TRANSFORMERS MAGAZINE'S
INDUSTRY NAVIGATOR

SUSTAINABILITY AND DIGITALIZATION

Transformers digitalization in practice: Smarter decisions to operate and maintain

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Hitachi Energy - Transformers
June 2023

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Agenda: Smarter decisions to operate and maintain

- Trends & Challenges
  - ✓ Mega-trends driving digitalization: Energy transition & decentralization
  - ✓ Challenges: How transformers behave and fail
- How can Digital help:
  - ✓ Hitachi's approach to enable digital transformers; **The digital ecosystem**
  - ✓ Practical cases
  - ✓ The digital Ecosystem in detail
  - ✓ Cybersecurity aspects

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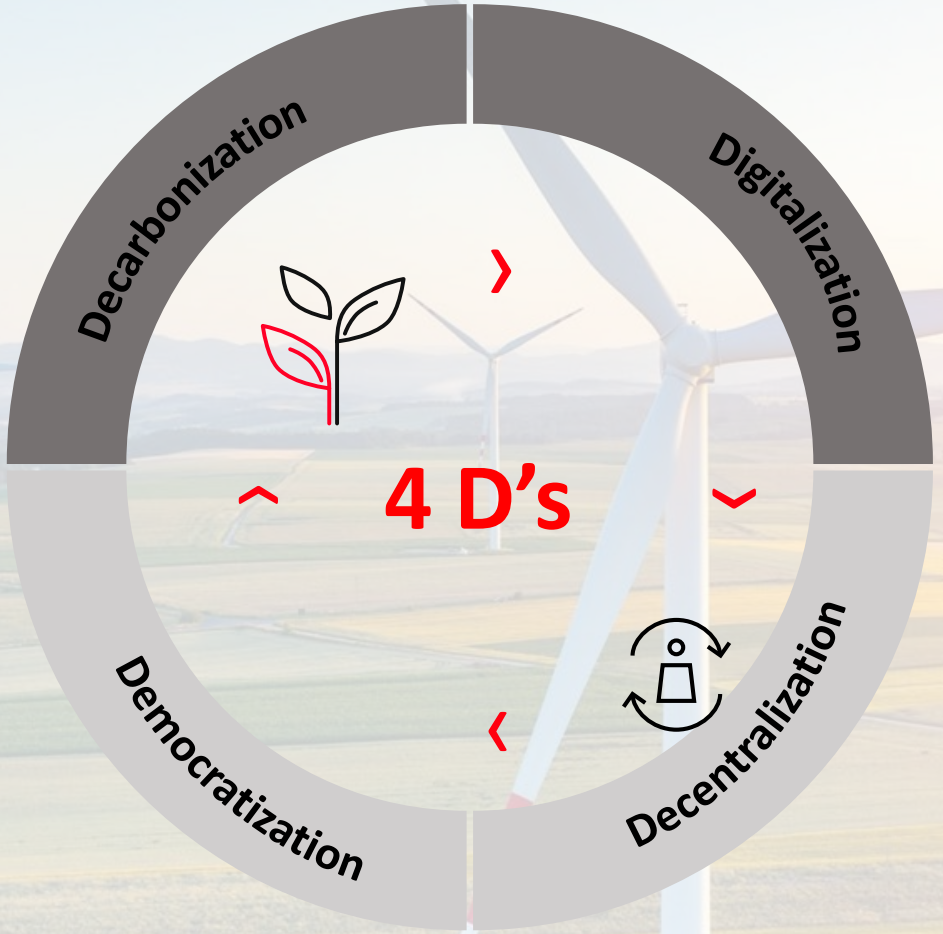
Energy Transition – 4 D's

DECARBONIZATION
IPCC TAR **Observed** warming of the Earth's surface, attribution of observed warming to human activities imperative to reduce carbon emissions = **we can no longer rely on burning fossil fuels**.

DEMOCRATIZATION
The energy system will no longer be confined to "Power houses" or experts, it will be opened up so that any interested and motivated stakeholder can actively engage and make a difference.



DIGITALIZATION
We must harness digital technologies, mastering the world of sensors and data analytics, machine learning (ML), and the internet of things (IoT).

DECENTRALIZATION
We are now embracing decentralized energy resources (DERs), moving from relatively few remote bulk generation points. Transitioning to "the grid to millions" of smaller locally based systems.

