, 49)
- Sudden Pressure Relays (63)
- Gas Accumulators and Buchholz Relays (33, 63)
- Dissolved Gas and Moisture Monitors
- Bushing Monitors
Relay Protection of Transformers

Common Relay Protection of Transformers:
- 87T Differential
- 50/51, 51G Overcurrent
- 86T Lockout Relay

Other Relay Protection:
- 24 Volts/Hertz
- REF Restricted Earth Fault
- 87Q Negative Sequence Differential

Other Non-Relay Protection:
- Lightning Arrestors
- Protection from Sabotage
## Impact of Faults

<table>
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<tr>
<th>Consideration</th>
<th>Transformers</th>
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<tr>
<td>Frequency of Faults</td>
<td>Low</td>
</tr>
<tr>
<td>Public Safety</td>
<td>Low</td>
</tr>
<tr>
<td>Impact to the System</td>
<td>Medium</td>
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<tr>
<td>Risk of Fire</td>
<td>Very High</td>
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<td>Damage to Adjacent Equipment</td>
<td>Very High</td>
</tr>
<tr>
<td>Cost or Repair</td>
<td>High</td>
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<tr>
<td>Time to Repair</td>
<td>High</td>
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Transformer Faults
Blind Spots in Transformer Protection

87 and 50/51 relays may not be able to detect:

- Turn-to-Turn Faults
- Faults near the star point of a Wye winding

These faults may have negligible current change at the bushings where the current is measured, but they are still faults.

By the time the fault is detectable by the 87, 50/51, it’s probably too late.

Other devices can help:

- Mitigate the blind spots.
- Detect problems with insulation or oil.
- Predict faults, or detect them when they are still small.
- Improve maintenance practices to prevent faults
Oil Level Gauges

- ANSI 71Q
- Usually two stages:
  - Low = Alarm
  - Low-Low = Trip
- Trip before the oil becomes low enough that the top of the core is exposed. Trip before there is a fault.
- Seismic events can be a challenge.
  - Use a time delay, or two gauges on opposite corners with trip wired in series.
**Thermal Devices & Protection**

ANSI 26 – Apparatus Thermal Device  
ANSI 49 – Machine or Transformer Thermal Relay

ANSI 26 and 49 often confused:  
- 49 is reserved to be the temperature of the current-carrying element  
  - For a transformer 49 = Winding Hot-Spot Temperature  
- 26 is anything else related to the equipment temperature  
  - For a transformer, 26 = Oil Temperature (Top Oil, Bottom Oil)

Common designations:  
49W (winding temp)  
26Q (oil temp)
Thermal Considerations

Causes:
- High ambient temperature
- Cooling system failure
- Overload
- Slow clearing of faults
- Abnormal system conditions (low frequency, high voltage, harmonics)

Results:
- Shortens transformer life
  - Rule of thumb: 2x aging for every 6% above nominal temp
- Creates gasses in the transformer oil
- Extreme overheating can cause immediate insulation failure or heating of oil beyond its flash point
Thermal Devices & Protection

ANSI 26 – Apparatus Thermal Device
ANSI 49 – Machine or Transformer Thermal Relay

ANSI 26Q is a simple thermometer or RTD device.

ANSI 49W is more complex. Options include:

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.
Thermal Devices & Protection

Source: www.reinhausen.com
Thermal Devices & Protection

ANSI 26 – Apparatus Thermal Device
ANSI 49 – Machine or Transformer Thermal Relay

26 and/or 49 devices often have multiple set points (stages):

- Stage 1 = turn on cooling
- Stage 2 = turn on more cooling
- Stage 3 = alarm
- Stage 4 = trip (optional)
Thermal Devices & Protection
ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

NOT actually 49W.

- Top Oil is an indication of long-term winding temperature.
- Least accurate and slowest response time.
- May be adequate for small transformers.
ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

Commonly called WTI (Winding Temperature Indication).
Simulates the temperature of the winding using:

- Current
- Oil Temperature
Winding Temperature Indication – Oil Well

Source: IEEE C37.91-2008 Figure D.2
Winding Temperature Indication – Thermal Plate

Source: www.qualitrolcorp.com
CLASS ONAN/ONAF/ONAF 3-PHASE 60 HZ SER. NO WT00856
MVA 32/42.67/53.33 CONT. TEMP. RISE 65° C
HV 117875GRDY/68060 VOLTS BIL 450 KV
LV 6900 VOLTS BIL 150 KV
HV NEUTRAL IMPEDANCE % AT 117875-6900 VOLTS AND 32.0 MVA

TYPE OF CORE CONSTRUCTION:
3 LEGGED CRUCIFORM

ELEVATION TO TOP OF CORE: 116°

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C800
CT: A, B, C, D, E
THERMAL RATING FACTOR = 2.0

CURRENT RATIO TAP CURRENT RATIO TAP
100:5 X2-X3 600:5 X2-X4
200:5 X1-X2 800:5 X1-X4
300:5 X1-X3 900:5 X3-X5
400:5 X4-X5 1000:5 X2-X5
500:5 X3-X4 1200:5 X1-X5

