Dry-Type Transformers
Increasing Safety and Reliability for Distribution Networks
Chad Powell, Business Development - Distribution Transformers
Dry-type transformers

Speaker

Chad Powell
- Business Development – Distribution Transformers
- ABB; Power Grids
- Denver, CO
- +1 (720) 327-3946
Your safety is important to us

Hand Safety
You abuse your hands every day and subject them to conditions that are questionable at best, so the least you can do is take every precaution possible to protect them against known hazards

<table>
<thead>
<tr>
<th>Regular Hand Exercises</th>
<th>Proper Work Gloves</th>
<th>Don't Forget About Your Skin</th>
<th>Meaningful Breaks to Give Hands a Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Make a light fist and release it 10 times</td>
<td>✓ Use protective gloves from when you start working</td>
<td>✓ Ensure hands are not wet for &gt; 2 h/day or &gt; 20 times each day</td>
<td>✓ Taking several short breaks throughout the day is better than a few long ones</td>
</tr>
<tr>
<td>✓ Bend each finger, one at a time, toward the palm. Hold for a few seconds, then release</td>
<td>✓ If protective gloves are used for &gt;10 min wear cotton gloves underneath</td>
<td>✓ Wash hands in warm (not cold or hot) water and dry thoroughly</td>
<td>✓ Breaks only need to last about 10 minutes each time</td>
</tr>
<tr>
<td>✓ Stretch each thumb toward the pinkie, and repeat 10 times</td>
<td>✓ Keep gloves intact and dry inside</td>
<td>✓ Avoid introducing irritants into the gloves</td>
<td>✓ Try to determine how long you can perform your job before your hands start to feel strained or cramped</td>
</tr>
<tr>
<td>✓ Form an “O” with each hand</td>
<td>✓ Not sure if you are wearing the best gloves? Consult with your HSE Advisor</td>
<td>✓ Do not wear rings at work – they trap water and contaminants</td>
<td>✓ That’s the limit that you can reach before risking a Repetitive Strain Injury and then reduce that time by about 10 minutes, and you’ll get a break before the strain begins</td>
</tr>
<tr>
<td>✓ Make a fist, rest it on a table or flat surface, and raise the thumb. Repeat this 10 times</td>
<td>✓ Keeping your hands clear of machinery, checking of guards safety interlocks etc.</td>
<td>✓ Use lipid-rich moisturizing creams at and after work</td>
<td></td>
</tr>
<tr>
<td>✓ Lay palms flat on a table, and raise each finger separately</td>
<td>✓ Always check for any loose clothing, jewellery etc. before you start working</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Agenda

- Use of distribution transformers in network systems
- The potential hazards and risk associated with network distribution transformers
- Understanding Risk of Ownership (failure modes, safety, protection)
- A comparison between liquid filled vs dry-type network transformers
- Dry-type transformers for network applications
- Digital advancements in distribution network transformers
Network Transformers

Where are network transformers used?

**Location & Environment:**

- Used in major metropolitan / city environments
  - New York, San Francisco, Toronto, Chicago, Washington DC, many others

Standard ratings

- kVA: 300, 500, 1000, 1500, 2000, 2500,
- HV: 2400 – 34,500, LV: 216Y/125, 480Y/277

City network transformers can be found inside of downtown buildings, outside in vaults underneath grates in city street / sidewalk areas, or underground in subway tunnels

Urban utilities employ networks to eliminate the need for overhead distribution cables running through congested or densely populated areas

**Primary Network Transformers Users:**

<table>
<thead>
<tr>
<th>User</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Con Ed</td>
<td>27,000</td>
</tr>
<tr>
<td>PEPCO, PSEG</td>
<td>4,500 - 5,000</td>
</tr>
<tr>
<td>Toronto Hydro, NStar</td>
<td>2,000 – 2,500</td>
</tr>
<tr>
<td>Com Ed</td>
<td>2,000</td>
</tr>
<tr>
<td>National Grid</td>
<td>1,200 – 1,500</td>
</tr>
<tr>
<td>Seattle City Light</td>
<td>1,500</td>
</tr>
<tr>
<td>LG&amp;E, Dominion</td>
<td>500 - 700</td>
</tr>
</tbody>
</table>
Why the need for a safer transformer
Although rare, events occur and are costly


There was an oil transformer accident in Toronto. A transformer in an underground electrical vault, causing explosions and a smoke cloud. They had to evacuated a bank tower.
Network transformer failures
Street vault examples
The transformer vaults are concrete and may be occasionally completely submerged in water. The vaults do not have drainage systems so all surface debris is washed off the street from rain and into the transformer vault through the grates above. Some vaults that are close to waterways have continuous standing water in them.

