# **Transformer Basics - Why Temperature is Important**

Trent Williams Application Engineer

# **Transformer Basics**

- Paper Insulation Deteriorates at Elevated Temperatures
- Temperature Limits the Ability to Load a Transformer
- Higher Temperatures Lead to Gas Evolution and Insulation Damage

- Maximum Ambient per the IEEE Standard is 40° C (104°F)
- Allowable Temperature Rise of Top Oil above Ambient is Either 55 or 65° (131°F)
- Maximum Top Oil Temperature Is Either 95 or 105°
  C (221°F)
- Allowable Winding Rise Above Ambient per the IEEE Standard is 80° C (176°F)
- > Maximum Winding Temp Rise 120° C (248°F)

# Your Cooling System Is Designed for these Temperatures!

# How Does Temperature Affect Insulation?

- The Degree of Polymerization (DP) Indicates Paper Insulation Health
- > DP Decreases with Exposure to High Temperature
- Initially Paper Has a DP of 1000 to 1200<sup>1</sup>
- > At End of Life DP Will Be About 125
- Once DP Is Zero, any Through Fault Could Cause Movement which may result in Dielectric Failure

# **Bubble Formation**

- > All Transformers Have Some Moisture
- Bubble Formation Is the Generation of Water Vapor
- Bubble formation Occurs at Temperatures of 140° C
- Bubble Formation Leads to Transformer Failure





**Transformer Basics** 

# **Heat Sources**

Overcurrent

# **Heat Sources**

- Overcurrent
- Harmonics or DC Offset

# **Harmonics and DC Offset**

- Variable Speed Drives, Furnaces, Computer.
- Geomagnetically Induced Current
  - Solar Mass Ejections
  - Disturbance of Earth's Magnetosphere
  - Induced in Long Transmission Lines
  - NERC TPL-007-1 Over 200KV

# **Heat Sources**

- Overcurrent
- Harmonics or DC Offset
- Overvoltage

# **Overvoltage**

- System Voltage Problems
- Wrong Tap Selection
- Core Saturation Results in Overcurrent and Overheating

# **Heat Sources**

- Overcurrent
- Harmonics or DC Offset
- Overvoltage
- Internal Problems

# **Internal Problems**

- Not Detected by Gauge
  - Shorted Core Laminations
  - Inadvertent Core Ground
  - Case or Other Metal in Magnetic Field
  - Arcing

# **Heat Sources**

- Overcurrent
- Harmonics or DC Offset
- Overvoltage
- Internal Problems
- LTC Problems

# **LTC Problems**

- Contact Problems
  - Mainly Older LTC's
  - Coking of Contacts
  - Eventually Leads to Failure in LTC
  - Can Fail Transformer
  - Can be Detected if LTC is Monitored

# **Heating Sources**







• Fans will aid cooling – ONAF





- Fans will aid cooling ONAF
- Adding an oil pump will further enhance cooling OFAF
- Cooling Provides More Load Capability





- Adding directed oil flow further enhances cooling DFOA or ODAF
- Baffles direct oil into the coils for greater cooling
- Design Has a small Gradient

- Keep your transformers hot and dry
- Don't touch your transformers unless absolutely necessary
- Use Predictive Maintenance
  - ✓ Monitor your temperatures
  - ✓ Let automatic controls operate cooling
  - Be proactive in exercising the cooling system
  - ✓ Use antisipatatory cooling
  - ✓ Monitor your load tap changers
  - ✓ Monitor gases
  - ✓ Monitor your bushings

- Electric Power Transformer Engineering, 3<sup>rd</sup> edition, CRC Press, Chapter 24, On-Line Monitoring of Liquid-Immersed Power Transformers
- IEEE Std C57.143-2012, IEEE Guide for Application for Monitoring Equipment to Liquid-Immersed Transformers and Components
- IEEE Std C57.91-2010, IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators

### **Advanced Power Technologies**

# Advances in Transformer Cooling Control and Monitoring

- > Oil Temperature Measurement
- Hot Spot Temperature Measurement Techniques
- New Strategies for Cooling Control
- Improving Reliability
- Load Tap Changer Condition Monitoring
- Strategies for Remote Communications and Local Monitoring

# **Oil Temperature**



- Time constant (thermal lag) 2 to 3 hours. Responds very slowly.

### **Oil Temperature Measurement**

### **Capillary Tube Technology:**



#### Advantages:

- Inexpensive, Depending on Options
- Simpler to Retrofit

- Not Rugged
- Limited Accuracy
- Limited Telemetry Options
- Limited Flexibility for Control
- No Failure Alarm

### **Oil Temperature Measurement**

# **Electronic Technology:**



### Advantages:

- Rugged
- Superior Accuracy
- Variety of Telemetry Options
- Built-in or Programmable
  Control Logic
- Built-in Device Alarms
- Easy to set

#### **Disadvantages:**

- Can be More Expensive
- Retrofit May be More Difficult

Advanced Power Technologies Hot Spot Temperature Measurement

### **Methods:**

- Hot Spot Measurement by the Heated Well AKA - Simulated Method
- Direct or Fiber Optic Method
- Calculated Method

# **Winding Temperature**



### **Used to Start Cooling**

- Uses CT circuit to react to loading
- Resistive well with either mechanical gauge or RTD
- Does Not React Quickly to Sudden Load Increase

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# **Temperature Probes in Wells**



# **Mechanical Gauges**

# **Heated Well**



# **Sending unit with Heater**



### **Hot Spot Measurement**

## **Simulated Method:**



#### Advantages:

• Low Initial Cost



- No Failure Alarms
- Inherently Inaccurate
- High Replacement Cost
- Limited Telemetry Options
- Limited Control Options
- Slowest Response Time