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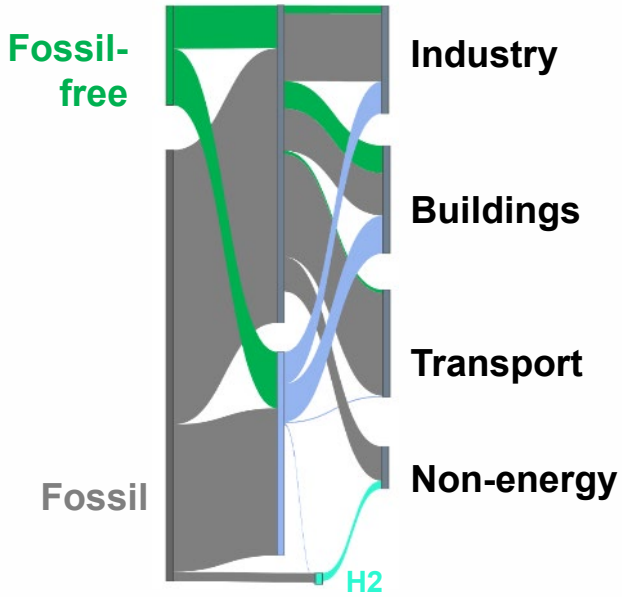
Accelerating towards a carbon-neutral energy system

World today
~20% electrification

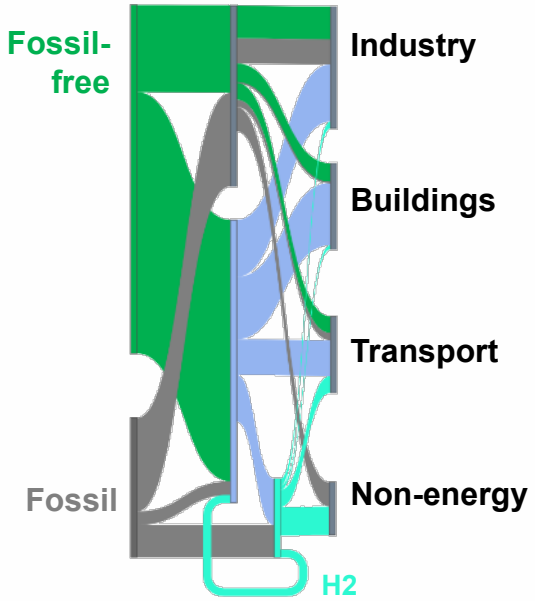
Primary energy sources dominated by fossil fuels

Electrification ~20% of total energy consumption, mainly from coal and gas

Variable renewable contribution small



World in 2050
> 50% electrification



Power generation & transfer x3

Electrification & system efficiency Increasing

Variable renewable capacity ~20 times

Significant transformation in all markets

Optimise asset use and rapid digitization to achieve net zero targets

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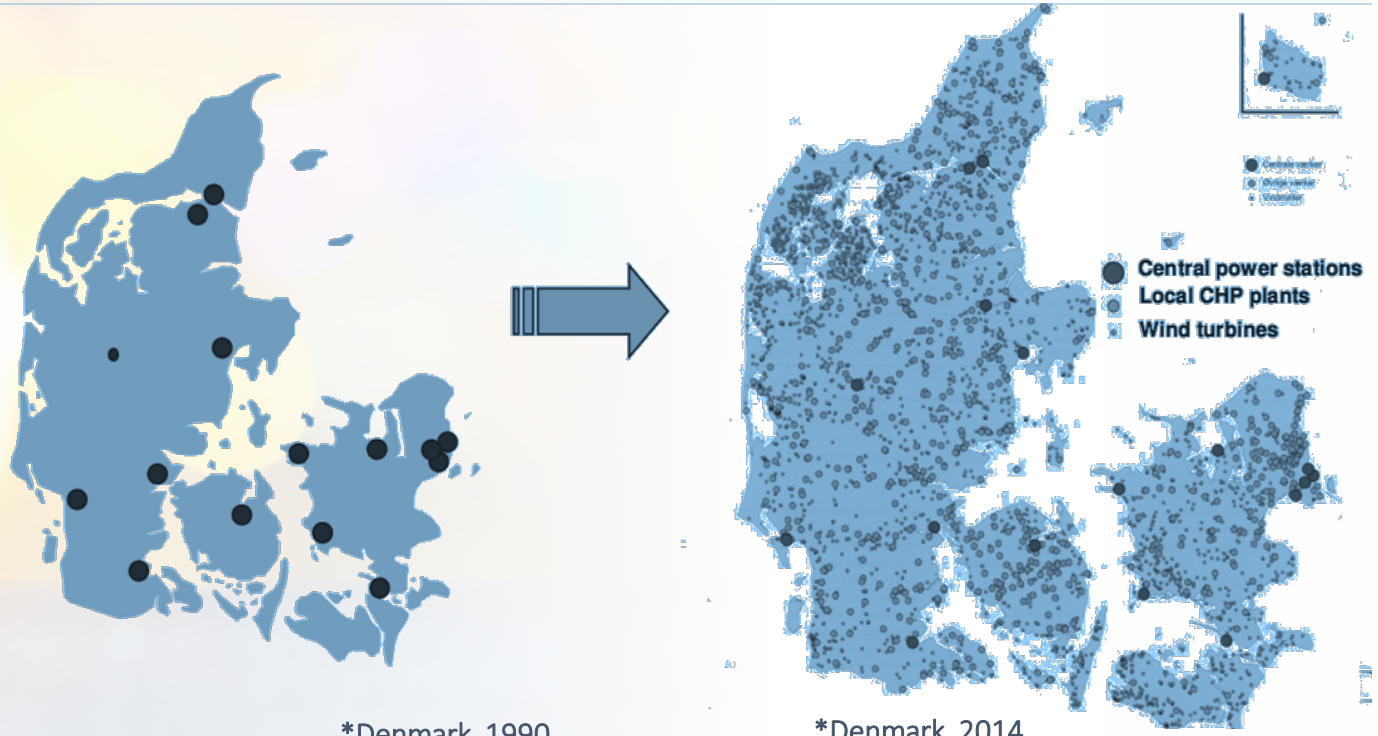
Decentralisation – what does it look like?

