3AC ENGINEERING

Transformer Auxiliary Protection Devices

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Presented at the
36th Annual Hands-On Relay School
March 11-15, 2019

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 (80)
  - 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 (over-excitation)
  - REF Restricted Earth Fault
  - 87Q Negative Sequence Differential

- Other Non-Relay Protection:
  - Lightning Arrestors
  - Protection from Sabotage

Transformer Faults

Consideration	Transformers
Frequency of Faults	Low
Public Safety	Low
Impact to the System	Medium
Risk of Fire	Very High
Damage to Adjacent Equipment	Very High
Cost or Repair	High
Time to Repair	High

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 at the bushings where the current is measured, but they are still faults. By the time this type of fault is detectable by the 87, 50/51, it is probably too late.

- Other devices can help…
  - Mitigate the blind spots
  - Detect problems with insulation or oil before there is a fault
  - Predict faults, or detect them when they are still small
  - Improve maintenance practices to prevent faults

Auxiliary Protective Devices

- Oil Level Gauges (71)
- Thermal Protection (26, 49)
- Sudden Pressure Relays (63)
- Gas Accumulators and Buchholz Relays (80)
- Dissolved Gas and Moisture Monitors
- Bushing Monitors

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 (before there is a fault)
- Seismic events can be a challenge
  - Use a time delay
  - Use 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 are often confused:
  - 49 is for 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: 26T, 49T
- Preferred Designations: 26Q, 49W

Thermal Devices & Protection

- Causes of Temperature Problems:
  - 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 26Q – Apparatus Thermal Device
- ANSI 49W – Machine or Transformer Thermal Relay

- 26Q and/or 49W 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 26Q – Apparatus Thermal Device
- ANSI 49W – Machine or Transformer Thermal Relay

- ANSI 26Q is a simple thermometer or RTD

- 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

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

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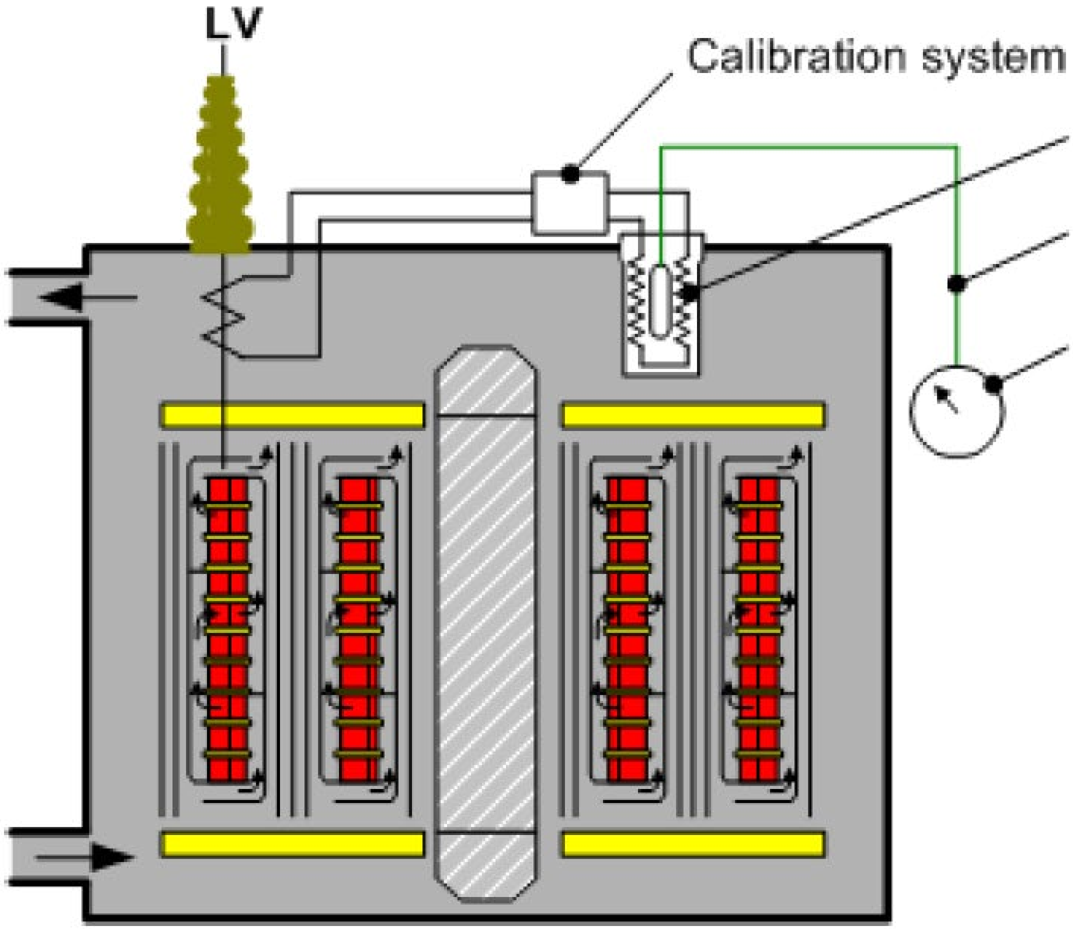
- Commonly called WTI (Winding Temperature Indication)
- Simulates the temperature of the winding using:
  - Current
  - Oil Temperature

