ABB Dry-type Transformers

Dry transformers: providing valuable solutions to many electrical systems’ challenges.

Michael Goggioli, CoE Dry Transformers for Data Centers
Agenda

ABB Group
Product Group Dry-type transformers

Challenges & solutions
- Inrush currents in transformers
- Vacuum circuit breakers and voltage surges
- High temperatures – overloads - lifetime
- Neutral creation
- High voltages

Q&A
# Four market-leading entrepreneurial divisions

All businesses in #1 or 2 positions

<table>
<thead>
<tr>
<th>Partner of choice for...</th>
<th>Position</th>
<th>Revenues²</th>
</tr>
</thead>
<tbody>
<tr>
<td>...electrification of all consumption points</td>
<td>#2 in electrification</td>
<td>$9.9 bn</td>
</tr>
<tr>
<td>...robotics and intelligent motion solutions</td>
<td>#1 in motion</td>
<td>$7.9 bn</td>
</tr>
<tr>
<td></td>
<td>#2 in robotics</td>
<td></td>
</tr>
<tr>
<td>...industrial automation</td>
<td>#1 in process control</td>
<td>$6.8 bn</td>
</tr>
<tr>
<td>...a stronger, smarter and greener grid</td>
<td>#1 in T&amp;D</td>
<td>$11.0 bn</td>
</tr>
</tbody>
</table>

²2016 revenues in new structure as of January 2017
Power Grids division organization
Delivering differentiated customer value

Leveraging portfolio and expertise to maximize customer value

- Power and automation products, systems & service solutions across the power value chain
- Global footprint ensures competitiveness and proximity to customers
- Proven track record and unmatched worldwide installed base
- Lifecycle support services
- Unparalleled domain expertise backed by skilled and experienced workforce

Offering solutions through four business units

- Transformers
- High Voltage
- Grid Automation
- Grid Integration
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Q&A
ABB dry-type transformers

Facts and figures

- Revenues: 600 MUSD /year in more than 40 countries
- Annual production capacity around 30,000 MVA from 14 locations
- More than 500,000 units and a field failure rate of less than 1%
- Around 1700 employees in 14 countries
- 6 technology centers worldwide
- ABB has the broadest portfolio of dry-type transformers available in the market
## ABB dry-type transformers

Reliable solutions for all applications

<table>
<thead>
<tr>
<th>Solutions for all applications</th>
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<tbody>
<tr>
<td><strong>Low voltage magnetics</strong></td>
</tr>
<tr>
<td>− Transformers and reactors</td>
</tr>
<tr>
<td>− Up to 1000 V and 10 MVA</td>
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<tr>
<td><strong>MV magnetics</strong></td>
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<tr>
<td>− Transformers and iron core</td>
</tr>
<tr>
<td>− Up to 36 kV and 20 MVA</td>
</tr>
<tr>
<td><strong>HV transformers</strong></td>
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<tr>
<td>− First dry-types for subtransmission</td>
</tr>
<tr>
<td>− Up to 145 kV and 63 MVA</td>
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<td><strong>Sealed/submersible transformers</strong></td>
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## ABB dry-type transformers

Customized technologies for special needs

<table>
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<tr>
<th><strong>Vacuum cast coil</strong></th>
<th><strong>Resibloc</strong></th>
<th><strong>Open wound</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Can reach highest voltage class for dry-type transformers (145kV/550kV, BIL)</td>
<td>- Most robust winding technology</td>
<td>- Highest insulation class (220°C)</td>
</tr>
<tr>
<td>- Suitable for corrosive, outdoor environments</td>
<td>- Great for high current or high vibration applications</td>
<td>- Most economical type of transformer</td>
</tr>
<tr>
<td>- Smooth coils for easy cleaning</td>
<td>- Suitable for corrosive, outdoor environments (-60°C)</td>
<td>- Ideal for indoor environments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Requires vacuuming of coils if dirty</td>
</tr>
</tbody>
</table>

Reliable, ecological, safe for people and ambient, maintenance-free
ABB dry-type transformers
Dry-type global producer with focus factories

