Power Transformers Basics
Transformer Basic Objective

• Introduce Basic Transformer Theory as it Relates to Diagnostics
• Provide a Better Understanding of the Diagnostic Test Environment
• Identify Important Information that should be collected in the Diagnostic Test Process
Topics of Discussion

• Definition
• Transformer Types and Classifications
• Transformer Configurations
• Vector Groups
• Life Expectance
• Oil Preservation Systems
• Insulating Materials and Fluids
• Construction Forms
• Core Steel
• Nameplates
• Ratings
• Cooling Schemes
• Tap Changers (OLTC, DETC)
Transformer Categories

- Insulation System
  - Liquid Immersed
  - Dry Type
  - Gas Filled

- Construction
  - Tank Type
  - Core Type / Shell Type
  - 1 Phase / 3 Phase
  - Double-Wound, Multi-Winding, Auto
  - Winding Configuration and Type

- Application
Transformer Types and Classifications

- Distribution
- Power
- Rectifier
- Arc-Furnace
- Network
- Regulating (Voltage Regulators)
- Phase Shifting
- Reactors*
Transformer Classifications

• Distribution
  • Rated 500 kVA and Below
  • Up to 34.5 kV
  • Step-down Application
  • Used in Customer Circuit

• Power
  • Rated 500 kVA and Above
  • Between Generation and Distribution
  • GSU Generator Step-Up, Autos, Transmission
  • Class XFMRs
  • Autotransformers
Winding Configurations

- Delta
- Wye
- Auto
- Zig-Zag
Vector Groups

DELTA

H2

H1

H3

WYE-STAR

X2

X1

X0

X3

ZIG-ZAG

X1

X2

X0

X3

AUTO

H2

X2

H0X0

X3

X1

H1

H3
Vector Groups
Vector Groups – Head to Tail Relationship

<table>
<thead>
<tr>
<th>Phase</th>
<th>HV</th>
<th>LV</th>
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<tbody>
<tr>
<td>Phase A</td>
<td>H1-H3</td>
<td>X1-X0</td>
</tr>
<tr>
<td>Phase B</td>
<td>H2-H1</td>
<td>X2-X0</td>
</tr>
<tr>
<td>Phase C</td>
<td>H3-H2</td>
<td>X3-X0</td>
</tr>
</tbody>
</table>

DELTA

WYE-STAR
Life Expectancy of Transformer Insulation

- 180,000 hrs or 20.55 years
- 110 °C Hottest Spot for 65 °C Temp Rise insulation
- Degree of Polymerization (200 - 1200 DP)
- 1200 DP - New Paper
- 200 DP at 150,000 hrs (end of life)

- Heat
- Moisture
- Oxygen
Insulating Materials and Fluids

- Oil
  - Mineral
  - Silicone
  - Askeral – Polychlorinated Biphenyls (PCB)
  - Natural and Synthetic Esters
  - High Molecular Weight Hydrocarbons
  - Synthetic

- Paper (cellulose)
  - wood fiber
  - manila rope

- Pressboard (wood fiber and cotton)
- Resin
- Varnish
Oil

- Most insulating fluids have very good properties, however the unique characteristics and attributes of each product must be considered when selecting an insulating fluid for a specific application.

- Purpose
  a. Dielectric Withstand
  b. Heat Exchange (Cooling)
  c. Arc Mitigation
Winding Types

1. Disk Winding
2. Pancake Winding
3. Helical Winding
4. Cylindrical or Layer Winding
Disk Winding

- Each disk is wound in series
- Disks are stacked in parallel
- Uses crossovers (inner-outer)
- Used mostly in 34.5 kV and above core types

Courtesy of Delta Star, San Carlos, CA
Disk Winding “Crossover” Close-up

Courtesy of Delta Star, San Carlos, CA
Disk Winding – Autotransformer Common Winding

Courtesy of Delta Star, San Carlos, CA
Pancake Winding

- Used in Shell-Type Transformers
- Stacked by Interleaved Scheme

Courtesy of ABB TRES - ABB Inc., Saint Louis, MO
Helical Winding

- Strands wound in parallel
- High-Current
- Low Voltage

Courtesy of Delta Star, San Carlos, CA
Helical Winding – Low Voltage Winding

Courtesy of Delta Star, San Carlos, CA
Layer or Barrel Winding

- Conductors wound side by side
- Layers can be wound on top each other
- Regulating Windings
- Tertiary Windings