ANSI 49W Hot Spot Options

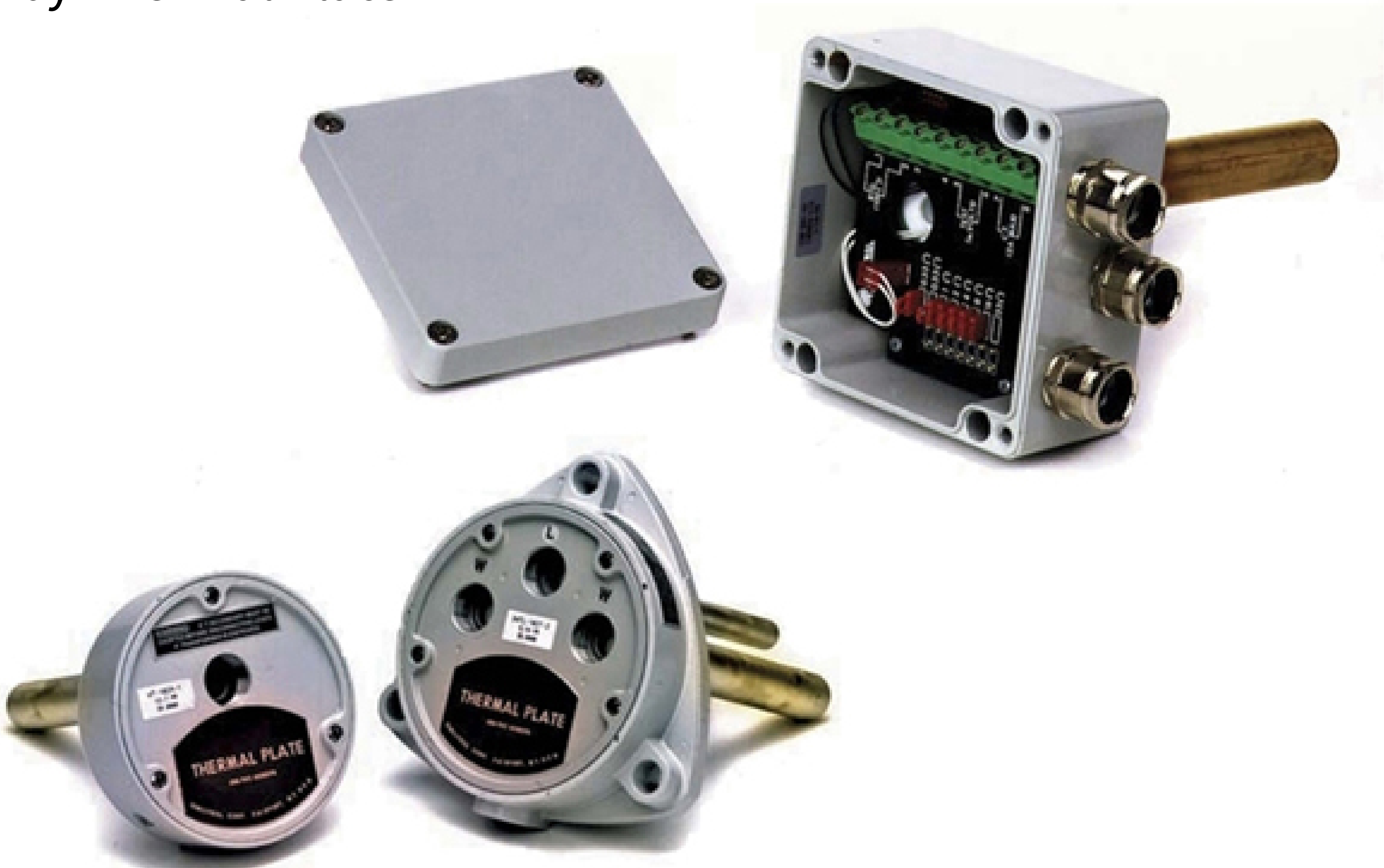
WTI by Oil Well



Source: IEEE C37.91-2008 Figure D.2

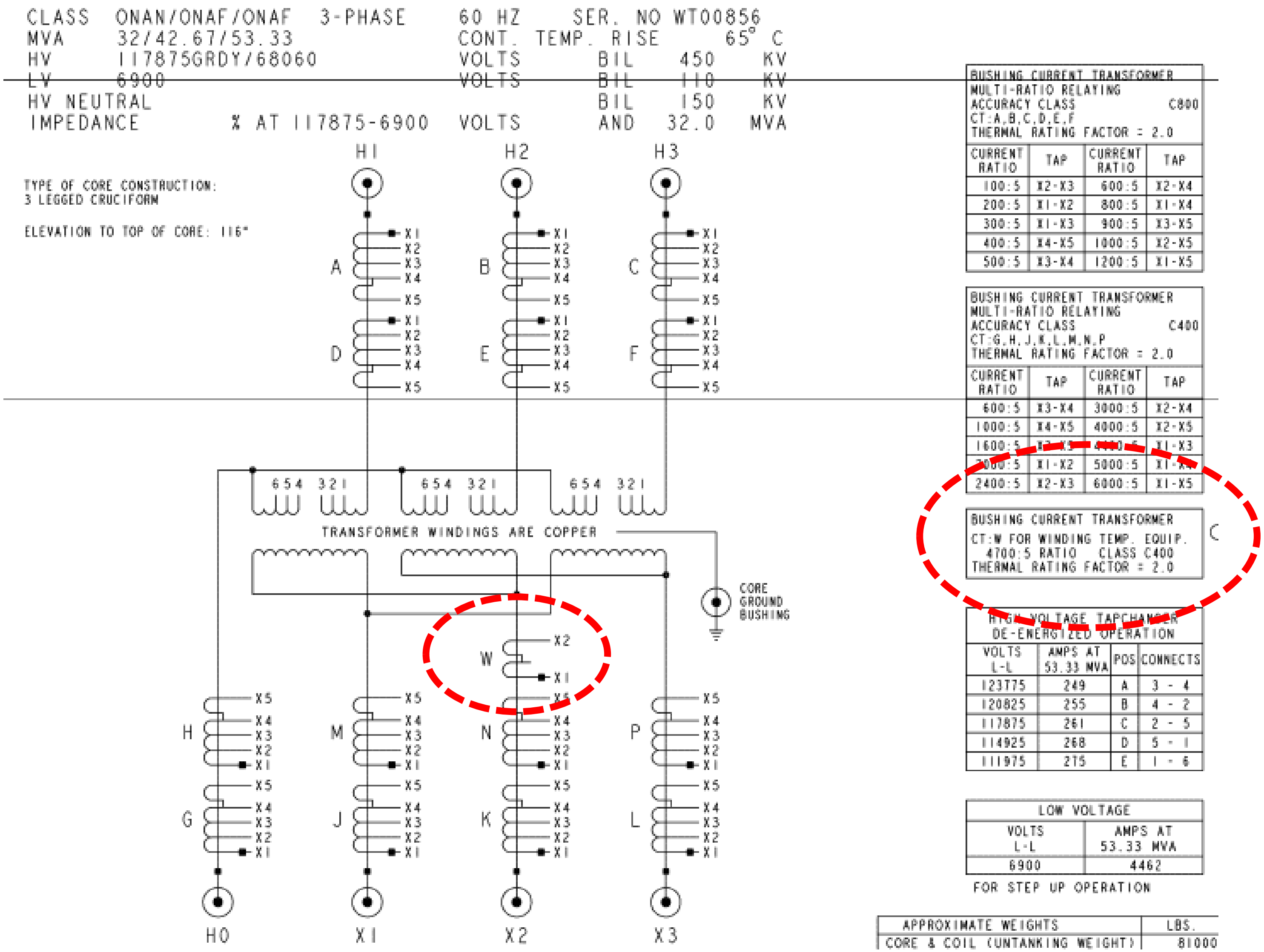
ANSI 49W Hot Spot Options

WTI by Thermal Plate



Source: www.qualitrolcorp.com

