CWIEME BERLIN

3-5 JUNE 2025
MESSE BERLIN

A Hyve Event

Advances in Aramid Paper Insulation: Enhancing Transformer Safety and Performance

Radoslaw Szewczyk
Nomex® Technical Service & Development; **DuPont Nomex® Energy Solutions**

Contents

- Nomex® common applications
- Update on thermal performance
- Fire performance
- Portfolio of materials
- UL systems
- Emerging applications

Nomex® common applications

Timeline for transformer insulation systems with Nomex®

Photo: DuPont

1960's
Nomex® aramid paper developed by DuPont: Dry-type transformers and rotating machines

Photo: DuPont

1984
Traction transformers with Nomex® based insulation system

Photo: Delta Star

1984
First Mobile transformers with Nomex®

Photo: Weidmann

2021
Nomex® Wet Board for high voltage power transformers

1982
Nomex® Board development by Weidmann/DuPont

Photo: Weidmann

1988
Power transformers
Upgraded applications
Re-engineered with Nomex®

Photo: DuPont

Common applications

Dry-type transformers

- Low voltage general purpose
- Mining, marine, railways, drives
- Distribution transformers

Liquid-filled transformers

- Railway traction units
- Wind energy (onshore and offshore)
- Mobile power transformers
- Fast deployable, resiliency units

Robust, compact, light weight, overloadable, fire safe

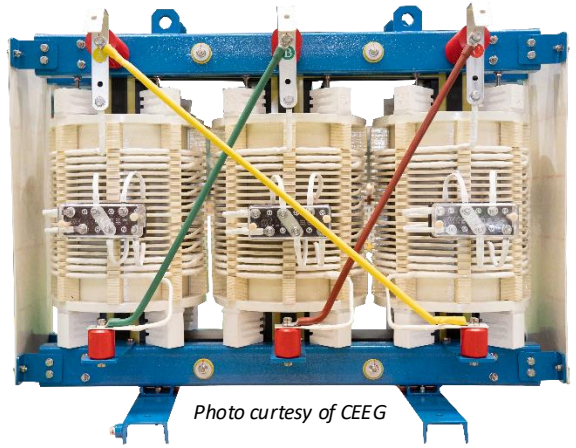
Photo curtesy of CEEG

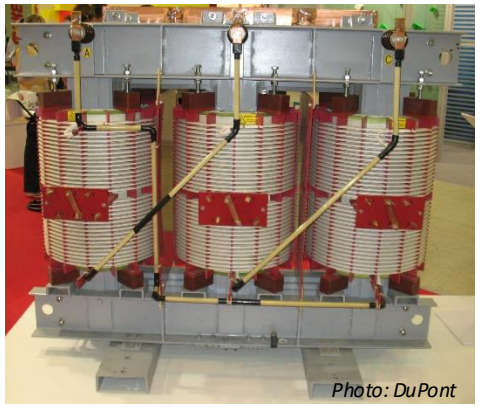
Photo: DuPont


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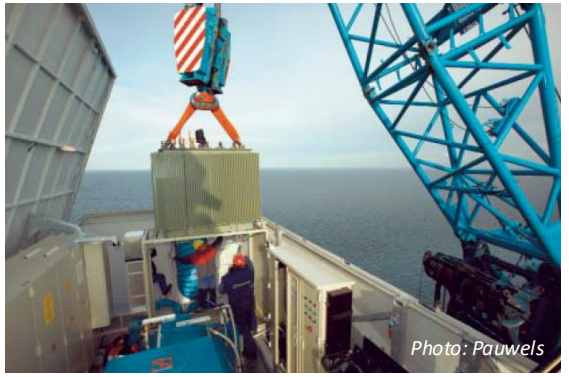
Photo: Pauwels


Photo: Pauwels

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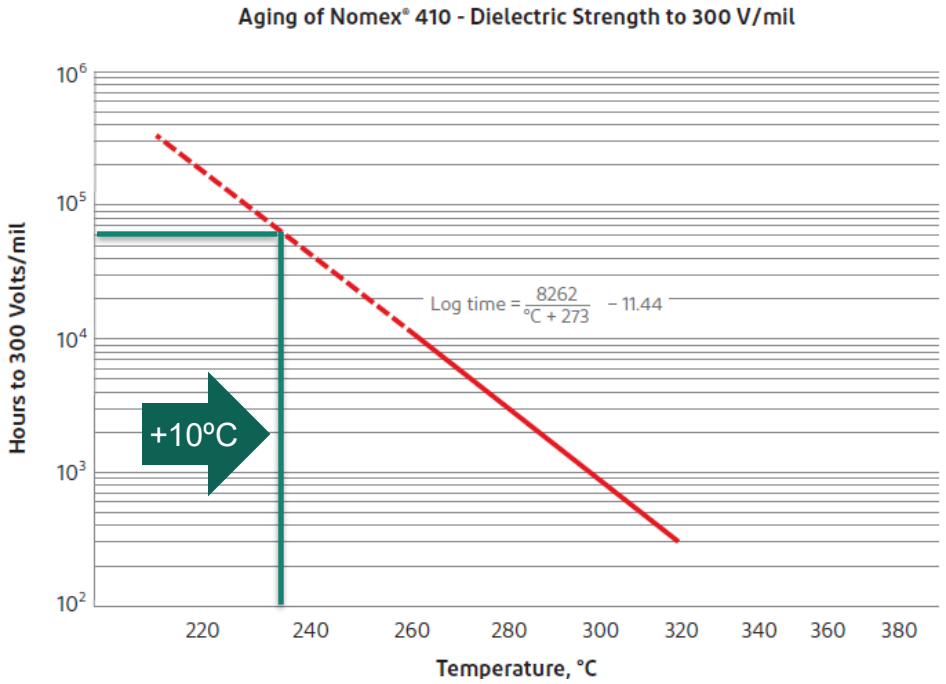
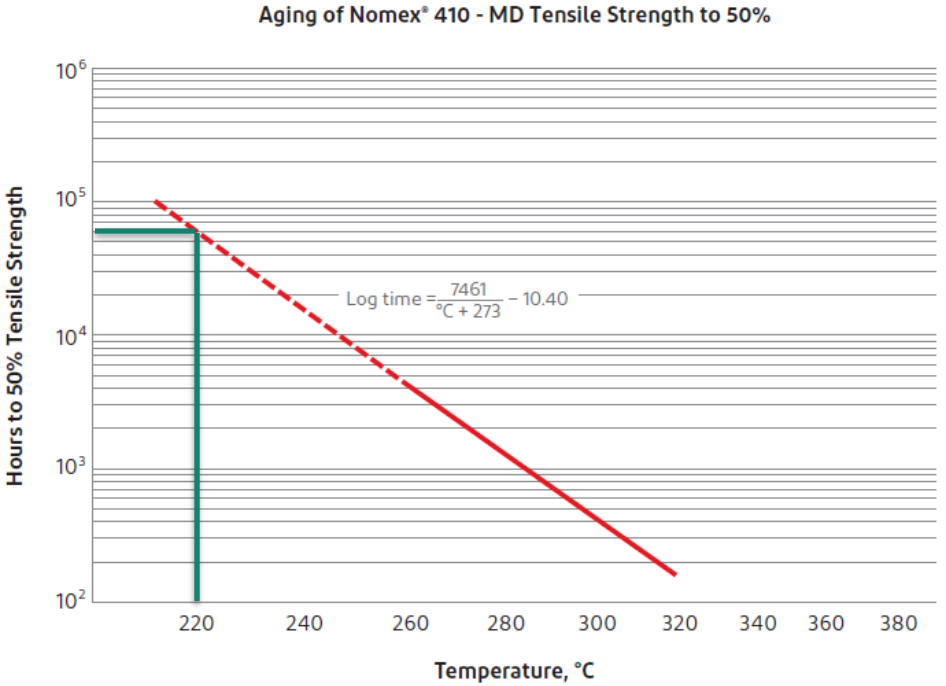
Update on thermal performance