Global footprint

Insulation technology

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<thead>
<tr>
<th></th>
<th>VCC</th>
<th>Resibloc</th>
<th>VPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Brazil</td>
<td>✓</td>
<td></td>
<td>✓</td>
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<tr>
<td>Spain</td>
<td>✓</td>
<td></td>
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<tr>
<td>Germany</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Switzerland</td>
<td>✓</td>
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<td>Italy</td>
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<td>Bulgaria</td>
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<tr>
<td>India</td>
<td>✓</td>
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<tr>
<td>China</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>S. Korea</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Colombia – only assembly</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt - only assembly</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>S. Arabia - only assembly</td>
<td>✓</td>
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ABB Group
Product Group Dry-type transformers

Challenges & solutions
- Inrush currents in transformers
- Vacuum circuit breakers and voltage surges
- High temperatures – overloads – lifetime
- Neutral creation
- High voltages

Q&A
When the transformer is first energized, a transient magnetizing (or exciting inrush) may flow in the windings, due to the core magnetizing process. Many factors impact on the duration and magnitude of the current, among which:

- Size of the power system
- Type of core
- Flux density
- Prior history (residual flux)
- ......

This inrush current, which appears as an internal fault to the differential relays, may reach instantaneous peaks of 8 to 30 times the full load current.
Inrush current is mostly limited by:

- Increasing the reactance of the transformer primary winding (impractical)
  **Consequence:** unwanted transformer impedance value

- Decreasing the core flux density and saturation point
  **Consequence:** higher transformer cost
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Solution – Pre-magnetization transformer

From MV side

From LV side

Note:
The pre-mag transformer rating is approx. 0.5~1% rating of the main transformer
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Solution – Pre-magnetization transformer

Typical layout

Advantages
- Cancellation of inrush current
- Compact solution
- Relatively low cost
- Short cable runs

Simple, fast, reliable
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Product Group Dry-type transformers

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Q&A
Vacuum circuit breakers (VCB’s) have incredible arc-quenching capabilities that bring increased safety and efficiency to electrical systems.

However, VCB (and SF6) switching can produce fast transient overvoltages inside of transformer windings; some leading to failures.

These failures result in system downtime and unrepairable equipment; both incredibly costly to network managers.
**ABB dry-type transformers**

Investigation - What is actually happening; two types of voltage stress

---

**Voltagess spikes due to pre- or re-strikes in breaker**

- Occurs when the voltage potential across the poles of the circuit breaker are still high enough to cause a spark across the terminals
- Chance to occur during every switching event with current

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**Voltage rise due to resonance amplification**

- Occurs when sustained current (ex. short circuit) is interrupted and the wave frequency matches the natural frequency of the windings
- Depends greatly on system characteristics
- Least captured case during lab testing

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Each peak is a reignition

Voltage at transformer terminals

![Voltage at transformer terminals chart]

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Investigation - peak voltage vs. current chopping level

Many variables make peak voltages unpredictable

Test: Full unit, disconnect with variable loading (graph)
– Result: Peak voltages are large and unpredictable

Conclusion:
– It is impossible to predict the max. peak voltage and, therefore, impossible to design a stand alone winding to resist fast switching for all scenarios, no matter the transformer technology
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Solution - Transient Voltage Resistant™ Transformer (TVRT)

**ABB’s solution to avoid TVs**

The TVRT:

- Varistors are strategically integrated into the transformer windings to enhance the coil technology
- The varistors act as a pressure relief valve, preventing over-voltages inside the coil from growing beyond known levels
- With the peak voltage known, then the internal windings are designed to resist
- This solution works in ALL system configurations because it prevents voltage rise
Advanced solutions; winding varistors

Solution - Worst case switching scenario comparison

<table>
<thead>
<tr>
<th>No protection</th>
<th>RC snubber circuit</th>
<th>Winding varistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta primary, VCC</td>
<td>Delta primary, VCC</td>
<td>Delta primary, VCC</td>
</tr>
<tr>
<td>168 kV peak voltages</td>
<td>250 Hz oscillation, 85 kV peak amplitude</td>
<td>40 – 45 kV (hf transients up to ≈ 65 kV)</td>
</tr>
</tbody>
</table>

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BIL of test transformer

Varistor arrangement shows clear reduction in peak voltages AND number of reignitions
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Q&A
ABB Dry-type Transformers