ANSI 49W Hot Spot Options



ANSI 49W Hot Spot Options

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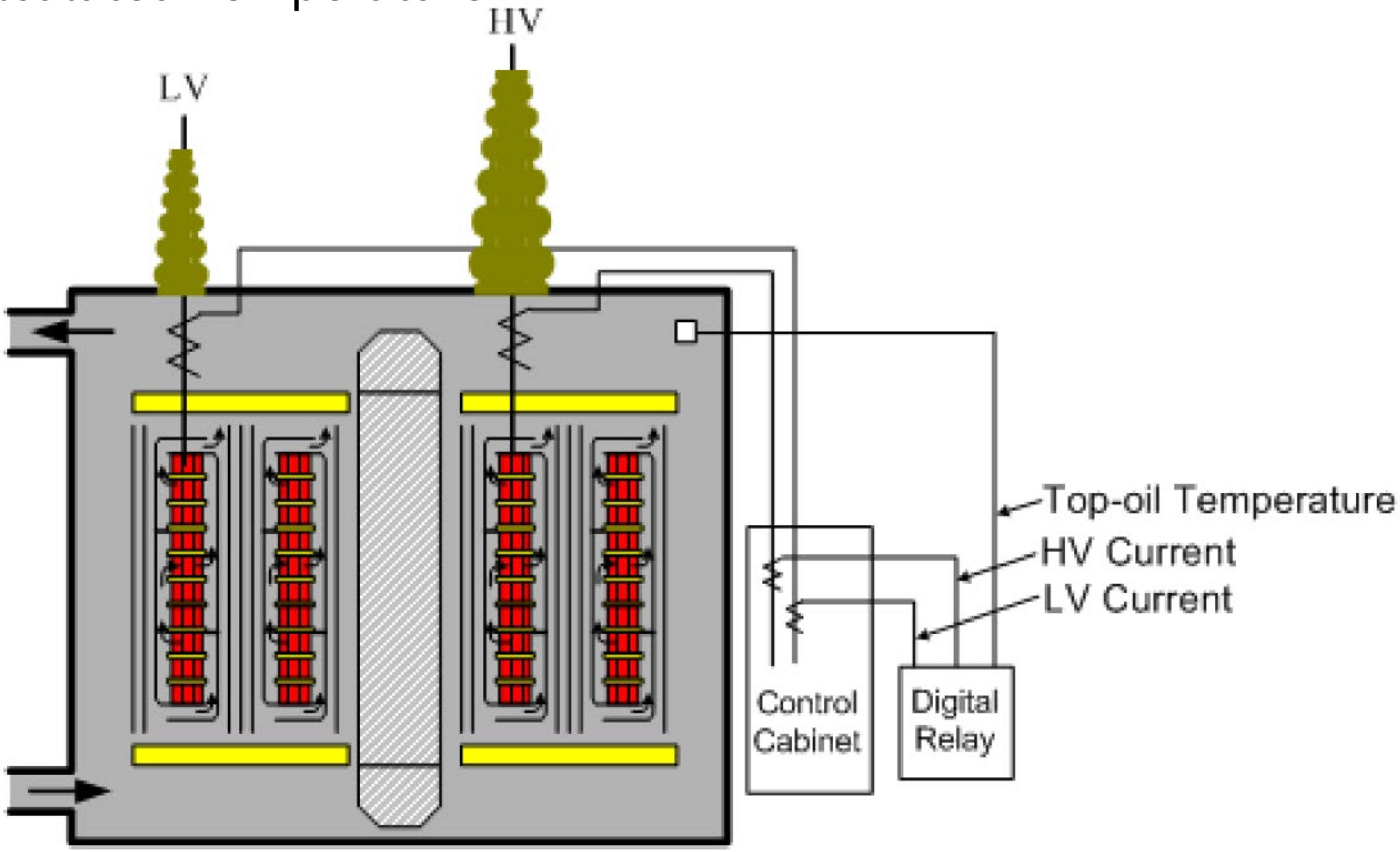
  - Direct measurement of the winding temperature using Fiber Optics