The average life of vault-type network transformers is shortened due to high overloading and tank deterioration. Enclosure “tanks” are designed with thick walls and epoxy coatings to impede rust-through. Internal faults or short circuits can lead to large, street level events that cause significant harm to people and surrounding property.

65% of transformer failures due to corrosion.
Assessing Risk of Ownership
Determining your level of risk

Factors to consider:
- Number of units in service
- Average age of fleet
- Time based maintenance
- Condition assessments of individual assets
- Transformers near or around people
- Number of units older than 15 years of age
- Units in coastal areas or near harsh/corrosive environmental conditions
- Condition of containment systems

In the news...
- “One injured in transformer explosion”  ~ Istanbul, Jan 2016
- “3 injured in transformer explosion”  ~ Massachusetts, April 2016
- “Transformer explosion kills 3, injures 5”  ~ Nigeria, July 2016
- “7 people injured in transformer explosion”  ~ Pakistan, July 2016
- “Six injured in power plant [transformer] explosion”  ~ Cincinnati, Jan 2017
- “$8.5 Million Settlement for Family of Assistant Fire Chief Killed in Neiman Marcus Transformer Fire”  ~ Chicago, June 1999

Damage and repercussions from transformer explosions/fires as well as environmental fines and penalties from leaks and spills can range from several thousands to several million dollars
Why oil-free? Avoid rupture and fire
Dry-Type vs Liquid Filled Transformers
Understanding the difference
Oil-filled and dry-type transformers
The simple difference

Oil-filled transformers
Uses OIL for main dielectric and cooling media

Dry-type transformers
Uses SOLID INSULATION materials for main dielectrics and natural AIR for cooling
## Dry-type vs oil-filled solutions

Key feature advantages (generally speaking)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Oil-filled</th>
<th>Dry-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size &amp; Weight</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Initial Cost</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Losses / Efficiency</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Overload capability</td>
<td></td>
<td>☑️</td>
</tr>
<tr>
<td>No Bushings Required</td>
<td></td>
<td>☑️</td>
</tr>
<tr>
<td>Fire Safety</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Environmental Safety</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Total Installation Cost*</td>
<td>☑️</td>
<td>☑️</td>
</tr>
<tr>
<td>Maintenance Cost</td>
<td>☑️</td>
<td></td>
</tr>
<tr>
<td>Short Circuit Strength</td>
<td>☑️</td>
<td></td>
</tr>
</tbody>
</table>

*Driven mostly by regional building safety codes
## Combustibility Risk

### Transformer oils

<table>
<thead>
<tr>
<th>Mineral oil</th>
<th>Ester oils</th>
<th>Dry</th>
<th>Dry w/ Internal Fault Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Nonflammable, but combustible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Flash point of 170°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Largest installed base of transformer technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Long history of being safe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Nonflammable, but still combustible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Flash point of 330-360°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 98% biodegradable seed oil (when unused)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Not suggested for indoors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Non-flammable AND non combustible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Flash point is negligible (no oil or fuel source to ignite)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Only technology suited for both indoor and outdoor applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Same features as standard dry-type transformer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Additional features limit damages in rare event of internal arc fault</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Increased safety and environmental benefits = LOWER RISK**
# Oil-filled and dry-type transformers

## The simple difference

### Oil-filled transformers

- Oil Levels / Pressure Gauge / Relief Valves
- Porcelain Insulator / Surface Cleaning
- Connections (Tighten) / Painting State
- Oil Analysis (Dielectric Testing) / SILICAGE
- Accessories Checks (Over Pressure Relay, WTI, Buzcholz)

Over the life, oil filled units may have issues/symptoms that require insulating fluid analysis, metals analysis, dissolved gas analysis, etc.

Gauges are sometimes prone to failure over time

Routine preventative maintenance can be expensive if performed regularly

### Dry-type transformers

- Surface Cleaning
- Connections (Tighten)
- Winding Temp Indicator (WTI)

Very little preventative maintenance is required for a dry-type transformer to keep the transformer in good running order.