Thermal performance – UL update

- Historically, UL component: 220°C
- Benchmark for other aramid papers (180-210°C)

- **Data shows higher Thermal Index (+10°C)**
  - **experience in manufacturing**
  - **proven performance**
  - **higher safety margins**
- **Rating 220°C proven also for thin paper (0.05 mm)**
  - **dielectric / mechanical – 235°C / 225°C**



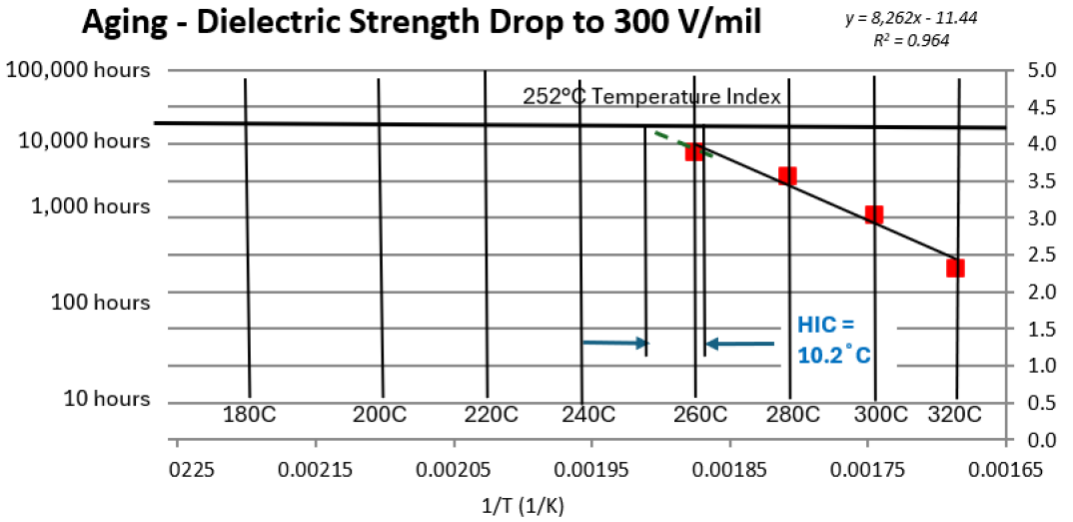


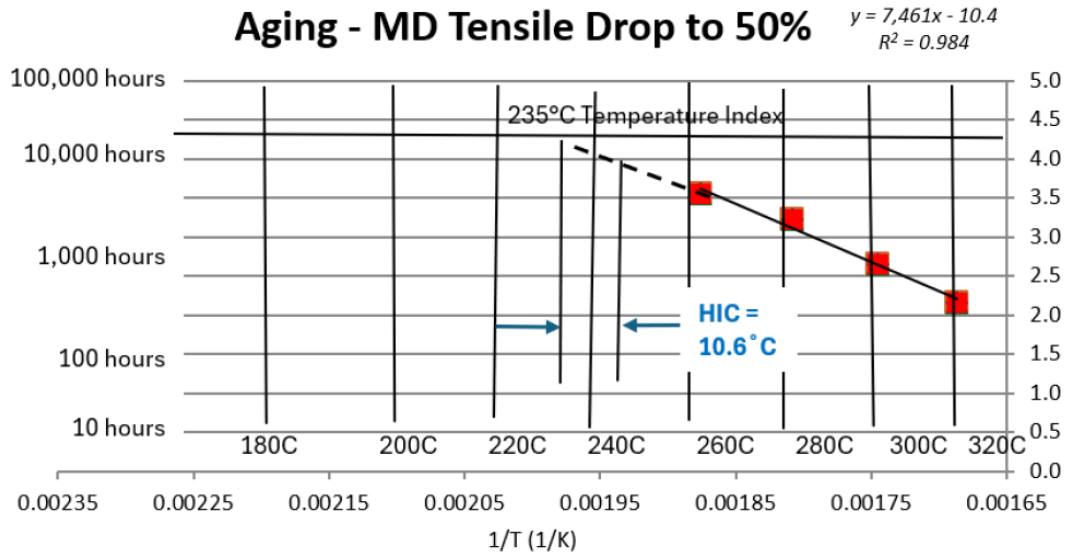
Thermal performance – IEC 60216

- Demand for IEC ratings from global industry
- Reference lifetime 20 000 h vs. 60 000 h
- Certification ongoing