Courtesy of Delta Star, San Carlos, CA
Oil Preservation Systems

- Free Breathing Conservator
- Sealed - Air/Gas Headspace
- Pressurized Nitrogen
- Conservator with Bladder
Free Breathing Conservator

- Oil is exposed to air in the conservator
- Only a small portion of the oil is exposed to air
Sealed – Air/Gas Headspace

- Operates at +/- 5 psi differential to atmosphere
- Always verify pressure before sampling
Pressurized Nitrogen Blanket

- Maintains positive pressure
- Purges nitrogen >5 psi
- Always verify pressure before sampling
Conservator with Bladder

- Oil is isolated from atmosphere
- Operates at atmospheric pressure
Construction Forms

Core Form
- Concentric
- Less Iron
- More CU

Shell Form
- Interleaved
- More Iron
- Less CU
Core Steel

- Goal – Minimize cost of ownership by minimizing losses
- Constructed from steel sheets (0.25 mm) that has a coating (insulation); stacked laminations
- Eddy Losses – Proportional to the sheet thickness
- Hysteresis Losses – Influenced by the metallurgical recipe and process
- Grain Oriented – Align magnetic domains for the best performance in plane of intended flux paths.
Nameplates

• Identification: Manufacturer, Year, Serial Number
• Ratings
  - MVA, kV, BIL, Amperes, %Z p.u.
  - Cooling Class
  - Insulation Temperature Rise
• Vector Diagram
• Wiring Diagram
• Weights and Volumes
• OLTC, DETC Rating and Connection Mapping
### Nameplate Drawing

**Load Tap Changing Power Transformer**

- **Class:** ONAN/ONAF/ONAF
- **Main:** 3-PHASE 6D HK SER. NO. KKKK
- **MVA:** 16.00/24.00/30.00
- **KVA:** 20.16/36.33/33.00
- **Volts:** 138000 Delta, 31500 Volts BIL 550 kV
- **Freq:** 60 Hz
- **Impedance:** % at 138000-13000 Volts and 18.00 MVA

**Designated Sound Levels:**
- **Onan:** 73 db
- **Avg/Max:** 76 db

**Conditions:**
- Ambient temperature level of PCS: 40 K below ambient
- **kg:** 1.45
- **I/O Insulation:** Type J, Glass dipped
- **Conduit:** Type J, Glass dipped

**Altitude:** 2600 feet above sea level

**Instruction Book No.:** V.2.2

### Transformer Connections

<table>
<thead>
<tr>
<th>Type</th>
<th>High Side</th>
<th>Low Side</th>
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</thead>
<tbody>
<tr>
<td>Delta</td>
<td>138000</td>
<td>31500</td>
</tr>
<tr>
<td>Delta</td>
<td>130000</td>
<td>31500</td>
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</table>

### Transformer Tap Values

<table>
<thead>
<tr>
<th>Tap Value</th>
<th>110000</th>
<th>121000</th>
<th>138000</th>
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<tbody>
<tr>
<td>kVA</td>
<td>121000</td>
<td>138000</td>
<td>110000</td>
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</table>

**Date of Manufacture:** [Insert Date]
## Ratings

<table>
<thead>
<tr>
<th>CLASS</th>
<th>ONAN/ONAF/ONAF</th>
<th>3-PHASE</th>
<th>60 HZ</th>
<th>SER. NO.</th>
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</thead>
<tbody>
<tr>
<td>MVA</td>
<td>18.00/24.00/30.00</td>
<td>CONT. TEMP. RISE</td>
<td>55°C</td>
<td></td>
</tr>
<tr>
<td>MVA</td>
<td>20.16/26.88/33.60</td>
<td>CONT. TEMP. RISE</td>
<td>65°C</td>
<td></td>
</tr>
<tr>
<td>HV</td>
<td>138000 DELTA VOLTS</td>
<td>BIL</td>
<td>550 KV</td>
<td></td>
</tr>
<tr>
<td>LV</td>
<td>13090 GRDY/7560 VOLTS</td>
<td>BIL</td>
<td>110 KV</td>
<td></td>
</tr>
<tr>
<td>LV NEUTRAL</td>
<td></td>
<td>BIL</td>
<td>110 KV</td>
<td></td>
</tr>
<tr>
<td>IMPEDANCE</td>
<td>% AT 138000–13090 VOLTS</td>
<td>AND</td>
<td>18.00 MVA</td>
<td></td>
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</table>
Vector Diagram
Weights and Volumes