Energy transformation

From centralized and well controlled generation	To distributed and weather dependent generation
From deterministic and well defined load profiles	To volatile and reverse power flows
From load following control	To demand integrated in system operations
From operations based on historical data	To operations based on dynamic needs



*Denmark, 1990

*Denmark, 2014

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Decentralization of energy production has challenged many countries in the world

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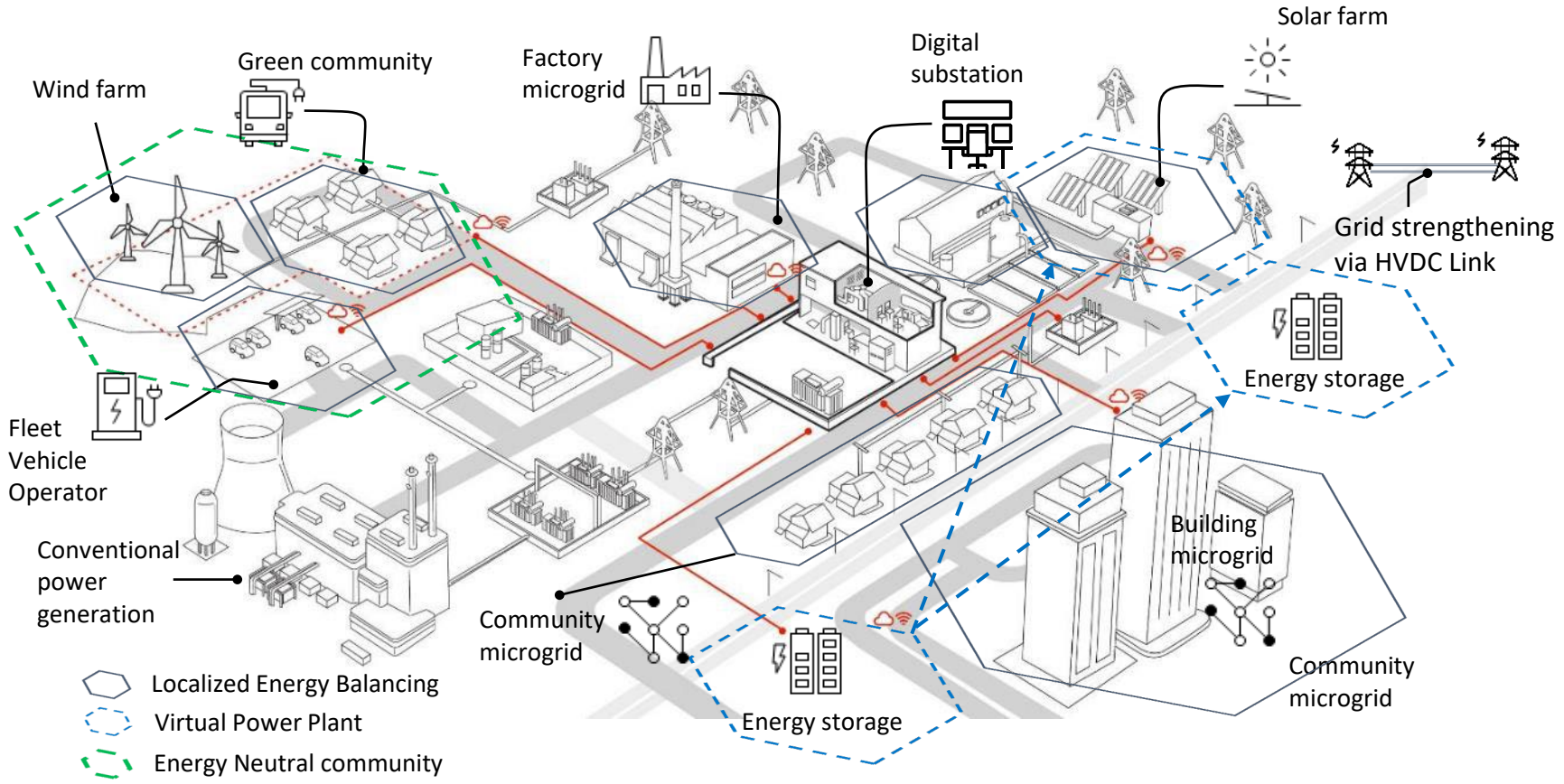
Energy system 2050: digitalization is fundamental