Thermal Index

- **Dielectric: 252°C HIC=10.2°C**
- **Mechanical: 235°C HIC=10.8°C**

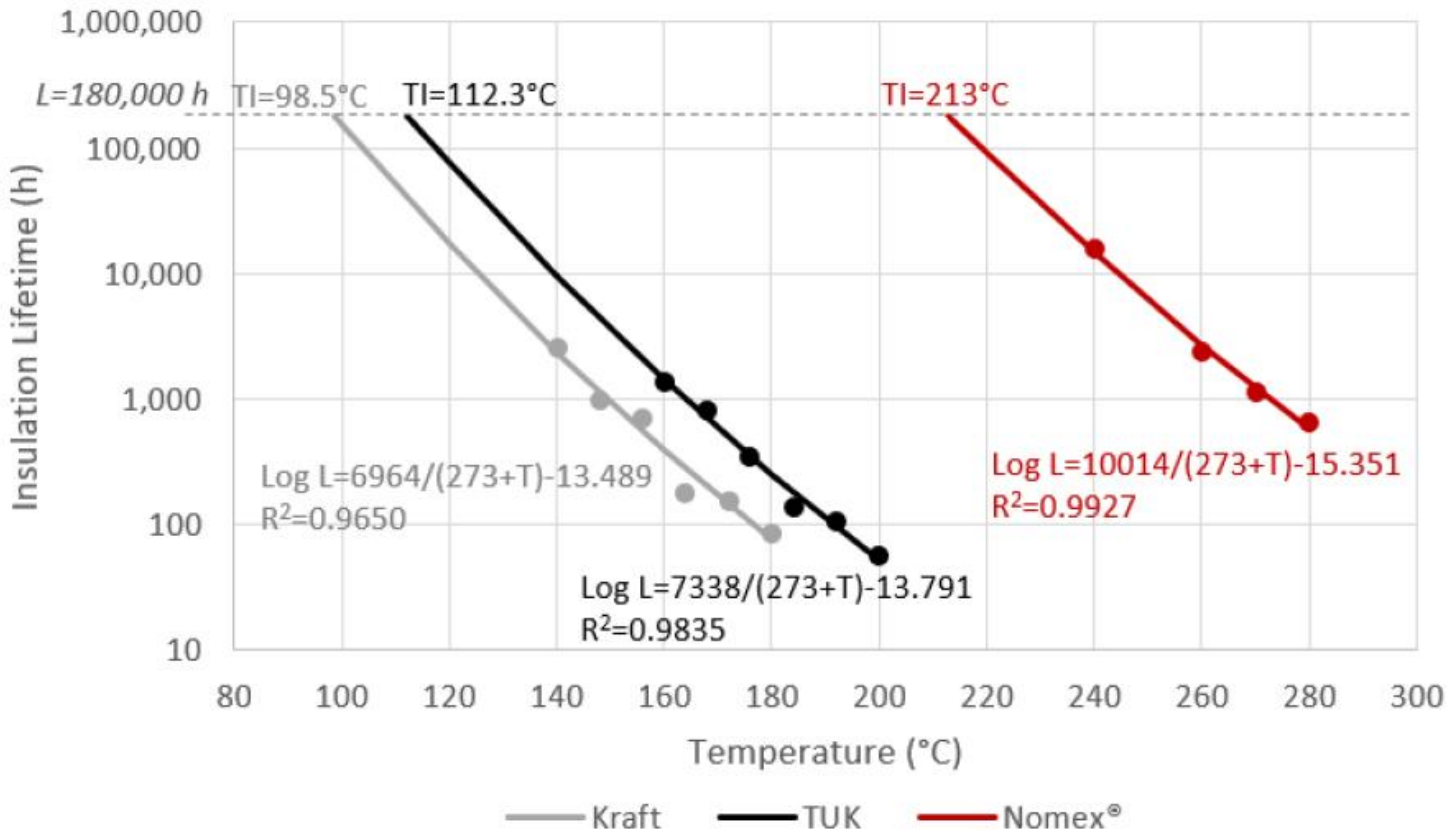




Thermal performance of Nomex® in transformer liquids

- Long-term insulation system aging in dual-temperature aging cells
- Reference: IEEE C57.100
- End-of-life criteria: 50% tensile retention

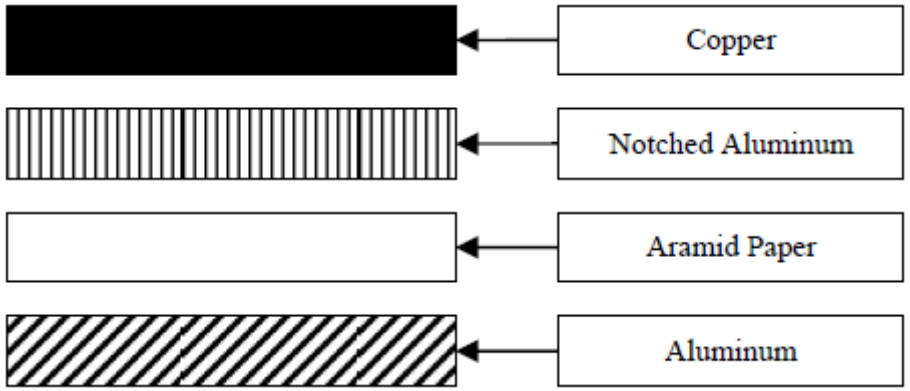
- **Suitable for class 180 (H) liquid filled insulation systems acc. to IEC/EN 60076-14 and IEEE C57.154**
- Aramid paper aging data can be used for aramid pressboards
- Aging data in mineral oil can be used for esters (same or better performance)



Thermal performance – going beyond standards

Nomex® papers are designed to maintain superior performance when aged

- in air (UL/IEC tests),
- in liquids,
- **but also, in presence of Cu or Al (to model real application).**



Temperature: 300°C; time in oven: 48 h

Test procedure described in: "*New Test Method to Evaluate the Thermal Aging of Aramid Materials*" by S. Filliben, Electrical Insulation Conference (EIC), 2011

