Wind Power Transformer Design
By Philip J Hopkinson, PE

Wind Power Transformer at base of Tower

Critical link to successful Wind Turbine connection to the grid

Subject of Many complaints
1. Gassing
2. Winding Failures
3. Contact coking
4. Arc-Flash
5. Low liquid level
Wind Power Transformer Design
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1. Consideration focused on Generator step-up Transformers from 600 volt to 34,500 volt
2. Inputs from field experience
3. Standards work within IEC TC 14 and IEEE
4. Arc-Flash Safety considerations from NFPA 70E 2009
5. Work with Manufacturers of Transformers
6. Analytical studies
7. Attempt to develop meaningful universal standard requirements for transformers rated up to 10 MVA.
8. IEEE Transformer Working Group P60076-16
9. IEC Document 60076-16
10. Currently 100 members on IEEE Working Group
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Typical Wind Turbine transformer

1. 3-Phase Pad mounted
2. 600 volt low voltage Gr Y
3. 34,500 volt high voltage
4. Commonly Wye high voltage
5. Sometimes Delta high voltage
6. Most with 5-leg wound cores
7. Some with 3-leg stacked cores
8. Nearly 100% liquid filled
9. Nearly all with sheet low voltage
10. All with wire high voltages
Typical Wind Turbine transformer concerns

1. High Hydrogen gas
2. High voltage winding failures
3. Safety of HV load-break switch
4. Carbonized HV Switches and Tap changers
5. Low liquid levels in cold temperatures
High Hydrogen Gas

1. Present in Up to 50% of transformer populations
2. Hydrogen as high as 20,000 ppm
3. Small amounts Ethane and Ethylene and Methane
4. Windings apparently OK
5. Most transformers returned to factories pass Routine Tests, including Impulse.
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High Hydrogen Gas always partial discharge related

1. But windings not involved
2. Leads not involved in most cases
3. Hot spots in windings OK
4. Some gassing improves with time
5. If not windings or leads then what else?

Doble Engineering Conference 021913
What about the iron core?

1. Magnetic energy reservoir
2. Voltage generator from changing flux
3. Many laminations of thin steel
4. Very thin inter-laminar insulation
5. High inter-laminar capacitance
6. Susceptible to static charge
Transformer Core Grounds in Wound Cores
By Philip J Hopkinson, PE

1. The issue is gassing and Partial Discharge
2. Dielectric Breakdown in windings not the problem
3. Gassing and PD worst at 34.5 kV
4. Gassing not an issue at 5 kV
5. Gassing at 15 kV an annoyance only
6. Gassing coming from Core
7. Solution via grounding or shielding
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Ground Lead

Vi Outer Core
Vi Inner Core
Vi Inner Core
Vi Outer Core

C5
C2
C1
C3
C4
C1
C4
C1
C4
C1
C4
C3
C1
C2
C3
C5

LV
Grounded Clamp
HV

1/22/2013
Transformer Core Grounds in Wound Cores
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HV = 34500
LV = 600 Gr Y
kVA = 1850
Frequency = 60 Hz

C1-C5 calculated in EXCEL
Transformer Core Grounds in Wound Cores
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1. Outside core grounds at 34.5 kV result in high core volts
2. Inside core grounds eliminate static charges and drop core volts to volt/turn levels

Case I, Core Ground Connected to Frame
Voltage drop in Outer Core stacks = 804 Volts

1. Outside core grounds at 34.5 kV result in high core volts
2. Inside core grounds eliminate static charges and drop core volts to volt/turn levels
1. Outside core grounds at 34.5 kV result in high core volts
2. Inside core grounds eliminate static charges and drop core volts to volt/turn levels
3. Core shields equally effective
With Outside Core Ground and no core shield:
1. Hydrogen at 15 kV typically 100-300 ppm
2. Hydrogen at 34.5 kV typically 3,000-10,000 ppm
3. Hydrogen accompanied by small amounts of
   a. Ethane
   b. Ethylene
   c. Methane
Transformer Core Grounds in Wound Cores
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With Outside Core Ground and no core shield:

1. Partial discharge best detector
2. PD should be conducted per Class II transformers
   a. Start at 50% of rated volts
   b. Go to 100% of rated volts and record
   c. Go to 110% of rated volts and record
   d. Go to 150% of rated volts and hold for 1 hour
   e. Drop back to 110% of rated volts and hold for at least 10 minutes and record.
   f. Drop back to 100% of rated volts and record.
   g. Drop back until pd extinguishes below 100 pc
3. Transformer fails test if extinguish Pd (< 100 pc) occurs at less than 110% of rated volts
Conclusions:

1. Wound Cores most responsible for High Hydrogen with Outside Core Grounds
2. Absolute Inside Core Grounds OK
3. Shielded Cores OK
4. 3-Leg Stacked Cores generally immune
Transformer Core Grounds
By Philip J Hopkinson, PE

Recommendations:
Specify Core Precautions in Standard
1. For 5 Leg Wound Cores
   a. Absolute inside core grounds or
   b. Shielding
2. 3 Leg Stacked Cores
3. 4 and 5 leg stacked cores May need some shielding
Load-break Switching often fails transformers

1. Switching often not done at transformer
2. Groups of ~15 transformers switched by vacuum breakers
3. First and / or Last transformer in Group most vulnerable
4. Current Chopping and Reignition Transients are failure-initiators
5. IEEE C57.142 Addresses Issues
6. Resistor-Capacitor Snubbers needed
Common Denominators for switching-induced problems