- Clean/ Dry Environment = fewer inspections and maintenance.
- Visual Inspections = reduced risk of insulation surfaces becoming dirty and obstructing effective cooling.
- Within the first few inspections, a routine maintenance schedule should be established.
- Dry = air cooled (ventilated) which isn’t subject to breaking down
- Dry = sealed and requires only periodic surface cleaning
**Dry-type technology**

Two predominate insulation systems available

**Resin based system**

**Open wound**

- Highest insulation class (220°C)
- 80/100/115/150°C temp rises
- Most economical type of transformer
- Ideal for indoor environments
  - VPE can be suggested for outdoor applications
- Requires vacuuming of coils if dirty
- Highest installed base in NAM.

**Epoxy based systems**

**Vacuum cast coil (VCC)**

- Can reach highest voltage class for dry-type transformers (145 kV/550 kV BIL)
- 80/100/115 temp rises
- Insulation of epoxy 185°C
- Best suitability for corrosive, outdoor environments
- Superior dielectric strength
- Highly resistant to short circuit events
- Little maintenance (NEMA 3R)
- Maintenance free (Sealed Tank)
ABB Dry-Type Network Transformers
Safest Power for Urban Areas

**Ventilated Networks**
- NEMA 1, 2, 3R enclosure
- Protection from airborne dust and water leaks
- Up to 5 MVA, 34.5 kV

**Submersible Networks**
- Submersible networks
- Complete absence of oil
- Entirely welded tank assembly with similar footprint to liquid filled unit
- Up to 1500 KVA, 15kV
Oil-free development
Primary design considerations

**Thermal rise**
Must stay within material thermal limits with no enclosure ventilation and limited air flow inside the fault.

**Lifetime expectancy**
Must have usable life expectation of 30+ years while in high thermal performance environment.

**Internal fault**
Must withstand most dangerous failure mode: internal electrical fault.
Getting inside the vault

Lifetime expectancy

From thermal rise testing

- Able to calculate thermal rise constants at each PU load profile
- At 2.04 PU, hotspot estimated to be 260°C
- Time to failure under continuous loading:

<table>
<thead>
<tr>
<th></th>
<th>1.0 PU Load</th>
<th>1.3 PU Load</th>
<th>1.7 PU Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max HS +</td>
<td>116.85</td>
<td>159.32</td>
<td>231.63</td>
</tr>
<tr>
<td>26°C Amb</td>
<td>2,909</td>
<td>153</td>
<td>1.02</td>
</tr>
<tr>
<td>Insul. Life (yrs)</td>
<td>152.53</td>
<td>194</td>
<td>0.10</td>
</tr>
</tbody>
</table>
ABB Dry-Type Network Transformers

Type Testing

Custom Design Validation:

Full type certification
- Applied potential, double induced, 95 kV, 100% full wave impulse
- Short circuit test at 25x rated current for 2 sec
- (3) High fault energy resistant for an arc current up
- (1) @ 47.5 kA, (2) @ 38 kA for 100 milliseconds
- Through fault test on ground switch
- 24 hr applied potential @ 18 kV (1.33%) of nameplate rating
- Audible sound test – 47.4 dBA

Successful thermal testing in a wooden replica vault at 170% of nameplate power rating

Simulated transformer life in excess of (40) years under user loading profile
ABB Dry Type Network Transformers

Ensuring against the worst failure mode

**Internal Arc Fault Testing:**

Three internal arc fault test were conducted identical designs to prove safety

Tests conducted at KEMA labs

- (1) 47,500+ amp arcs generated (7 in. gap)
- (2) 38,000+ amp arcs generated (7 in. gap)
- Over 10 MJ of energy dissipated
- >100 PSI pressure change in 0.15 milliseconds

All (3) trials successfully passed

Performed post weld and steel analysis with no indications of degradation
Implementation and results
Submersible Dry-Type Network Transformer
Sealed; Maintenance Free

Product Features:

- Capable of 70% overloading
- Similar in size to liquid-filled units with cooling fins
- Safest failure mode for submersible applications
- Up to 1500 kVA, 27 kV available for order
- Two position ground switch available for order
- Three position ground switch and/or tap changing capability available for pilot
- As close to maintenance free as possible
- Can be utilized in Class 1 Div 2 Applications

N₂ Gas Overpressure
Overpressure of 5 psi, non-flammable and non-corrosive N₂ gas with monitoring to give warning when tank deterioration has occurred

Epoxy Winding Insulation
Primary vacuum cast coil (VCC), 185C insulation class; secondary is epoxy encapsulated high 220C insulation system

Welded Tank Assembly
Completely welded, subway-type tank assembly

2-Position Ground Switch
Dry-type disconnect switch with solenoid interlocking for clear and ground connections

HV tap changer
95 kV BIL primary, no load tap changer

Stadium Core & Oval Coil Shape
Optimized coil and core shape to reduce total weight and length of design. Aspect ratio over 2.0.
ABB Dry Type Network Transformers

Existing Protector & Transformers

Three (3) – 167KVA single phase transformers banked together in high rise with remote mount network protector. Customer driven to eliminate oil from the building.