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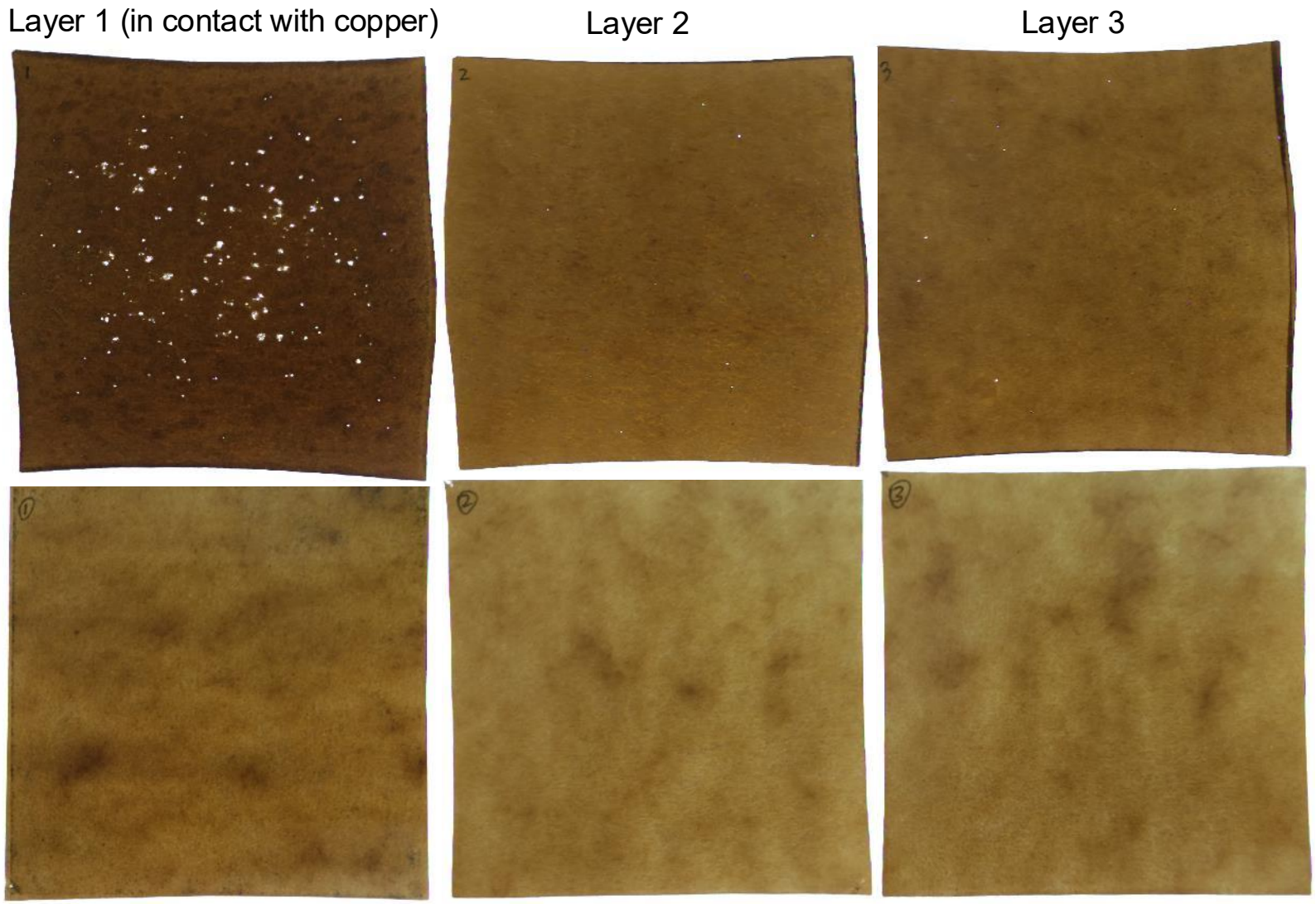
Aging with copper – spot degradation (pinhole) effect



- Tests conducted at DuPont CTC lab in Shanghai
- Test conditions: 48 h @ 300ºC

Different performance of aramid papers

	DuPont™ Nomex® 410	Lower performance aramid paper
UL/IEC thermal ratings - dielectric strength - tensile retention	220°C or higher	180-210°C
Spot degradation thermal rating - non-standard test (published in 2011) - aging in presence of Cu (photos: after 48 h @ 300ºC)	220°C 	<150°C 

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UL94* Fire rating ** Test method may not be adequate for thin papers typically used for conductor wrapping application.*	VTM-0 (from 0.10 mm) V-0 (from 0.13 mm)	VTM-0 (from 0.025 mm) V-0 (from 0.25 mm)

Fire performance

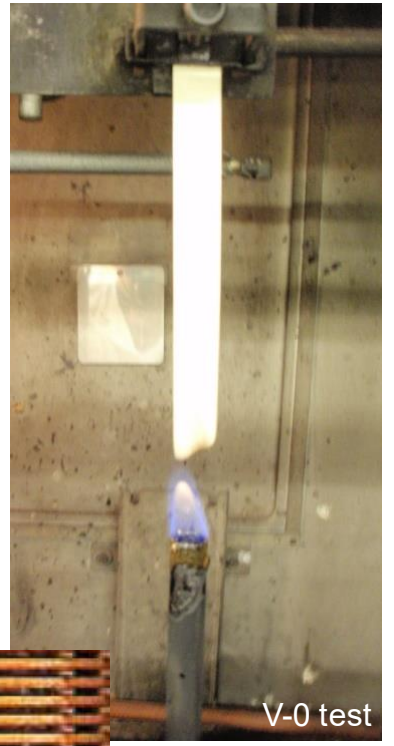
Fire performance

- UL94 V-0 class historically available for Nomex® papers (>0.1 mm)
- Fire performance proven in traction, mining, marine and other critical applications
- Fire certification as per EN 45545-2 (fire safety in railways) – HL2/HL3

EN 45545-2:2020

- *"The exposed surface of the test specimen shall be the same as in the end use condition."*
- *"Exposed surfaces of a material which form part of an assembly shall be tested (…)"*

UL94 testing:
paper fully exposed to air


V-0 test


VTM-0 test

Fire performance

- UL94 may not be suitable for thin papers used for conductor wrapping.
- Thin papers should be tested in conductor wrapping or layer insulation configuration.

Thin Nomex® papers (0.05-0.08 mm) getting highest fire performance class (HL3) when certified in winding model (EN 45545-2).

THIS CERTIFICATE REMAINS THE PROPERTY OF CSI SPA

CSI

CERT: 0668\DC\REA\25_3

ATTESTAZIONE DI CONFORMITÁ
STATEMENT OF ARTICLES COMPLIANCE

Visti i rapporti di prova CSI n. 0668\DC\REA\25_3 e 0053\DC\TOX\25_3
Referring to the CSI test reports n . 0668\DC\REA\25_3 and 0053\DC\TOX\25_3

si dichiara che
this is to declare that

Combined component - model of winding with DuPont Nomex® 410, 0.05 mm
(carta aramidica + barretta/piastra in rame)
(aramid paper + copper rod/plate)

Fornito da:
Supplied by:

DUPONT SPECIALTY PRODUCTS OPERATIONS Sàrl
Route du Nant-d'Avril, 154
CH-1217 MEYRIN - GE (Switzerland)

è conforme alla norma
is found to comply with the standard

EN 45545-2:2020 requisiti R22-R23 per HL1, HL2 e HL3
per le prove T01, T10.03 e T11.02
EN 45545-2:2020 requirements R22-R23 for HL1, HL2 and HL3
for the tests T01, T10.03 and T11.02

Data di rilascio/*certificate issue date*: 15/05/2025

Il documento è firmato digitalmente ai sensi del D.Lgs. 82/2005 s.m.i. e norme collegate e sostituisce il documento cartaceo e la firma autografa
The document is digitally signed in accordance with Legislative Decree n. 82/2005 as amended and replaces the paper document and the handwritten signature.