“Decarbonization is transforming the energy system

1. Accelerated shift from fossil-based to renewable power generation
2. Growing electrification of Transportation, Industry and Buildings sectors
3. Leading to a massive increase in the number of smart systems to be integrated & managed



Digitalization is the only way to manage this complexity

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The challenge: Transformers reliability and life expectancy

Though robust, externalities will shorten life expectancies of Transformers

Aging equipment

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

Distributed generation

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

Environmental forces

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

Increasing demand

Growing need for AC to DC conversion subjects electrical networks to increased harmonics and transients

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External stresses are the number one cause of failure of transformers

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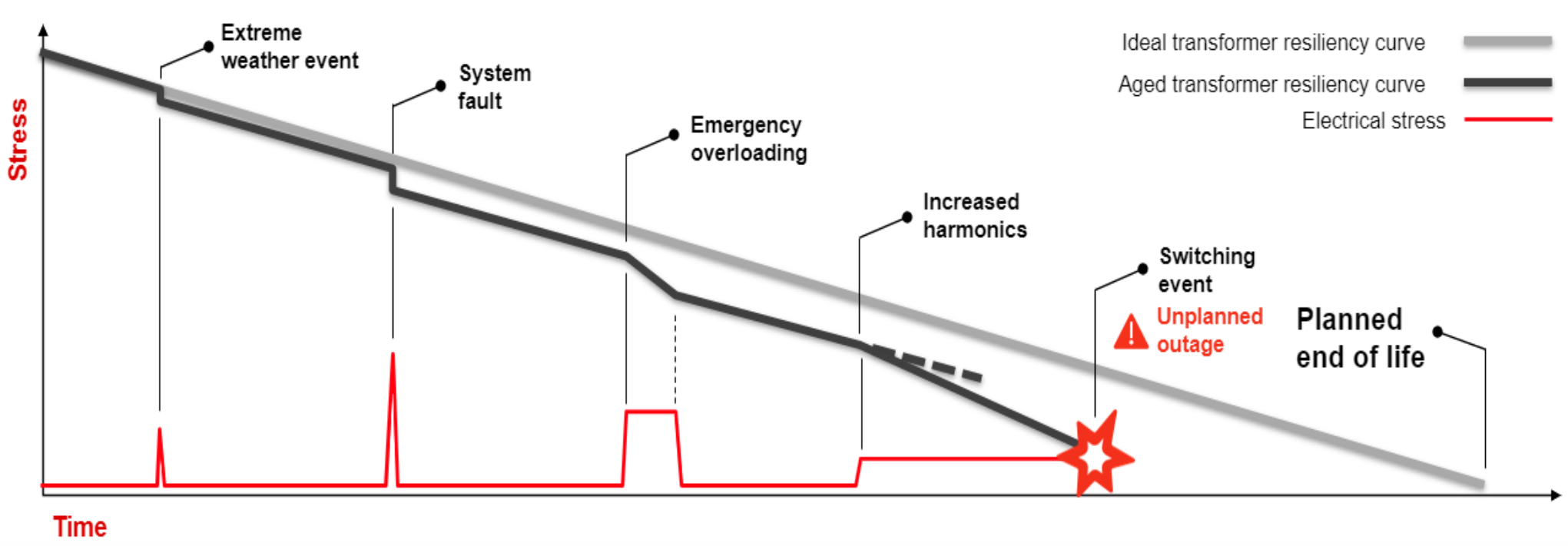
The lifecycle of a transformers

Transformer lifecycle



Unplanned outages are costly and result in significant downtime
With proper monitoring, they can be avoided

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Transformer failure analysis