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

Source: www.selinc.com

ANSI 49W Hot Spot Options

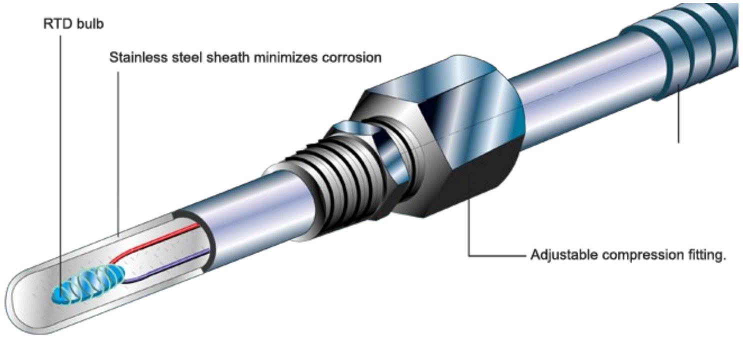
Calculated Temperature



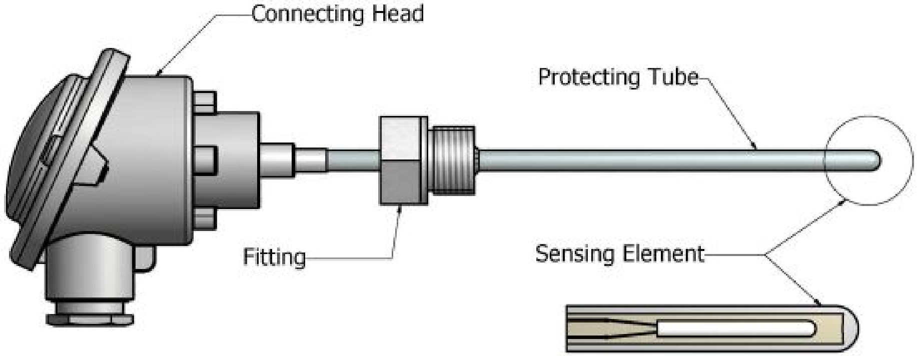
Source: IEEE C37.91-2008 Figure D.6

ANSI 49W Hot Spot Options

- 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
    - Resistance of all three wires must be identical
  - RTDs are used for measuring oil temp and ambient temp… but cannot be used for measuring winding temp



Graphics Sources: www.instreng.com, www.tutco.com

ANSI 49W Hot Spot Options

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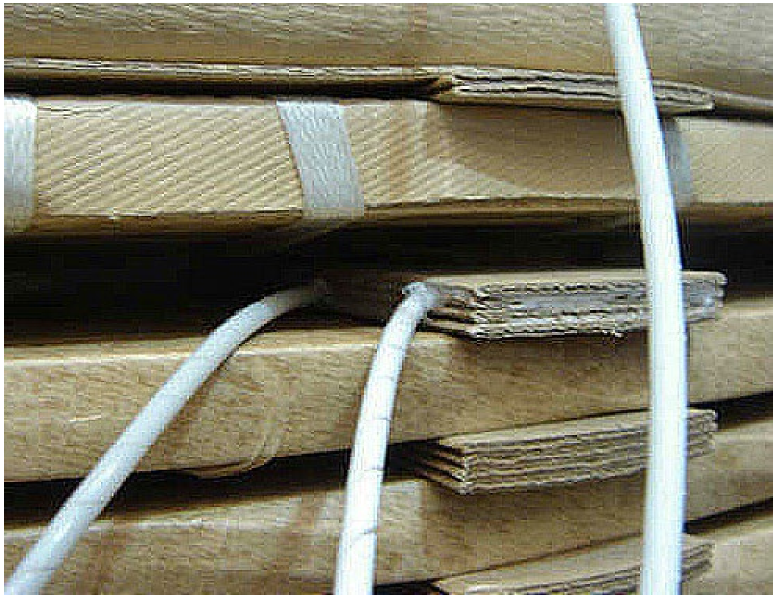
  - Simulated hot spot using a gauge with a Thermal Plate
  - Calculated hot spot using real-time modeling
  - <u>Direct measurement of the winding temperature using Fiber Optics</u>

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

ANSI 49W Hot Spot Options



Sources: www.deltastar.com, www.sarsash.com.au, www.qualitrolcorp.com

ANSI 49W Hot Spot Options

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  - 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