Ing. Paolo Mele

Pag.1/1

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EN 45545-2	**HL2 or HL3 (all thicknesses)**	?

Portfolio of materials

Building diversified portfolio for diversified needs

- Dry-type applications
  - Highest performance aramid papers
  - New economical grades for less demanding applications (Nomex® 358)

- Liquid-filled transformer applications
  - Grades with improved impregnability
  - Wet board for high voltage systems (Nomex® Wet Board)
  - Economical versions of cellulose enhanced with aramid (Nomex® 910)

- Advanced solutions for EV applications

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Nomex® insulation components


Photo: DuPont


Photo: Weidmann


Photo: Weidmann


Photo: Weidmann


Photo: DuPont


Photo: Weidmann


Photo: Schweizer


Photo: Weidmann

Example 1 – Wet board for high voltage power transformers

DuPont™ Nomex® Wet Board

- Experimental pressboard grade for wet forming of complex high voltage insulation components
- Suitable for angle rings, edge collars or snouts
- Suitable for class H (180) insulation systems as per IEC/EN 60076-14 or IEEE Std. C57.154

Photo: Weidmann

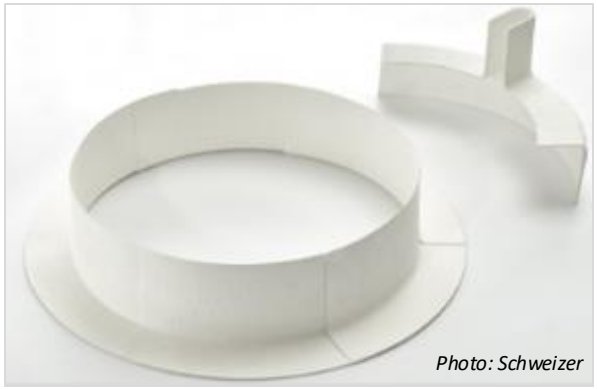
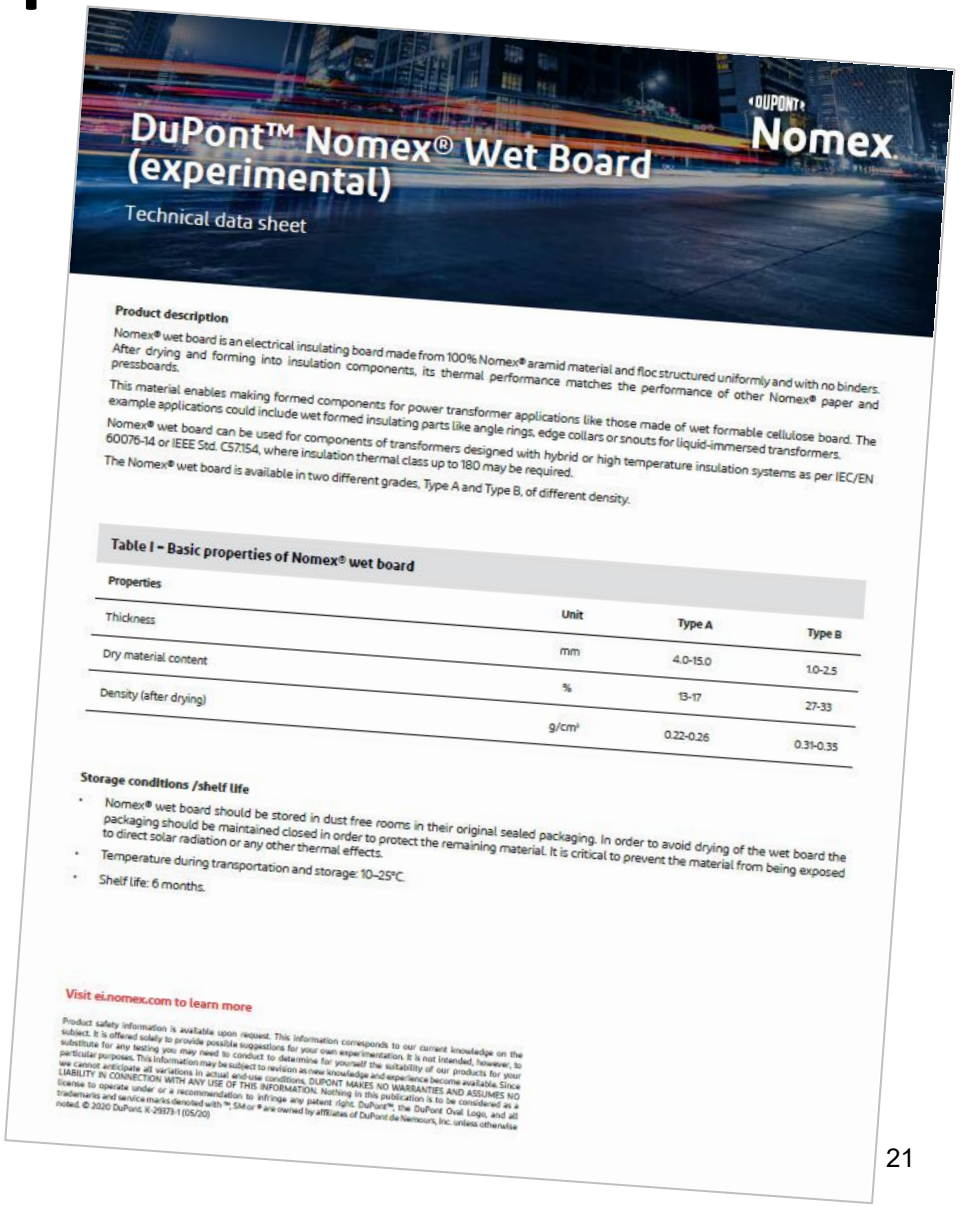


Photo: Schweizer



DuPont™ Nomex® Wet Board (experimental)

Technical data sheet

Product description

Nomex® wet board is an electrical insulating board made from 100% Nomex® aramid material and floc structured uniformly and with no binders. After drying and forming into insulation components, its thermal performance matches the performance of other Nomex® paper and pressboards.