BUSHING CURRENT TRANSFORMER
MULTI-RATIO RELAYING
ACCURACY CLASS C400
CT: G, H, J, K, L, M, N, P
THERMAL RATING FACTOR = 2.0

CURRENT RATIO TAP CURRENT RATIO TAP
600:5 X3-X4 3000:5 X2-X4
1000:5 X4-X5 4000:5 X2-X5
1600:5 X3-X4 4400:5 X1-X3
2000:5 X2-X3 6000:5 X1-X5
400:5 X2-X3 6000:5 X1-X5

BUSHING CURRENT TRANSFORMER
CT: W FOR WINDING TEMP. EQUIP.
4700:5 RATIO CLASS C400
THERMAL RATING FACTOR = 2.0

HIGH VOLTAGE TAPCHANGER
DE-ENERGIZED OPERATION
VOLTS L-L AMPs AT 53.33 MVA POS CONNECTS
123775 249 A 3 - 4
120825 255 B 4 - 2
117875 261 C 2 - 5
114925 268 D 5 - 1
111975 275 E 1 - 6

LOW VOLTAGE
VOLTS L-L AMPs AT 53.33 MVA
6900 4462

FOR STEP UP OPERATION

APPROXIMATE WEIGHTS LBS.
CORE & COIL (UNTANKING WEIGHT) 81000
ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

Mathematical model.

- Uses current and heat transfer theory (differential Equations).
- Can be done economically in relay-grade devices.

Source: www.selinc.com
Winding Temperature Indication – Thermal Plate

Source: IEEE C37.91-2008 Figure D.6
RTDs (Resistance Temperature Detector)

- RTDs are preferred over Thermocouples for measuring temperature.
- Platinum RTD most common
- Older transformers may have Copper RTDs
- 4-wire connections preferred
- 3-wire connections are more common and are acceptable IF the resistance of all three wires is identical.
- RTDs are used for measuring oil temp and ambient temp, but cannot be used for measuring Winding temp.

ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

Fiber Optics

- Allows placement of temperature measurement in the winding.
- Only way to truly measure the winding temperature.

Source: www.selinc.com
Fiber Optic Winding Temperature Measurement

ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

Thermal models make assumptions:

- Assumes the hot spot location based on design.
  - Variances in manufacturing are not detectable.
- Assumes the heat flow based on design modeling and design tests.
- Assumes the hot spot is in the LV winding; may not be valid for all taps.
- Assumes the cooling system is operating perfectly.
  - Calculated hot spot may be able to detect cooling system failures, or modify set points based on cooling system status.
ANSI 49W Hot Spot Options

Options for 49W Hot Spot Temperature

- Approximated hot spot based on Top Oil Temperature.
- Simulated hot spot using an Oil Well.
- Simulated hot spot using a gauge with a Thermal Plate.
- Calculated hot spot using real-time modeling.
- Direct measurement of the winding temperature using Fiber Optics.

Direct measurement is dependent on F/O Probe locations
ANSI 49W Hot Spot Options

Typical accuracy expectations:

- 15% Approximated hot spot based on Top Oil Temperature.
- 8% Simulated hot spot using an Oil Well.
- 8% Simulated hot spot using a gauge with a Thermal Plate.
- 2% Calculated hot spot using real-time modeling.
- 1% Direct measurement of the winding temperature using Fiber Optics.

Compare the accuracy expectations to some typical settings:

- 70°C Fan Stage 1
- 80°C Fan Stage 2
- 110°C Alarm
- 120°C Trip

Conclusion: Lower accuracy methods might be okay for cooling system control, but are probably insufficient for protection.
Sudden Pressure Relays

Also known as: Rapid Pressure Rise Relay, Fault Pressure Relay

ANSI 63 (63SPR, 63RPR, 63FP)
Sudden Pressure Relays

Arcing in mineral oil causes gas bubbles.
- The bubble has a much larger volume than the oil that gasified.
- This results in a very small but very rapid change in pressure.

63SPR immune to actual tank pressure due to temperature or other factors.

Source: www.electrical-engineering-portal.com
Sudden Pressure Relays

63SPR is one of the fastest transformer protection devices.

Especially useful in transformers that have less sensitive 87 (larger blind spot) such as Phase Shifter or Grounding Bank.

Installed in Oil or in the Gas layer at the top of the transformer.

- *Not interchangeable! Must use the right 63SPR.*

Different than Pressure Relief Device (63PRD).

Modern 63SPR very different than old Static Pressure Relays.
Sudden Pressure Relays

Challenges:
- False operations on high-current through faults due to windings moving.
- False operations due to operating valves or pumps.

Solutions:
- High-current blocking schemes.
- SPRs on opposite corners, wired in series.
- Installation designed by transformer manufacturer rather than as a field retrofit.

Due to bad experiences long ago, some utilities:
- Use 63SPR only as an alarm, not trip.
- Use three 63SPRs in a 2-out-of-3 voting scheme.
- *May be time to revisit the issue and give 63SPR another chance.* 63SPR is valuable and high-speed protection, and it is reliable and secure if used correctly.
Sudden Pressure Relays

Control circuits for sudden pressure relays

- Trip seal-in
- Guard scheme
- Targeting

Source: IEEE C37.91-2008 Figure 29
Sudden Pressure Relays – New Developments

87Q Negative Sequence Differential
- Can be used for better sensitivity for turn-to-turn faults.
- May prove to be as effective as sudden pressure relay.