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  - Calculated hot spot using real-time modeling
  - <u>Direct measurement of the winding temperature using Fiber Optics</u>

- Direct measurement is dependent on F/O Probe locations
  - Assumes the probe is located at the hottest spot of the winding

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

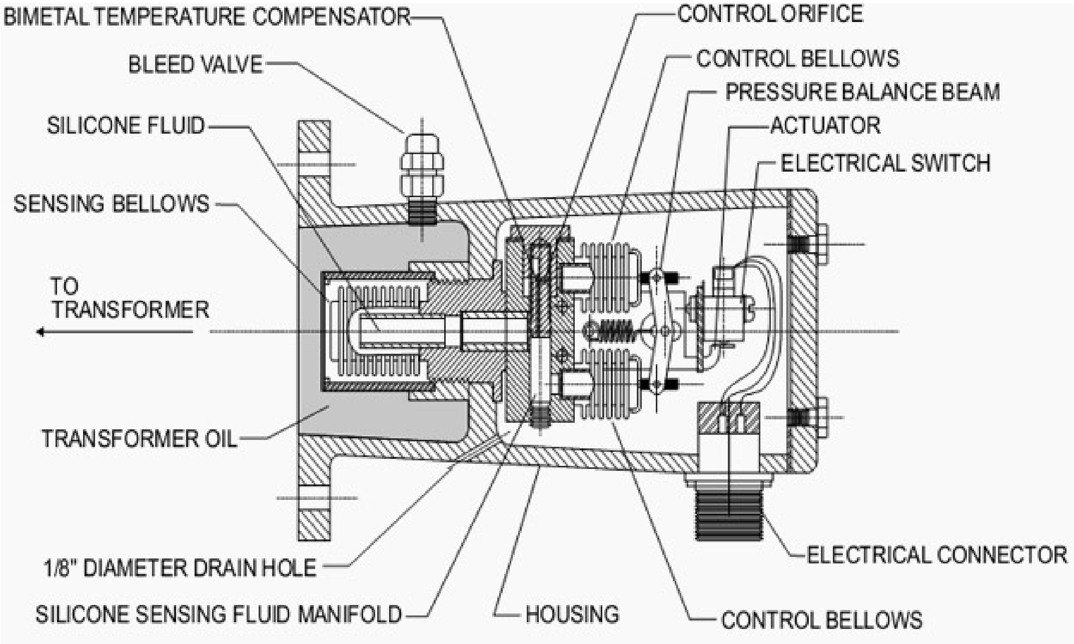
Conclusion: Lower accuracy methods might be okay for cooling system control, but are probably insufficient for protection

Sudden Pressure Relays

- Also known as: Rapid Pressure Rise Relay, Fault Pressure Relay
- ANSI 63 (63SPR, 63RPR, 63FP)
- Not the same as a Pressure Relief Device (63PRD)

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 (shock wave)
- 63SPR is immune to actual tank pressure due to temperature or other factors



Source: www.electrical-engineering-portal.com

Sudden Pressure Relays

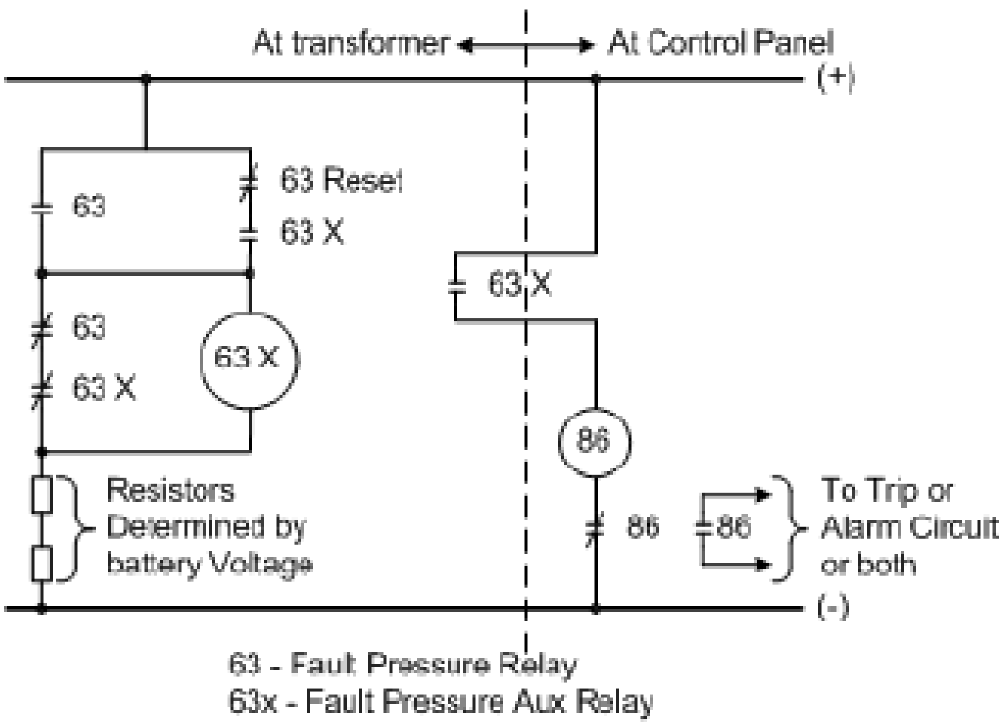
- 63SPR is one of the fastest transformer protection devices
- Especially useful in transformers that have less sensitive 87 (larger blind spot) such as Phase Shifter or Grounding Bank
- Installed in Oil or in the Gas layer at the top of the transformer
  - Not interchangeable; must use the right 63SPR
- Modern 63SPR very different than old Static Pressure Relays