### Approximate Weights

<table>
<thead>
<tr>
<th>Item</th>
<th>LBS.</th>
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<tbody>
<tr>
<td>Core &amp; Coil (Untanking Weight)</td>
<td>49070</td>
</tr>
<tr>
<td>Tank, Fittings, &amp; Radiators</td>
<td>53205</td>
</tr>
<tr>
<td>Rads. (Bolt On)</td>
<td>17800</td>
</tr>
<tr>
<td>Oil—Main Tank</td>
<td>5754</td>
</tr>
<tr>
<td>Oil—Tapchanger Compartment</td>
<td>100</td>
</tr>
<tr>
<td>Oil—Radiators</td>
<td>536</td>
</tr>
<tr>
<td>Oil—Total*</td>
<td>6390</td>
</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td>150200</td>
</tr>
</tbody>
</table>
Fault Protection

1. Pressure Relief Valves
2. Sudden Pressure Relay
3. Buchholtz Relay

- Sudden Pressure Relay
- Gas Accumulation Relay
- Only Applied to Conservator Systems
Cooling

- Prevent damage and loss of life to the insulation system
- Ages paper, pressboard, and oil
- Natural Convection
- Fans
- Pumps
- Water
- Directed Flow
Pumps, Fans, Radiators
Temperatures

- Top Oil
- Bottom Oil
- Average Oil
- Average Winding
- Hot Spot
Cooling Schemes – IEEE OLD

- **OA** = Oil-Immersed Self Cooled
- **FA** = Oil-Immersed Forced Air
- **FOA** = Oil-Immersed Forced Oil / Forced Air
- **OW** = Oil-Immersed Water Cooled
- **FOW** = Oil-Immersed Forced Oil / Forced Water
- **OW/A** = Oil-Immersed Water Cooled / Self Cooled
- **FOA*** = Oil-Immersed Forced Oil Directed / Flow Forced Air
- **FOW*** = Oil-Immersed Forced Oil Directed / Flow Forced Water

* Indicates directed oil flow
Cooling Schemes – IEEE/IEC New

- **ONAN** = Oil Natural / Air Natural
- **ONAF** = Oil Natural / Air Forced
- **OFAF** = Oil Forced / Air Forced
- **OFWF** = Oil Forced / Water Forced
- **ODAF** = Oil Forced-Directed / Air Forced
- **ODWF** = Oil Forced-Directed / Water Forced
Cooling Schemes – Conversion

- ONAN = OA
- ONAF = FA
- OFAF = FOA
- OFWF = FOW
- ODAF = FOA*
- ODWF = FOW*

* Indicates directed oil flow
OLTC

- North America – Low Side Application
- Often 33 position
- Often +/- 10% Regulation
- 16R, 15R, ....1R, N, 1L, ...15L, 16L
- Reversing Switch
Tap Changers
DETC

<table>
<thead>
<tr>
<th>VOLTS L-L</th>
<th>AMPS AT 33.60 MVA</th>
<th>POS</th>
<th>CONNECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>144900</td>
<td>134</td>
<td>1</td>
<td>21–22</td>
</tr>
<tr>
<td>141450</td>
<td>137</td>
<td>2</td>
<td>22–23</td>
</tr>
<tr>
<td>138000</td>
<td>141</td>
<td>3</td>
<td>23–24</td>
</tr>
<tr>
<td>134550</td>
<td>144</td>
<td>4</td>
<td>24–25</td>
</tr>
<tr>
<td>131100</td>
<td>148</td>
<td>5</td>
<td>25–26</td>
</tr>
</tbody>
</table>
DETC

- NOT to be operated in service (See #3 below)
- Follow local policies regarding movement
- Often 5 positions
- [1, 2, 3, 4, 5] [A, B, C, D, E]
Active LTC Diagnostics

- Exciting Currents
- Turns Ratio
- DC Winding Resistance, Slope, Ripple
- DGA
- IR
- Acoustics
Thank You for Your Attention