Challenge - High temperatures – overloads - lifetime

Data Center distribution transformers

Design challenges

- **Harmonic currents** present in distribution lines can cause overheating and saturations difficult to quantify, that force to oversize the transformers.
- **Overloading** due to extreme operation conditions can also decrease a standard transformer lifetime if not correctly considered.
- **High ambient** temperatures in summer conditions can create unexpected trips in the distribution line and deteriorate the insulation.
Hi-T Plus - High temperatures

- Insulation suitable for temperatures up to 180 °C and 220 °C as hot spot.
- Suitable for saline atmospheres.
- Vibration proof.
- Design tested up to 250 kV BIL.
- Optional design up to –40 °C.
## ABB dry-type transformers

### Solution – High Temperature Transformer (Hi-T Plus)

### Transformer ageing prevention

**Hi-T plus – High temperature insulation system**

- Transformer insulation system is suitable for temperatures up to 180°C
  - Suitable for saline atmospheres
  - Vibration proof
  - Design tested up to 550 kV BIL
  - Designs available for operation at -40°C

### Transformer characteristics

<table>
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<tr>
<th>Transformers</th>
<th>Standard</th>
<th>HI-T Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resin characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Insulation class</td>
<td>155°C</td>
<td>180°C ✓</td>
</tr>
<tr>
<td>- Average temperature rise</td>
<td>100 K</td>
<td>125 K ✓</td>
</tr>
<tr>
<td><strong>Transf. characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Full load temperature rise</td>
<td>100 K ✓</td>
<td>100 K ✓</td>
</tr>
<tr>
<td>- Admissible overload</td>
<td>0</td>
<td>25 K ✓</td>
</tr>
<tr>
<td>- Extra power</td>
<td>0</td>
<td>15% ✓</td>
</tr>
<tr>
<td>- Impact on lifetime</td>
<td>0</td>
<td>x8 approx * ✓</td>
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</tbody>
</table>

*Every 6°K that the hot-spot temperature of a transformer is reduced, the insulation’s expected lifetime is doubled – Arrhenius/IEC 60076-12*
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Q&A
Generators supplying in delta configuration need an artificial neutral in order to allow limitation of unbalanced currents and of fault currents.

Grounding is generally achieved via a Neutral Grounding Resistor however the Ohmic value of the resistance and its insulation level may have heavy impact on its cost.

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**Challenge**

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---

**Solution**

Creates an artificial neutral by using a zigzag or delta-star grounding transformer with a low voltage secondary winding

It can be connected to a suitably rated resistor of which the other terminal is earthed

Reduces the insulation level and Ohmic value of the NGR

Allows monitoring of the currents
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Q&A
ABB dry-type transformers

Challenge – Safe and ecological substation equipment

Requirements

- Safety for people
  - No flammable materials
  - No pressurized tank
  - Self-extinguishing transformer

- Safety for the environment
  - No oil as main insulation
  - No possibility of oil spillage
  - Low fire load

- Low amount of civil works and maintenance
  - No oil-containment systems
  - No fire-fighting system
  - No oil maintenance
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Solution – High voltage substation transformer (Hi-Dry)

Design challenges

- Ratings up to 63 MVA
- Voltages up to 145 kV
  (Impulse 550 kV IEC / 450 IEEE)
- 17 positions OLTC on Primary side
- Suitable for indoor or outdoor installation
- Cooling AN, ANAF, AFAF, AFWF
- Partial discharges < 10 pC
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Challenges & solutions

- Inrush currents in transformers → Pre-mag transformer
- Vacuum circuit breakers and voltage surges → Transient Voltage Resistant™ Transformer
- High temperatures – overloads – lifetime → Hi-T Plus transformer
- Neutral creation → Earthing transformer
- High voltages → Hi-Dry (145 kV) transformer

Q&A
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Reasons for choosing ABB

**Why ABB dry-type transformers?**
With the largest global production and installed base, we are your number one partner for worldwide initiatives

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**Solutions for any application**
From offshore arctic oil platforms, to up-top wind turbine nacelles, to the world's tallest building, we have a custom solution to fit your need

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**Large portfolio of product**
Abilities include a full line of LV magnetics, MV distribution and rectifier duty, and the first for sub-transmission, we are your one-stop-shop for dry-type transformers

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<td>Easy connectivity to any system</td>
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