Sudden Pressure Relays

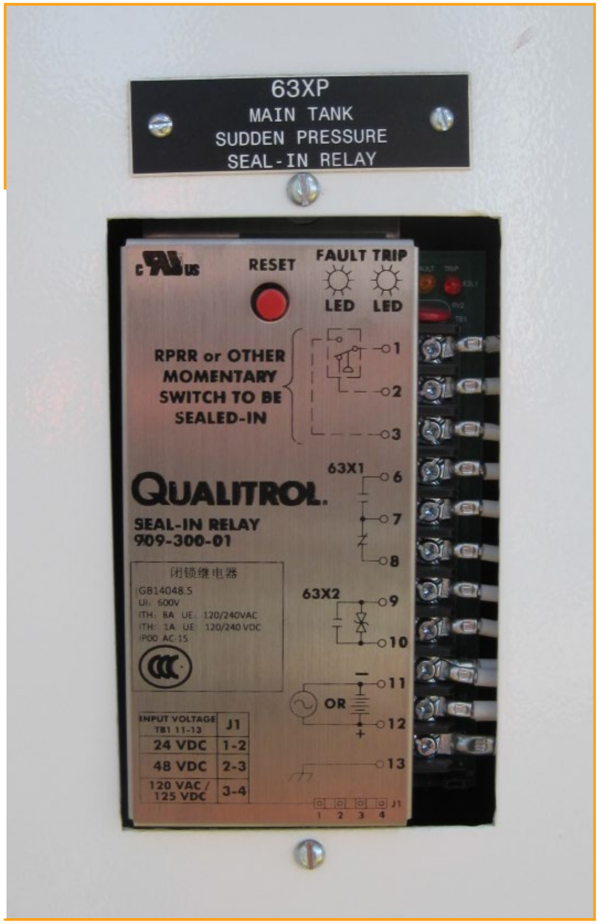
- Challenges:
  - False operations on high-current through faults due to windings moving
  - False operations due to operating valves or pumps
- Solutions:
  - High-current blocking schemes
  - SPRs on opposite corners, wired in series
  - Installation location determined by the transformer manufacturer
    - Retrofits may be more prone to misoperations
- 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

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

- NERC Compliance

NERC Terminology

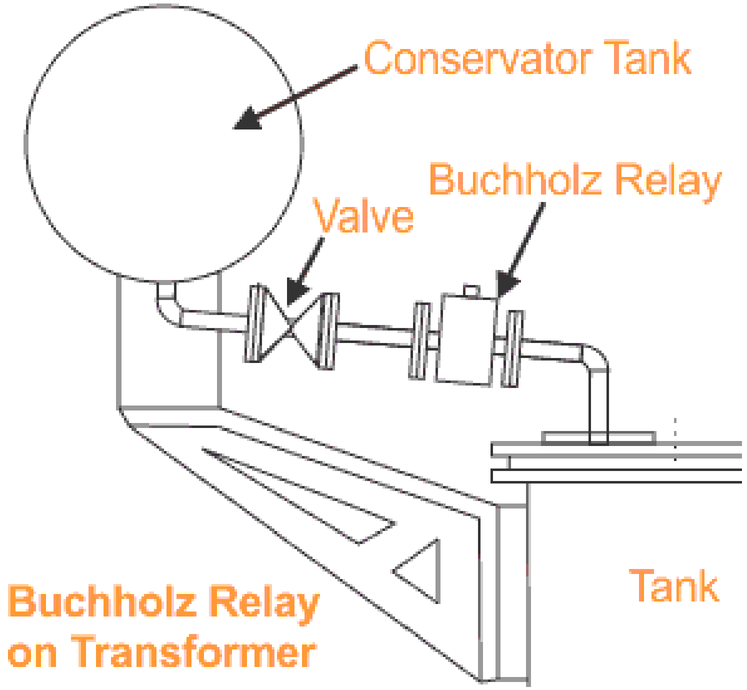
- History:
  - SPR – Westinghouse term; also used by IEEE
  - RPR – Qualitrol term for SPR
  - Buchholz – Named after Max Buchholz who patented the relay in 1921

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

Buchholz Relay

- Buchholz relay ONLY applies to a transformer with a Conservator

- Often mistakenly considered to be a 63SPR, but actually a very different device
  - May be labeled 63BCH
  - Should be labeled 80BCH (or possibly 33BCH)