Existing Installation / Location & Removal
Replaced all single phase banked transformers with one 500KVA rated dry type network transformer. Protector mounted on the tank wall.
ABB dry type network transformers
500 kVA, 15 kV installed Aug 26th, 2011

Hurricanes
Has survived (2) hurricanes: Irene and Sandy.
  - Submerged under 20 ft of water during Sandy and still functioning
Had a gradual loss in N2 over pressure due to an loose fitting. Checked/ tightened all connections and refilled in Dec. 2012; has maintained pressure to date with no other issues.
Have installed additional 6 units in the ground since 2013 and in the process of installing an additional 25 units currently.
New installation

Example: 50 California St, San Francisco

Location of Vault: 37th Floor
PG&E, ABB and Sheedy Drayage coordinated with customer on removal of old transformers and placement of new transformers
Installation of roof top crane needed and this was tied to building frame members (I-beams)
New dry type transformers weigh more than older oil filled units
Structural and seismic studies required to determine modifications to vault (new transformers required seismic tie downs, only slight modifications to vault)
But, we live in an ever changing world...
Though robust, transformers will not last forever; externalities shorten life expectancies

Aging equipment
As electrical equipment naturally approaches end of life, they subject networks to faults and transients causing disturbances

Environmental forces
Natural disasters, changing climates and electrical storms all stress grid equipment throughout their lifetimes

Distributed generation
Power is now flowing in all directions, creating new challenges for established grid networks

Increasing demand
Growing need for AC to DC converting subjects electrical networks to increased harmonics and transients

External stresses are the number one cause of failure of dry-type transformers
External stresses may affect life expectances
Ideal transformer life curve

- Operational stress
- Planned end of life

Stress vs. Time graph with two lines:
- Ideal transformer resiliency curve
- Electrical stress

Aged timeline is exaggerated for demonstration
External stresses may affect life expectancies

Realistic transformer life curve

Unplanned outages are costly and result in significant downtime. With proper monitoring, they can be avoided.
The age of digitalization - smart transformers
Bringing analytics for predictability and asset management

Current Features:

Provides valuable information on how the transformer is operating.
Maintenance planning, condition-based asset management, diagnosing & real time remote monitoring (Wi-Fi & LAN)
Data can be logged and stored for up to 20 years (fully encrypted)
Transformer consumed life & total harmonic distortion

Sensing & Output Features:

- Voltage, Current, Load Analytics
- Transformer lifetime, THD
- Asset Management
- Alarms
### Digital dry-type transformers

Additional features for increased monitoring and ease of use

<table>
<thead>
<tr>
<th><strong>Fan control</strong></th>
<th><strong>Connectivity</strong></th>
<th><strong>Certified</strong></th>
<th><strong>Flexibility</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Standard fan trip, alarm relays and programmable for auto exercising</td>
<td>- RFID and digital certificate protected local WiFi signal to allow for wireless connection and data download</td>
<td>- EMI/EMC, IEC 61000-4-X series for electrical and magnetic interference, IEC61326-1, IEC\ EN 61010</td>
<td>- Does not affect transformer operation or size and works with most indoor and outdoor applications</td>
</tr>
<tr>
<td>- Fan monitoring sensors to notify in the event of a fan motor failure</td>
<td>- Provided Ethernet hard-wire connection for remote access</td>
<td>- Sensor package and processing unit does not affect the UL listing or CE mark of the transformer</td>
<td>- Capable of future expansion for new hardware and software upgrades</td>
</tr>
</tbody>
</table>
Today’s situation...
Dry-type transformers are the safest and most reliable transformers on the grid.

- Eliminated risk of fires or explosions
- Eliminated risk of oil leaks or spills
- Lower ownership costs
- Low to no maintenance requirements
- Lower load losses
- Lower total installation costs
- No need for oil containment or fire suppression
- Less code restrictions
- No insurance premiums
- Indoor and outdoor installations
Q&A and Contact information

If you have questions, please contact me further

Speakers

Chad Powell
- ABB, Inc.
- Business Development
- +1 (720) 327-3946
- chad.powell@us.abb.com