This material enables making formed components for power transformer applications like those made of wet formable cellulose board. The example applications could include wet formed insulating parts like angle rings, edge collars or snouts for liquid-immersed transformers.

Nomex® wet board can be used for components of transformers designed with hybrid or high temperature insulation systems as per IEC/EN 60076-14 or IEEE Std. C57.154, where insulation thermal class up to 180 may be required.

The Nomex® wet board is available in two different grades, Type A and Type B, of different density.

Table I – Basic properties of Nomex® wet board

Properties	Unit	Type A	Type B
Thickness	mm	4.0-15.0	1.0-2.5
Dry material content	%	13-17	27-33
Density (after drying)	g/cm³	0.22-0.26	0.31-0.35

Storage conditions /shelf life

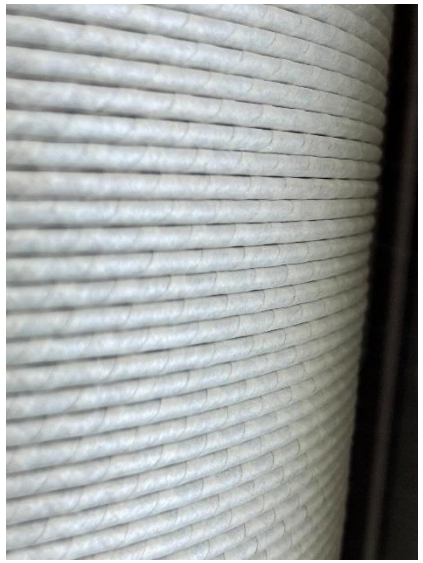
- Nomex® wet board should be stored in dust free rooms in their original sealed packaging. In order to avoid drying of the wet board the packaging should be maintained closed in order to protect the remaining material. It is critical to prevent the material from being exposed to direct solar radiation or any other thermal effects.
- Temperature during transportation and storage: 10–25°C.
- Shelf life: 6 months.

Visit ei.nomex.com to learn more

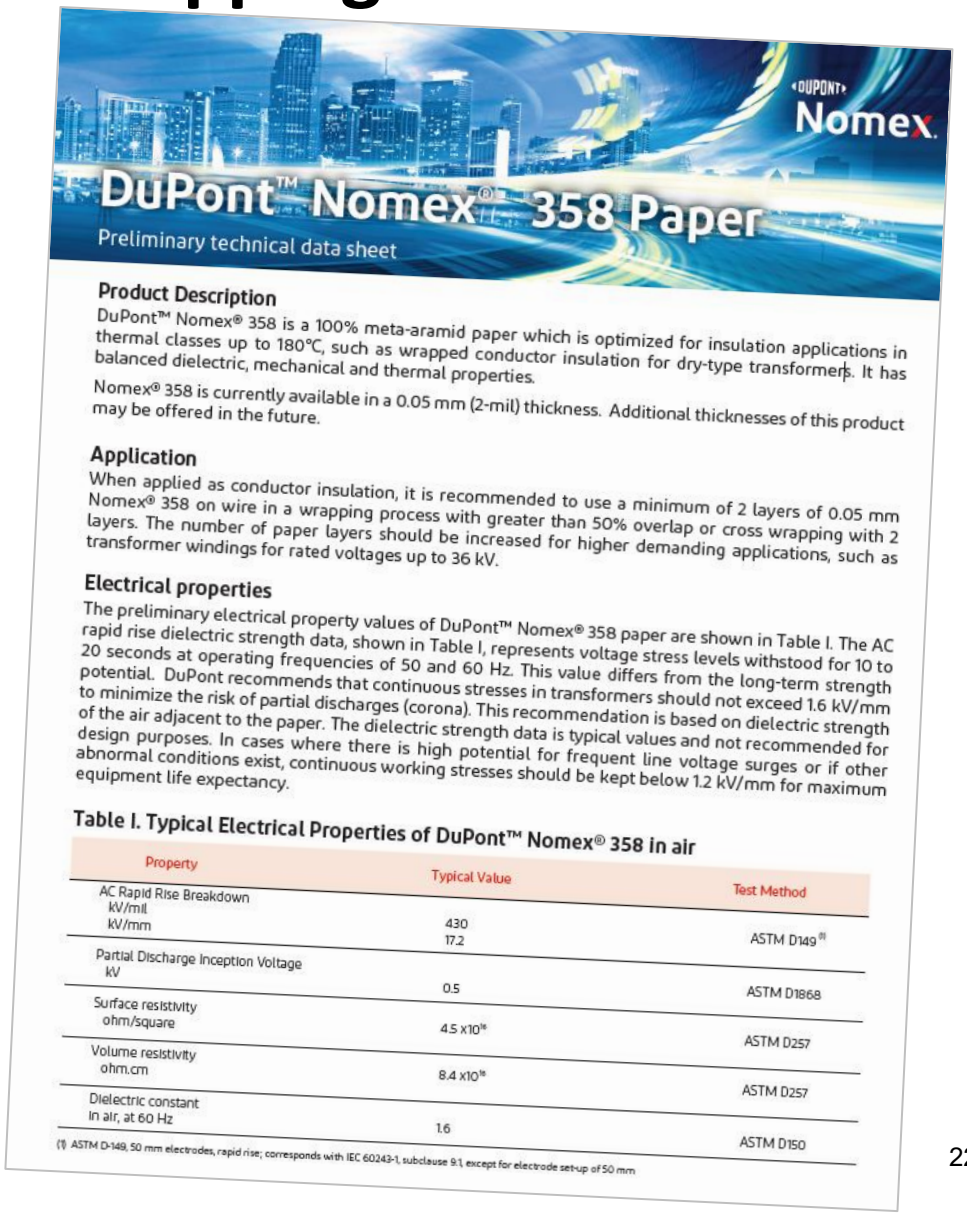
Example 2 - Economical paper for wire wrapping

DuPont™ Nomex® 358

- Meta-aramid paper optimized for balanced dielectric, mechanical and thermal properties
- Thermal class 180°C
- For conductor wrapping in dry-type transformers



Photos: DuPont



DuPont™ Nomex® 358 Paper

Preliminary technical data sheet

Product Description

DuPont™ Nomex® 358 is a 100% meta-aramid paper which is optimized for insulation applications in thermal classes up to 180°C, such as wrapped conductor insulation for dry-type transformers. It has balanced dielectric, mechanical and thermal properties.