Online monitoring covers >80% of transformer failures

Online monitoring covers >80% of transformer failures

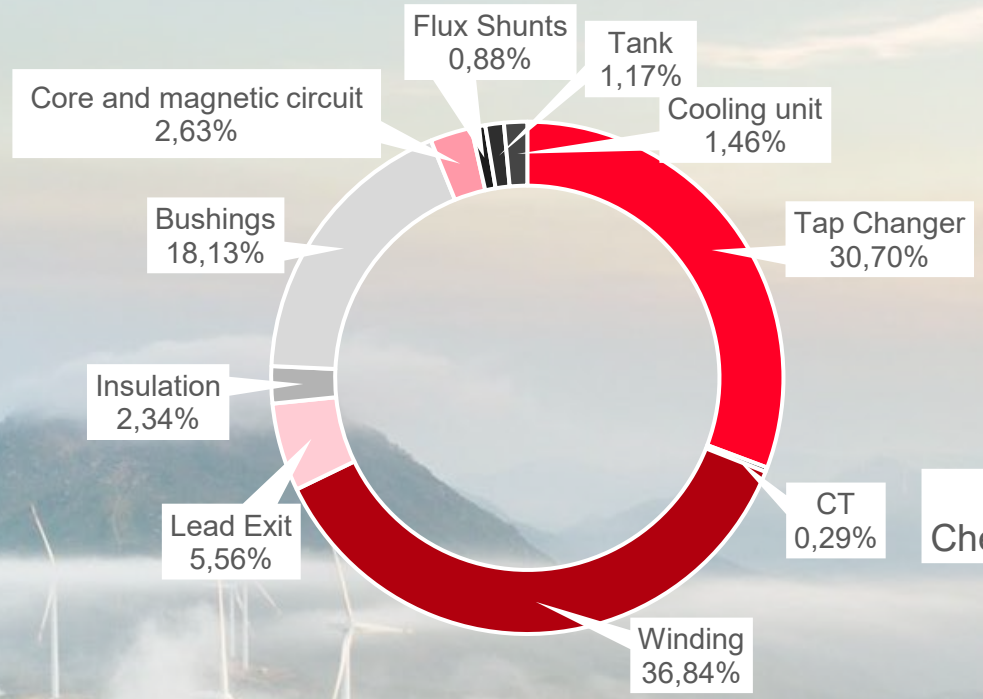
Failure rate

Between 0.5% and 2.5%

Industry average 1%

10 per 1000 fail in a year

Failure location



Failure mode

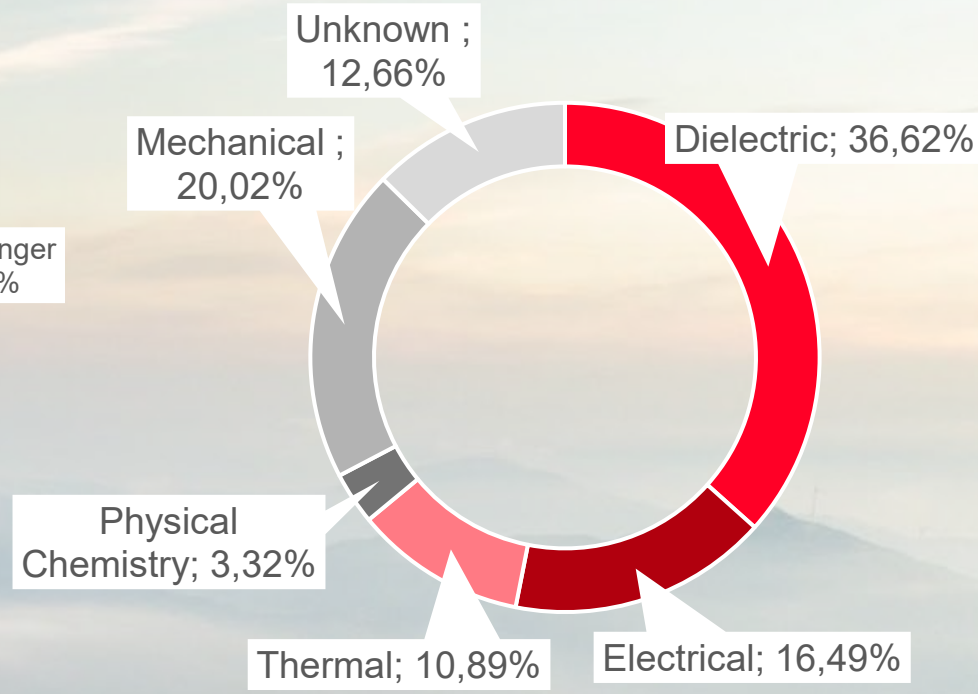


Fig 40 (342) Source: Cigre report TB 642/2015 Fig 42 (964)

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*Cigre Report TB642/2015 Transformer Reliability Survey