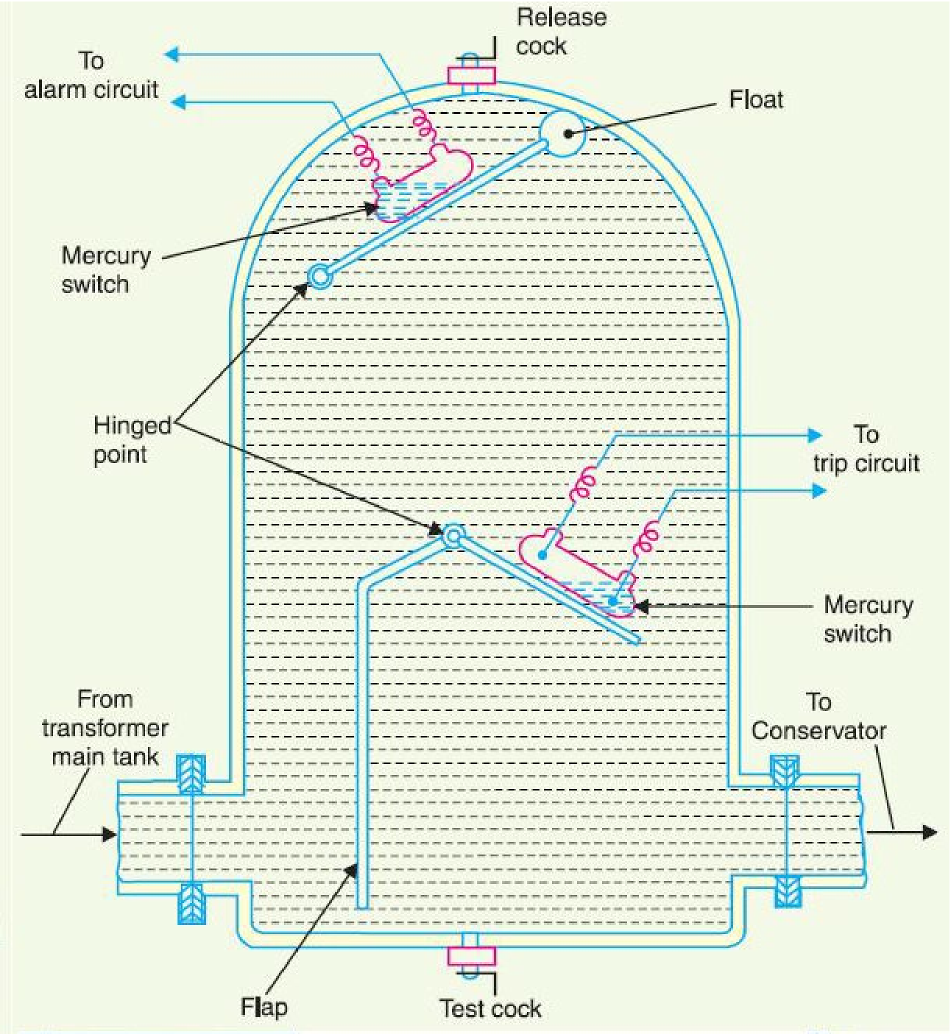


Source: www.electrical4u.com

Buchholz Relay

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

Buchholz Relay



Source: www. totalpowersystem.blogspot.com

- Gas Accumulator - Alarm
  - Gas in the transformer rises through the tank, and is trapped (accumulated) in the Buchholz
  - May need to be occasionally bled off; gas volume should be recorded and gas can be tested
- Rapid Oil Flow Rate - Trip
  - Operates flap in the Buchholz to Trip

Buchholz Relay

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

- Maintenance Issues:
  - Difficult to test due to location
  - Gas accumulator usually easier to test than the flow rate switch
  - Plunger tests the electrical contacts, but not the actual flow vane

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*

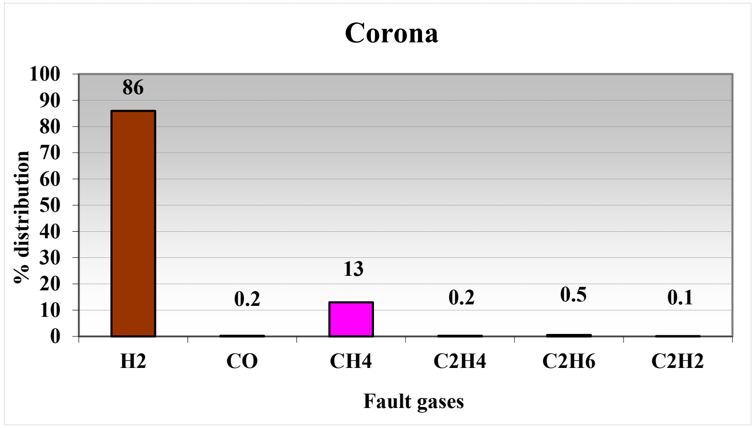
- New utility practice:
  - Real-time online DGA with continuous monitoring
  - Data for event analysis, trending, and troubleshooting
  - Possible to use for protective functions (but most commonly just for alarming)
  - *Becoming more part of the Relay Tech responsibilities*