Nomex® 358 is currently available in a 0.05 mm (2-mil) thickness. Additional thicknesses of this product may be offered in the future.

Application

When applied as conductor insulation, it is recommended to use a minimum of 2 layers of 0.05 mm Nomex® 358 on wire in a wrapping process with greater than 50% overlap or cross wrapping with 2 layers. The number of paper layers should be increased for higher demanding applications, such as transformer windings for rated voltages up to 36 kV.

Electrical properties

The preliminary electrical property values of DuPont™ Nomex® 358 paper are shown in Table I. The AC rapid rise dielectric strength data, shown in Table I, represents voltage stress levels withstood for 10 to 20 seconds at operating frequencies of 50 and 60 Hz. This value differs from the long-term strength potential. DuPont recommends that continuous stresses in transformers should not exceed 1.6 kV/mm to minimize the risk of partial discharges (corona). This recommendation is based on dielectric strength of the air adjacent to the paper. The dielectric strength data is typical values and not recommended for design purposes. In cases where there is high potential for frequent line voltage surges or if other abnormal conditions exist, continuous working stresses should be kept below 1.2 kV/mm for maximum equipment life expectancy.

Table I. Typical Electrical Properties of DuPont™ Nomex® 358 in air

Property	Typical Value	Test Method
AC Rapid Rise Breakdown kV/mil kV/mm	 430 17.2	ASTM D149 (1)
Partial Discharge Inception Voltage kV	 0.5	ASTM D1868
Surface resistivity ohm/square	 4.5×10^{16}	ASTM D257
Volume resistivity ohm.cm	 8.4×10^{16}	ASTM D257
Dielectric constant In air, at 60 Hz	 1.6	ASTM D150

(1) ASTM D-149, 50 mm electrodes, rapid rise; corresponds with IEC 60243-1, subclause 9.1, except for electrode set-up of 50 mm

Different performance of aramid papers

	DuPont™ Nomex® 410	DuPont™ Nomex® 358
IEC thermal ratings - dielectric strength - tensile retention	220°C	180°C
Spot degradation thermal rating - non-standard test (published in 2011) - aging in presence of Cu	220°C 	180°C 
UL94* Fire rating ** Test method may not be adequate for thin papers typically used for conductor wrapping application.*	VTM-0 (from 0.10 mm) V-0 (from 0.13 mm)	-
EN 45545-2	HL2 or HL3 (all thicknesses)	HL3

Enhancing transformer safety and performance

Advanced tests for insulation components

Dielectric tests

- Breakdown through material
- Creep strength
- PDIV in glued components

Mechanical tests

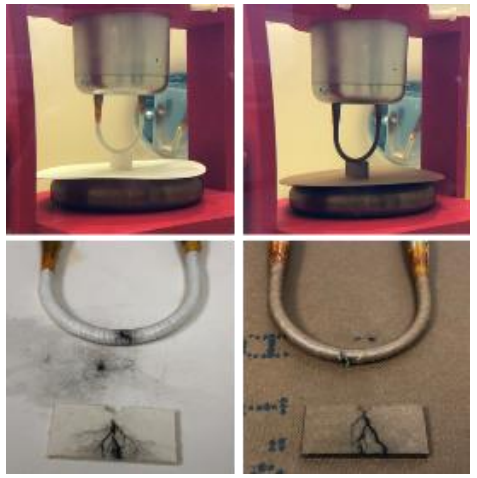
- Dynamic vs. static
- Dry material vs. oil impregnated
- Materials after thermal aging
- Adhesive materials (e.g. diamond dotted papers)

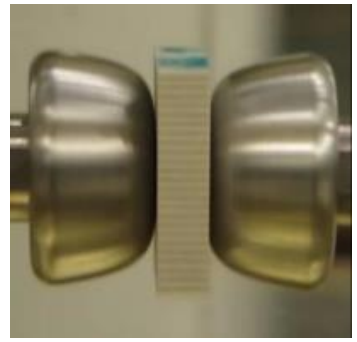
Thermal tests

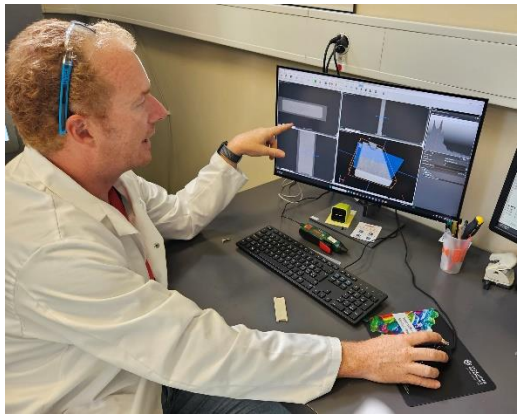
- Dual temperature test for hybrid systems (hot conductor – cool remote areas)
- Reference to cellulose aging

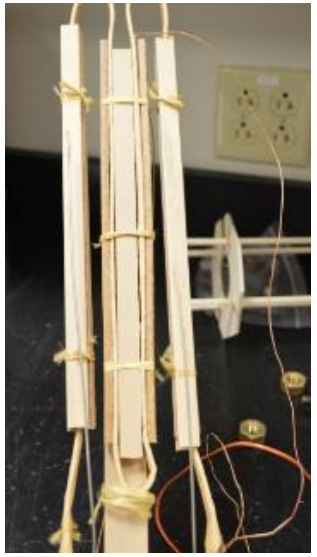
Chemical compatibility

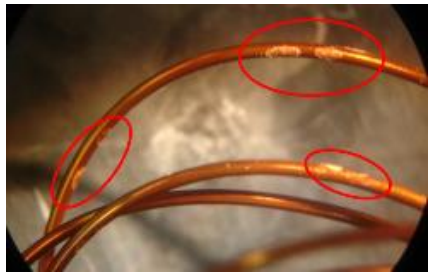
- Variety of new liquids
- Impacts on solid insulations and on liquids











Photos: DuPont

UL systems

UL Components and UL Electrical Insulation Systems (EIS)

Component / EIS	Standard
Insulation materials	UL 746 Standard for Polymeric Materials
LV EIS	UL 1446 Systems of Insulating Materials
EIS for dry-type transformers	IEEE Std. C57.12.60 Standard for Thermal Evaluation of Insulation Systems for Dry-Type Power and Distribution Transformers
EIS for liquid filled transformers	IEEE Std. C57.100 Test Procedure for Thermal Evaluation of Insulation Systems for Liquid-Immersed Distribution, Power, and Regulating Transformers