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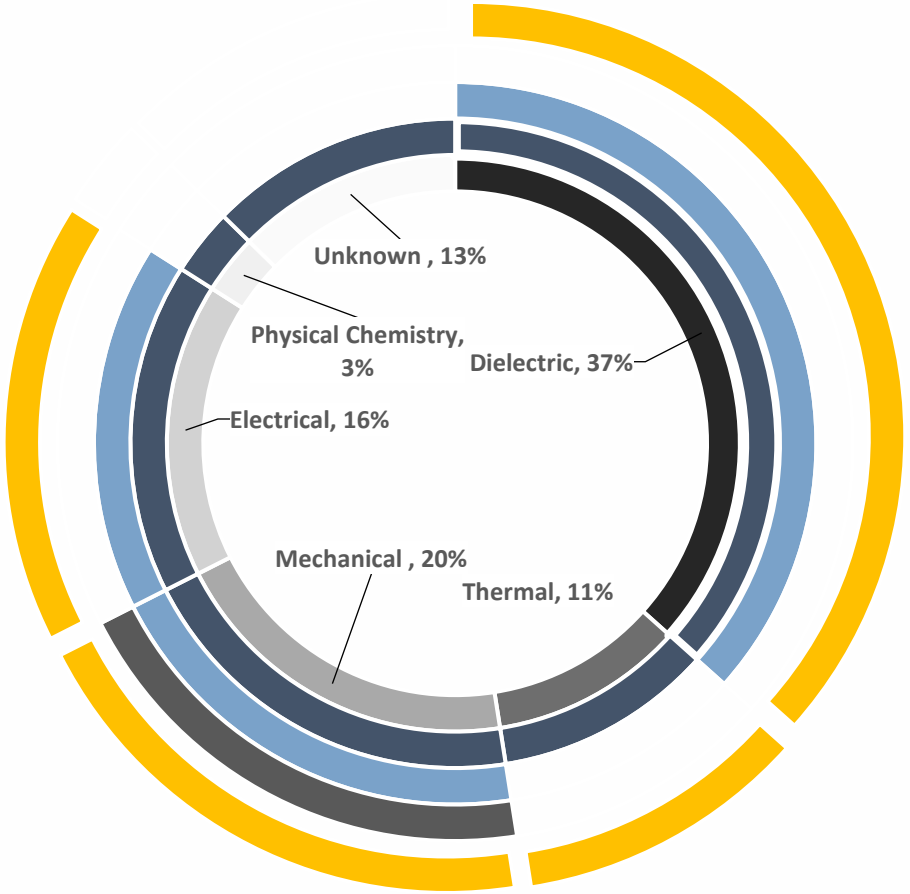
Reading the early warning signs



	Early warnings	Thermal	Electrical	Mechanical	Chemical
Mechanical faults	Short circuit	✓	✓	✓	✓
	Winding displacement	✓		✓	✓
	Winding looseness	✓		✓	✓
Electrical faults	Partial discharge		✓		✓
	Over voltage/ through faults	✓			✓
	Arcing		✓		✓
Thermal faults	Cooling issues	✓			✓
	Insulation ageing				✓
	Overloading	✓	✓		✓
	Overheating (e.g. Improper Connection)	✓			✓
Accessories	Cooling system	✓	✓	✓	✓
	Bushings	✓	✓	✓	✓
	Tap changers	✓		✓	✓
	Oil preservation system	✓			✓

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TXpert™ Ecosystem: Transforming performance

Reduced cost and risk

- **50% lower risk** of serious failures*
- **60% reduction in revenue loss** due to unanticipated problems/outages*
- **75% reduction in repair costs** due to early detection*

Optimized operations

- Maintenance driven by actual condition rather than time-based.
- Efforts focused on the right transformers at the right time.
- Remote analytics prior to physical inspection or costly activities.

Extend life-expectancy

- Prevents deterioration by trending and monitoring potential threats.
- Avoids unnecessary replacement with 'end of life' assessment.
- Unlocks additional capacity for added revenue.

Enhance environmental performance

- Facilitates easy integration of renewable generation sources.
- Prevents failures and their consequential environmental impact..
- Prolongs the life of the asset with predictive maintenance.

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*Cigre TB248, Economics of Transformer Management

*Cigre TB248, Economics of Transformer Management

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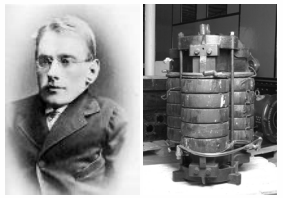
Our rich history of leadership in transformers and digitalization

1890
Jonas Wenström, a Swedish engineer from ASEA (later ABB) invented the world's first commercial three-phase electric power system, including the three-phase transformer



1980
Fiber optic temperature monitoring pioneered by Hitachi Energy

1990s
First digital control introduced for transformers

2001
Transformer Electronic Control (**TEC**) introduced to enable condition monitoring

2005
Remote monitoring introduced with **TEC version 2**

2010
Self Dehydrating Breather **eSDB** with digital tracking is launched

2013
Asset Health Center enterprise asset management solution is introduced, today known as **Ellipse®**

2015
CoreSense™ DGA sensors provide continuous monitoring for transformer faults

2016
Hitachi Energy continues to innovate in digitalization, launching **AssetShield™** ballistic detection and response solutions

2017
Hitachi Energy launches **TXpert™** the world's first digital distribution transformer and **CoreSense™ M10** multi-gas DGA

2018
Launch of the **TXpert™ Enabled Power Transformer** sets the digitalization benchmark. **TXplore™** Safe, fast and internal robotic inspection

2019
Hitachi Energy to launch **TXpert™DRY** the world's first digital dry distribution transformer and **APM EDGE** Station level solution.