NERC Compliance
- NERC has gone back and forth as to whether or not 63SPR will be included as a Protective Relay under PRC-005.
- Typically NERC has only been concerned with devices that measure electrical quantities (voltage, current), and has excluded mechanical devices. But they have specifically called for 63SPR testing and maintenance.
- Regardless of NERC – Commission and periodically test your 63SPRs! It’s the right thing to do.
NERC Terminology

History:
- SPR – Westinghouse term. Also used by IEEE.
- RPR – Qualitrol term for SPR.
- Buchholz – Named after Max Buchholz who patented the relay in 1921

NERC:
- SPR = A relay mounted in the gas layer
- RPR = A relay mounted under oil
- Buchholz = Buchholz Relay
Buchholz Relay

Often mistakenly considered to be a 63SPR, but actually a very different device.

Buchholz relay ONLY applies to a transformer with a Conservator.

Source: www.electrical4u.com
Buchholz Relay

Sources: www.pbsigroup.biz, elecinfo2all.blogspot.com
Buchholz Relay

Gas Accumulator
- Gas in the transformer rises through the tank, and is trapped (accumulated) in the Buchholz.
- Typically for Alarming, not tripping.
- May need to be occasionally bled off. Gas volume should be recorded, and gas can be tested.

High Oil Flow Rate
- Operates flap in the Buchholz to Trip.

Source: www.totalpowersystem.blogspot.com
Buchholz Relay

Requires the same seal-in, guard, target circuitry as 63SPR.

Issues:

- Difficult to test due to location.
- Gas accumulator usually easier to test than the flow rate switch.
Dissolved Gas Analysis/Monitoring

Traditional utility practice:

- Oil sample taken periodically and sent to the lab for a DGA.
- May perform a DGA after a transformer trip.
- *Not much for the Relay Tech to do.*

New utility practice:

- Real-time online DGA with continuous monitoring.
- Data for event analysis, trending, and troubleshooting.
- Possible to use for protective functions (but most commonly just for alarming).
- *Becoming more part of the Relay Tech responsibilities.*
Dissolved Gas Analysis

Moisture ($H_2O$) and Carbon Dioxide ($CO_2$) are indications of possible:
- Contaminated oil
- A failed oil preservation system
- A leak in the sealed tank.

Hydrogen ($H_2$), Carbon Monoxide (CO), Methane ($CH_4$), Ethylene ($C_2H_4$), Ethane ($C_2H_6$), Acetylene ($C_2H_2$) are indications of transformer problems:
- Overheating
- Arcing or partial discharge
Dissolved Gas Analysis

Relative ratios of dissolved gas concentrations indicate the type of problem.

Source: Morgan Schaffer
Dissolved Gas Analysis

Summary:
- Hydrogen is always present for any fault situation.
- Gas alarming (or tripping) can be based on:
  - $H_2$ only or TDCG (Total Dissolved Combustible Gas).
  - Total amount (ppm) or rate of change.
- Alarm/Trip action could be different based on the ratios of the gasses.

### Dissolved fault gases

<table>
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<tr>
<th>Dissolved fault gases</th>
<th>Corona</th>
<th>Overheating</th>
<th>Arcing</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Insulation</td>
<td>Oil</td>
</tr>
<tr>
<td>Hydrogen (H2)</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>Low</td>
<td>Traces</td>
<td>Medium</td>
</tr>
<tr>
<td>Ethane (C2H6)</td>
<td>Traces</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Ethylene (C2H4)</td>
<td>High</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Acetylene (C2H2)</td>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Source: Morgan Schaffer
Bushing Monitors

Leakage Current
Power Factor
Capacitance Value

Similar to DGA in that:

- Historically a periodic test performed by substation maintenance crews.
- Newer technology implementing real-time online continuous monitoring.

Source: www.mte.ch
ANSI Device 86 – Lockout Relays

Most protective devices trip 86 to lockout the transformer.
- Blocks closing. Requires reset (usually manual).

Transformer cooling systems may have an 86 cutout
- Stops the fans and oil pumps when the 86 trips.
- Prevents a larger fire or spreading of oil if there is a tank rupture.
- Over-temperature (26Q, 49W) devices must NOT trip the 86 and stop the cooling.
Conclusions and Comments

- Relay Techs and Protection Engineers need to have a working knowledge of transformer auxiliary devices.
  - Especially if it’s a tripping device (e.g. 63SPR and Buchholz).
- Increased use of intelligent devices and integration of data
  - More aligned with Relay Tech skills and tools compared to Substation Maintenance.
  - May become more built-in protective relay functions (e.g. 49W)
- Devices need to be commissioned and maintained.
  - Regardless of NERC mandates.
- Control circuitry, targeting, event reporting, lockout relays need to be designed correctly, commissioned, and periodically tested.
  - Regardless of NERC mandates.
Thank You

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