- Most of Nomex® papers and pressboards are **UL components**
- Multiple **LV systems** – support to industry in construction of reliable LV equipment (transformers and reactors)
- Selection **HV systems** – 15 kV and 34.5 kV
- Unique **UL system for liquid-filled transformers**: “Nomex® + Ester 130”

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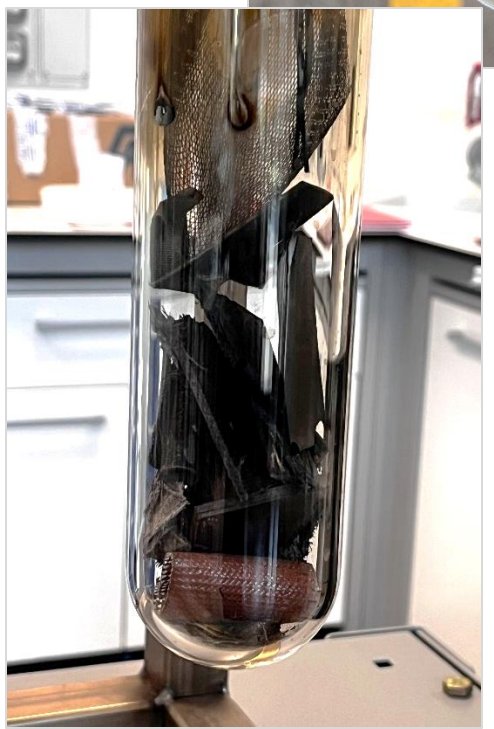
Variety of UL systems available

Authorizations

- DuPont developed multiple LV and HV systems to serve the industry
- Avoid time consuming and costly system developments

Modifications

- Existing systems can be modified to actual manufacturer needs
  - List of materials (tapes, laminates, prepregs…)
  - Varnishes / resins
  - Chemical compatibility test – typical requirement
- DuPont works on adjusting selected systems to satisfy local industry needs



Photos: DuPont

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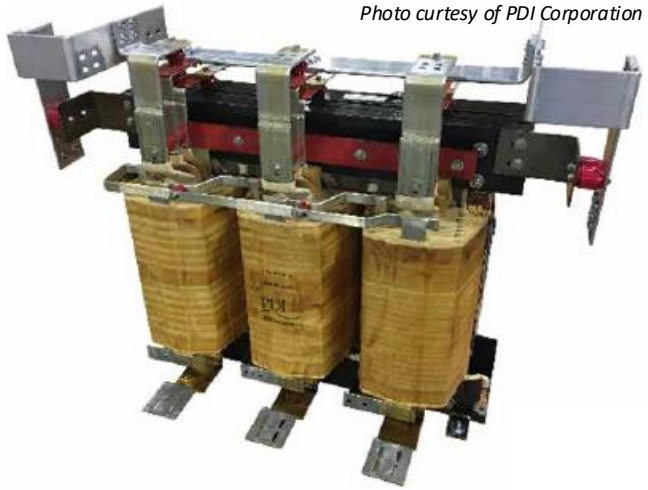
Emerging applications

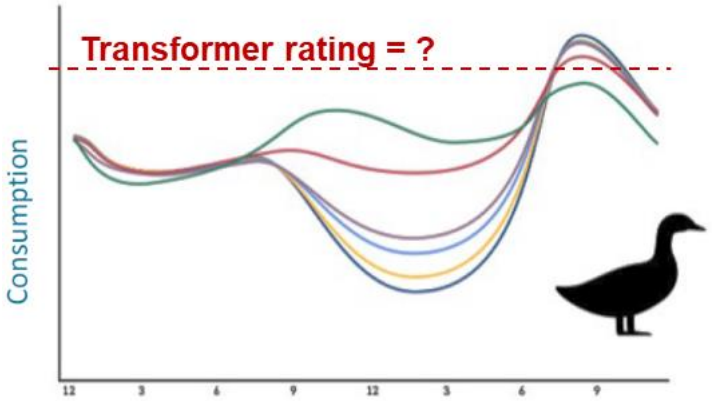
Emerging applications benefiting from Nomex®

Additionally to existing demanding applications…

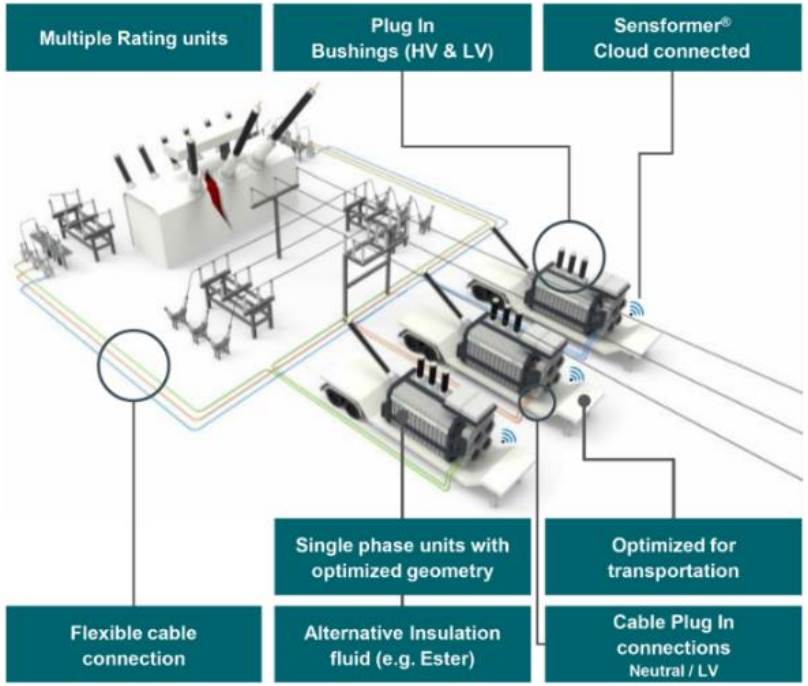
- Data center transformers (K-factor transformers, harmonic distortion)
- Large offshore wind turbine units (compactness, reliability)
- Solar PV installations (periodic loading)
- Sustainable Peak Loading units (loading flexibility)
- Resiliency overloadable power transformers

Photo curtesy of PDI Corporation





Source: Users viewpoint by E.DSO, 2022 ECI Transformers Workshop



Graphic by Siemens Energy

Thank you for your attention ☺

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