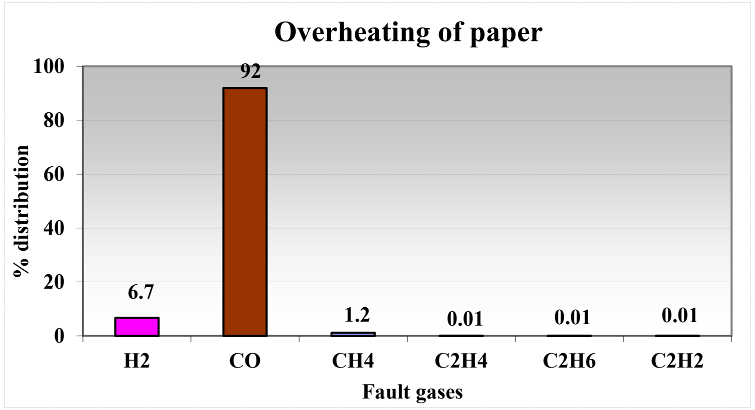
Dissolved Gas Analysis

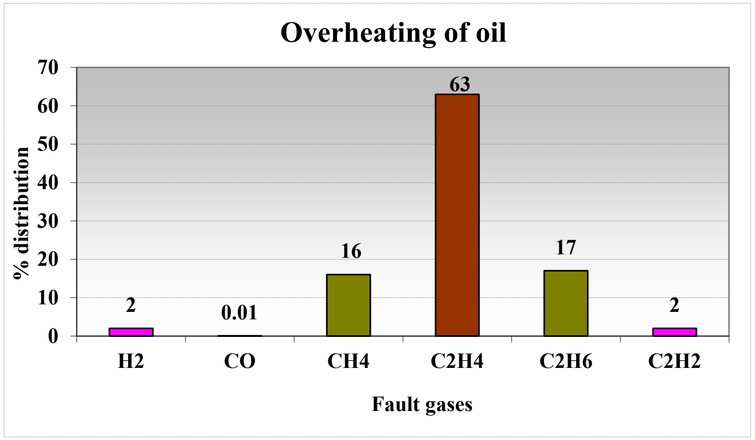
- Moisture (H_2O) and Carbon Dioxide (CO_2) are indications of:
  - Contaminated oil
  - A failed oil preservation system
  - A leak in the sealed tank

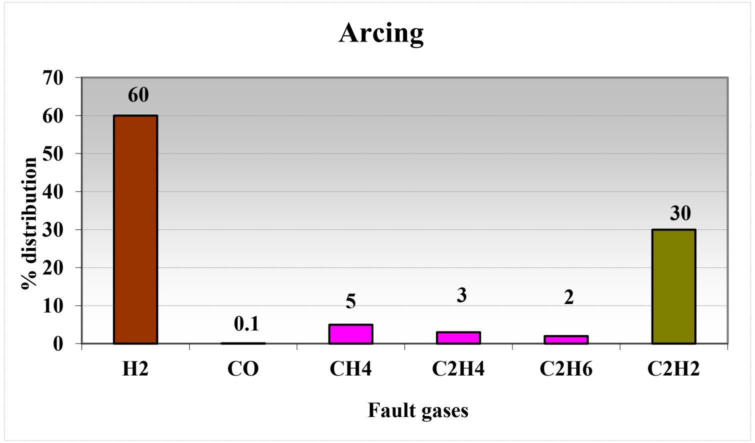
- Hydrogen (H_2), Carbon Monoxide (CO), Methane (CH_4), Ethylene (C_2H_4), Ethane (C_2H_6), and Acetylene (C_2H_2) are indications of transformer problems:
  - Overheating
  - Arcing or partial discharge
  - Insulation breakdown

Dissolved Gas Analysis









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

Source: Morgan Schaffer

Dissolved Gas Analysis

Dissolved fault gases	Corona	Overheating		Arcing
		Insulation	Oil	
Hydrogen (H2)	High	Low	Low	High
Carbon monoxide (CO)		High		
Methane (CH4)	Low	Traces	Medium	Low
Ethane (C2H6)	Traces		Medium	Low
Ethylene (C2H4)			High	Low
Acetylene (C2H2)			Low	Medium

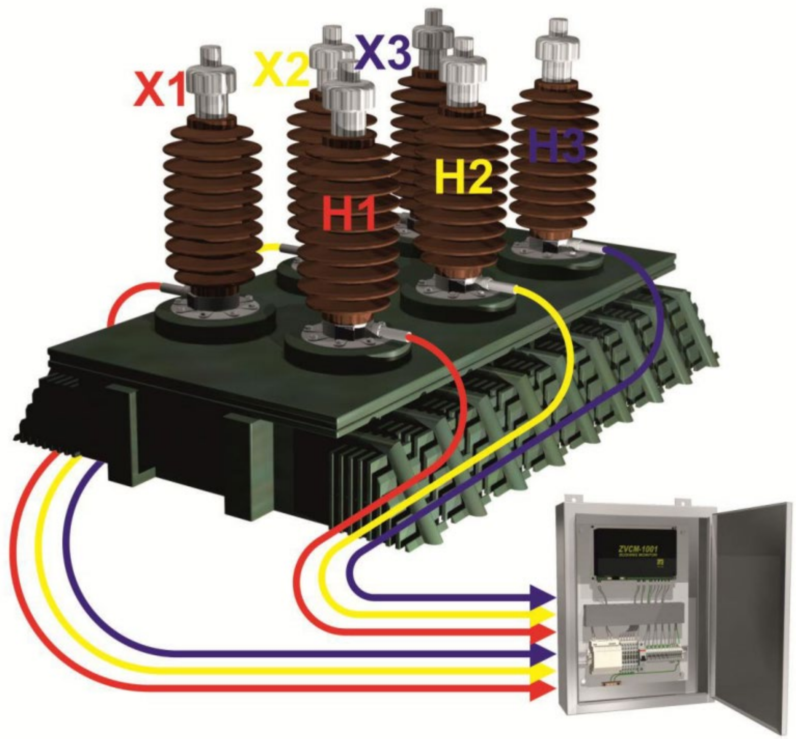
- Summary:
  - Hydrogen is always present for any fault situation.
  - Gas alarming (or tripping) can be based on:
    - H_2 only or TDCG (Total Dissolved Combustible Gas).
    - Total amount (ppm) or rate of change.
  - Alarm/Trip action could be different based on the ratios of the gasses.

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

Surge Arrestor Monitors

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 is a tripping device (e.g. 63SPR or 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

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