1. Switching done at Vacuum breaker
2. Transformers connected to vacuum breakers by shielded cables
3. No arresters at transformers but it wouldn’t help
4. Switched currents < 6 amps
5. Current chopping and reignition transients present

Winding failures in tap section or at line ends
High Voltage Winding Failures from Switching
By Philip J Hopkinson, PE

Grounding Switch
Combined 34.5 kV Vacuum Circuit Breaker & High Speed Grounding Switch VDH/GSMI™

VDH/GSMI™
Electrical Ratings

- Rated Voltage: 34.5 kV
- Rated Current: 38,000 A
- Rated Interrupting Current: 40 kA
- Maximum Interrupting Capacity: 400 MVA
- Rated Voltage Breakdown: 200 kV
- Rated Arcing Current: 60 kA
- Rated Arcing Time: 40 ms

Dimensions and Weight

VDH/GSMI™

- Dimensions:
  - Length: 120 in
  - Width: 80 in
  - Height: 60 in

- Weight:
  - Approx. 12 tons

US and Foreign Patents Pending

1/22/2013
Doble Engineering Conference 021913
High Voltage Winding Failures from Switching

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Vacuum breakers compact, clean, efficient, generally safe..
But Transformers often in trouble!
Shielded Cables integral part of damaging voltage transients

1. Act like Transmission lines
2. Wave velocity half the speed of light
3. Surge impedance independent of length
4. Low energy dissipation
5. EPR generally superior to XLPE due to higher dissipation

Shielded cables amplify resonances with reflected waves and voltage doubling
Load-break Switching often fails transformers

Current chopping unavoidable at light currents < 6 amps

Reignition transients likely at low power factor

Circuit damping key to solving problems

The higher the system energy efficiency the more likely are winding failures
Resistor-Capacitor Snubbers provide needed damping

1. Can be mounted in transformer
2. Can also be mounted in switchgear
3. Current chopping will still happen
4. Reignition transients will totally disappear
5. Transformer survives!
Conclusion

R-C Snubbers in Vacuum breaker cabinet can prevent switching failures

Recommendation

Include brief tutorial and recommendation in the new Wind Power Document P60076-16
Thermal Stability of Electrical Contacts in switches and tap changers

1. Desired stable life for 30+ years
2. Many electrical contacts susceptible to oxidation
3. Key Variables are:
   a. Contact materials
   b. Contact pressures
   c. Type of fluid
   d. Current amplitude and variability
   e. Temperature
   f. Worsened by high current harmonics
Thermal Stability of Electrical Contacts in switches and tap changers

1. Functional life test being documented in IEEE PC57.157
2. 30 day test with acceleration of 1000 times
3. 2 XN Current daily for 8 hrs. in 130 C bath followed by 16 hours cool down de-energized.
4. Test passed if:
   a. Stable
   b. Resistance change < 25%
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## Summary to Date:

Thermal Stability of Electrical Contacts in switches and tap changers

<table>
<thead>
<tr>
<th>Contacts</th>
<th>Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in order of stability)</td>
<td>Most Stable</td>
</tr>
<tr>
<td>FR3</td>
<td>Mineral Oil</td>
</tr>
<tr>
<td>Silver-Silver</td>
<td>Pass</td>
</tr>
<tr>
<td>Silver-Copper</td>
<td>Pass</td>
</tr>
<tr>
<td>Copper-Copper</td>
<td>Pass</td>
</tr>
<tr>
<td>Tin-Copper</td>
<td>Pass</td>
</tr>
</tbody>
</table>

1. Test quite meaningful
2. 40+ years proven to find stable contacts
3. IEEE PC 57.12.157 Guide should be helpful to the industry
4. Tests should be performed by each manufacturer for each switch type
5. These conclusions to be included in Wind Power Transformer Standard P60076-16
Arc-Flash Concerns

1. NFPA 70E reference for 2009
2. Both HV and LV Cabinets have concerns with LV worst
3. Suit-up needed to just check gauges
4. These conclusions to be included in Wind Power Transformer Standard P60076-16
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Arc-Flash Concerns

Desire third cabinet

1. Gauges
2. Load-break switch Handle
3. Schrader valve
4. Sampling port
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Arc-Flash Concerns

Desire HV Cabinet
Door to open first
Low Liquid Level Concerns

1. Meter shows level below minimum
2. No leak evidence
3. Cold temperatures
4. Transformer may be de-energized
5. Critical switchgear and other accessories may not be immersed in the liquid
Low Liquid Level Concerns

1. Volumetric change of mineral oil with temperature
   \[ \Delta V = 0.0007 \times (C-1) \]

2. Assume tank filled at +70°C
3. Assume coldest temperature (-) 40°C
4. Temperature change is (-) 110°C
5. Volume shrink = -7.6%
Low Liquid Level Concerns

Suppose original liquid height at 50”

A 7.6% volume reduction is (-) 4”

Recommendation

Specify added liquid level to fully cover switches and accessories
Summary

IEEE P60076-16 should be an important document for Wind Power Transformers

1. Normal C57.12.00 considerations
2. Core Grounds and shielding
3. Resistor – Capacitor Snubbers
4. Stable electrical contacts
5. Arc-Flash issues
6. Added liquid level