### Hot Spot Measurement

# **Direct or Fiber Optic Method:**



#### Advantages:

- Direct Hot Spot Measurement
- Telemetry Options
- Can be Most Accurate
- Fast Response Time

- Very High Cost
- Very Difficult to Retrofit
- Fragile, Difficult to Install

## Calculated Method :



#### Advantages:

- Easy Retrofit
- Telemetry Options
- Lowest Maintenance
- Built-in Control Options
- Built-in Failure Alarms

- Not as Accurate as Direct Method
- Requires Access to WTI CT or Bushing CT's
- Slower Response Time

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# **Calculated Method Continued:**

 $T_{Winding_{U}} = T_{RTO} * (Load * CTRatio / RatedLoad)^{2*m} + T_{TopOil}$  [1] Where:

> $T_{Windingv} = Ultimate calculated winding temperature$   $T_{RTO} = Hot Spot Rise over Top Oil temperature at rated load$  Load = Measured load current CTRatio = Primary CT ratio Rated Load = Rated load current m = 1.0 for directed FOA or FOW, 0.8 for all other cooling  $T_{TopOil} = Measured$  Top Oil temperature

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# **Electronic Temperature Monitor Control Options:**



 Set Points for Cooling Controls, Alarms, and Tripping Settable Through the Front Panel or PC

New Strategies For Cooling Control



# **Electronic Temperature Monitor Control Options:**



- Set Points for Cooling Controls, Alarms, and Tripping Settable Through the Front Panel or PC
- Full Programmable Scheme Logic Reduces External Wiring

Advanced Power Technologies New Strategies For Cooling Control

# **Examples of Scheme Logic:**

The outputs are completely programmable:

• Consolidate high temp alarms to control a single output:

OUT1 = SP11 + WSP1

Where SP11 is the top oil temp alarm and WSP1 is the winding temp alarm

- Control an output for fail-safe operation:
  OUT2 = !SP22
- Block operation of pumps in cold climates:
  OUT2 = !SP14 \* (SP12 + WSP1+ LSP1)

Where SP14 is set to operate in Under Temp.

### New Strategies For Cooling Control

# **Electronic Temperature Monitor Control Options:**



- Set Points for Cooling Controls, Alarms, and Tripping Settable Through the Front Panel or PC
- Full Programmable
  Scheme Logic Reduces
  External Wiring
- Built-in Fan Bank Alternate Feature

New Strategies For Cooling Control

### **Electronic Temperature Monitor Control Options:**



- Our Content of Cont
- Monthly, Weekly, Daily Fan Exercising Available
- Command Cooling on Sudden Increase of Load for Pre-Cooling

New Strategies For Cooling Control



New Strategies For Cooling Control

### **Electronic Temperature Monitor Control Options:**



**Universal Power Supplies** 

- Monthly, Weekly, Daily Fan Exercising Available
- Command Cooling on Sudden Increase of Load for Pre-Cooling
- Universal Temperature Probes Ease Retrofit



New Strategies For Cooling Control

### **Electronic Temperature Monitor Control Options:**



**Universal Power Supplies** 

- Monthly, Weekly, Daily Fan Exercising Available
- Command Cooling on Sudden Increase of Load for Pre-Cooling
- Universal Temperature Probes Ease Retrofit
- Alarms When Things Go Wrong.



### **Conventional Wisdom:**



### We Don't Need Electronic Temperature Monitors.

# We Turn On Fans in May and Turn Them Off in October.

### **Conventional Wisdom Debunked:**



- Increases Wear & Tear on Fans
- Running Fans Through the Summer Wastes Energy.
- How Will You Know When There is a High Temperature Alarm?

### Improving Reliability

### **Load Profile:**



The Analysis:

- 24 MVA Unit
- Unit Has Two Stages of Cooling With a Total of 12 fans.
- Each Fan Motor is 1/3 HP Running at 230VAC.
- Used NOAA Data to Extrapolate
- Compared Running Fans Continuously From May Through October vs. Automatic Control.

Improving Reliability

# The Conclussion:

• Fans Run Continuously May-October:

18,243 Kwh

• Fans Automatically Controlled:

6,558 Kwh

• Total Savings:

11,685 Kwh



- Savings Minimal On Units Less Than 18 MVA.
- There Are Big Savings on More Lightly Loaded Units



### LTC Condition Monitoring





• Telemetry Through Analog Outputs

 ASCII Data Through RS-232 For Protective Relays & SCADA

• DNP3.0 or MODBUS For Telemetry, Status and Control

- Report of Min and Max Temperatures
- Data Logging:
  - Rolling Data Log.
  - Data exports as a text file (CSV) to MS Excel.
  - Stores Months of Data Time Stamped Every 60 Min.
  - Selectable Time Base & Points for increased storage.
  - Power back up for clock to ride through outages

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- Retrofitting of Capillary Tube Gauges with Electronic Temperature Monitors (ETM's) is an Economical Option.
- The Benefits of ETM's Outweigh the Drawbacks for use on all New Units.
- ETM's Permit Strategies to Lower Maintenance Costs.
- ETM's Permit Strategies to Improve Transformer Life.
- ETM's Allow Multiple Methods of Temperature Data Acquisition to Facilitate Better Loading Decisions and Forensics.
- An ETM with Top Oil and Winding Temperature Measurement Will Likely Cost Less Than a Mechanical Top Oil Gauge (then you still have to buy the winding gauge, a second well, and the heated well apparatus).

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