2020 & the future
TXpert™ Ecosystem, Machine learning Artificial intelligence to maximize transformer performance

A truly interconnected smart grid emerges

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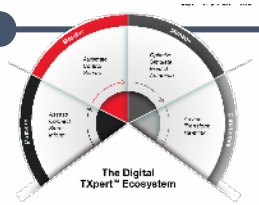
Evolving the technology, retaining our expertise

2001 *TEC*
Transformer Electronic Control (TEC) introduced to enable condition monitoring.

2009 *TEC 2.2*
Improved version, building on early pioneering experience from the field.

2018 *CoreTec™ 4 + AAPT*
Off the shelf and market competitive device, Powers the worlds first digitally native Power Transformer (AAPT).

2020 *TXpert™ Ecosystem*
Open, Modular, Scalable Manufacturer agnostic for Green & Brownfield.



2023 *CoreTec™ 5 & TXpert™ Hub* New hardware for remote monitoring.
Build on the CoreTec 4 software foundation
Meets cyber security, retrofitability and compatibility requirements.

2019 *TXpert DRY*
World's first dry-type digital transformer

2017 *TXpert Distribution*
World's first digital distribution transformer

2021 Remote Monitoring

2020 APM Edge

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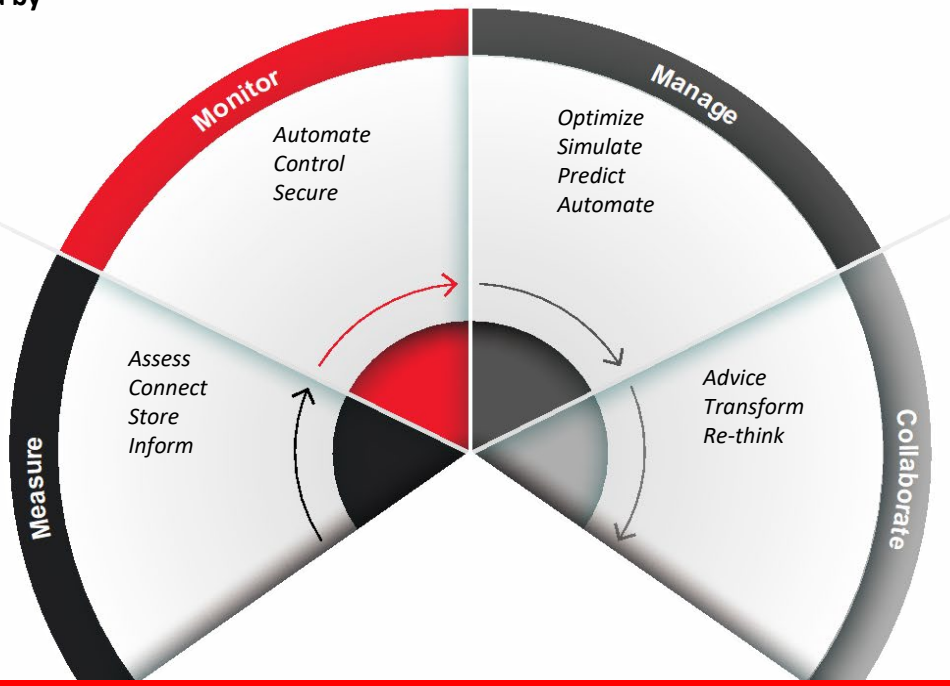
From Digital Products to a whole Ecosystem

TXpert™ Hub

Transformer Monitoring System powered by CoreTec

The Digital TXpert™ Ecosystem



Lumada APM

Asset Performance Management
Edge
On-premise
Cloud

TXpert Ready Sensors

Temperature,
Dissolved gases,
Bushing and tap changer,
And more…

TXpert Services

Transformer Care
Service Agreements

TXpert OnDemand
Device hire

And more…

Unlocking more value by expanding the boundaries

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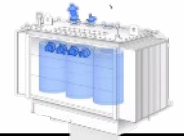
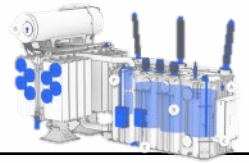
Actionable Insights for new and existing transformers





		Distribution DRY		Distribution Oil		Power		
		Basic	Basic+	Basic	Basic+	Basic	Basic+	Advanced
Thermal	Temperature Monitoring	✓	✓	✓	✓	✓	✓	✓
	Cooling control / Cooling exercise	✓	✓			✓	✓	✓
	Hot-spot temperature / Ageing		✓	✓	✓	✓	✓	✓
	Hot-spot forecast / Overload capacity					✓	✓	✓
Electrical	Voltage & Current Unbalance Factor / Voltage & Current Total Harmonic Distortion		✓		✓			
	Individual Harmonics / Voltage Crest Factor / Harmonic Loss Factor		✓		✓			
	Phase & Line Voltage / Reactive and Apparent Power / Power Factor / Frequency		✓		✓			
	Bushing Capacitance / Bushing Dielectric dissipation factor (tanδ and Δtanδ) / Bushing Leakage current						✓	✓
Chemical	Fast forming faults with hydrogen and moisture trend analysis				✓		✓	✓
	Bubbling temperature / Moisture in paper				✓		✓	✓
	Detailed analysis with IEC gas ratios / Rogers Ratios / Duval triangles							✓
Mechanical	Number of operations / Next recommended maintenance							✓
	Contact wear for Hitachi Energy tap changers							✓

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Thermal Management – Use case

Industrial customer detects a fault

- Industrial plant installed online monitoring: DGA, temperature and load monitors on its transformer.
- Operator detected an increase of dissolved gasses due to an increase of oil temperature while constant load.
- The monitoring system allowed our experts to detect the blocking of a OFWF heat exchanger due to a mineral buildup.

Based on data gathered with CoreTec 2

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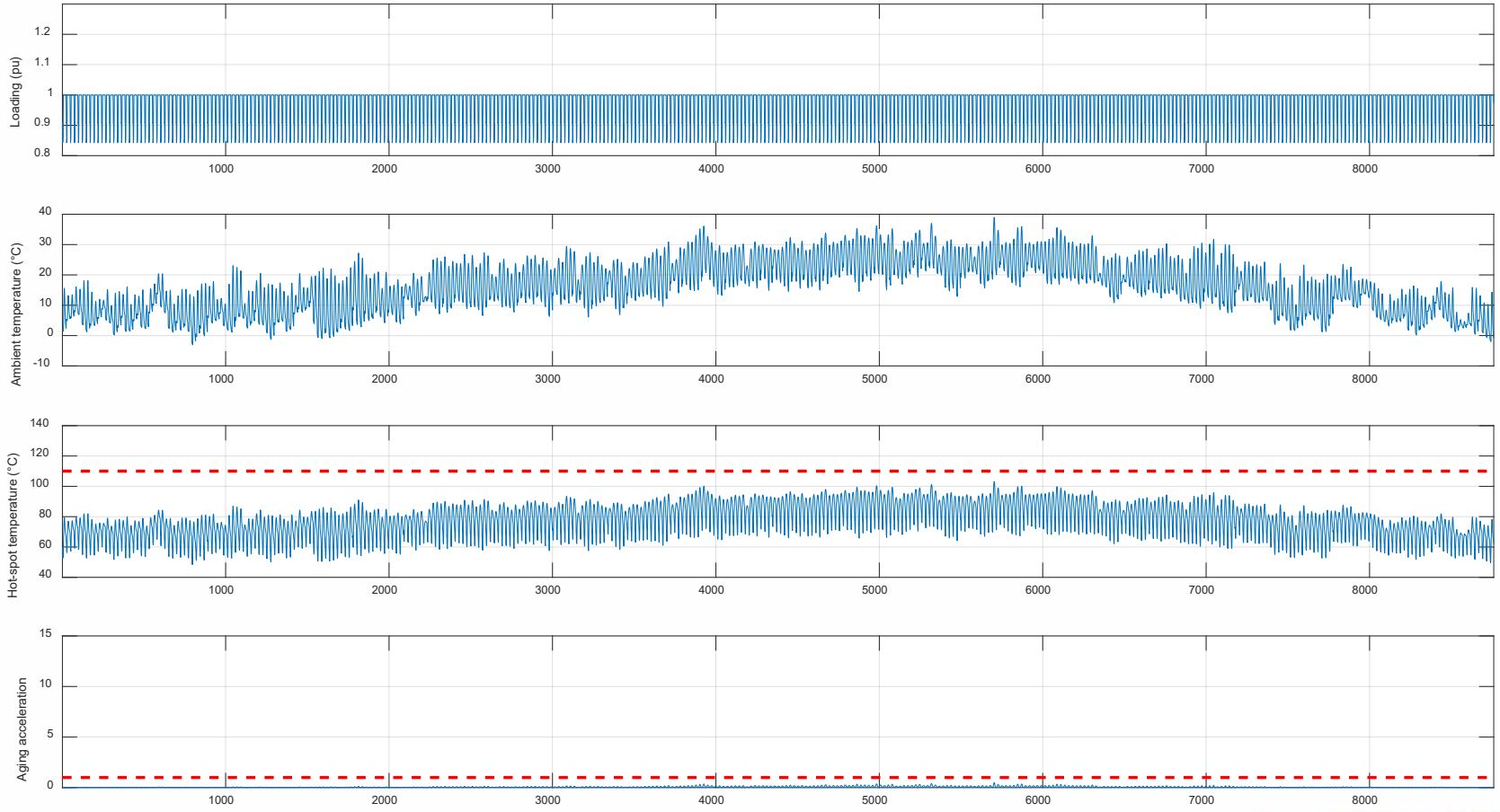
Thermal Analysis Theory

Overload Capability (1/3) - Nominal rating (500 MVA)



- Unit loaded at 100% at all time
- Ambient temperature varying over time
- Hot-spot temperature under limit (red line) even when Ambient is high
- Aging accelerating factor acceptable

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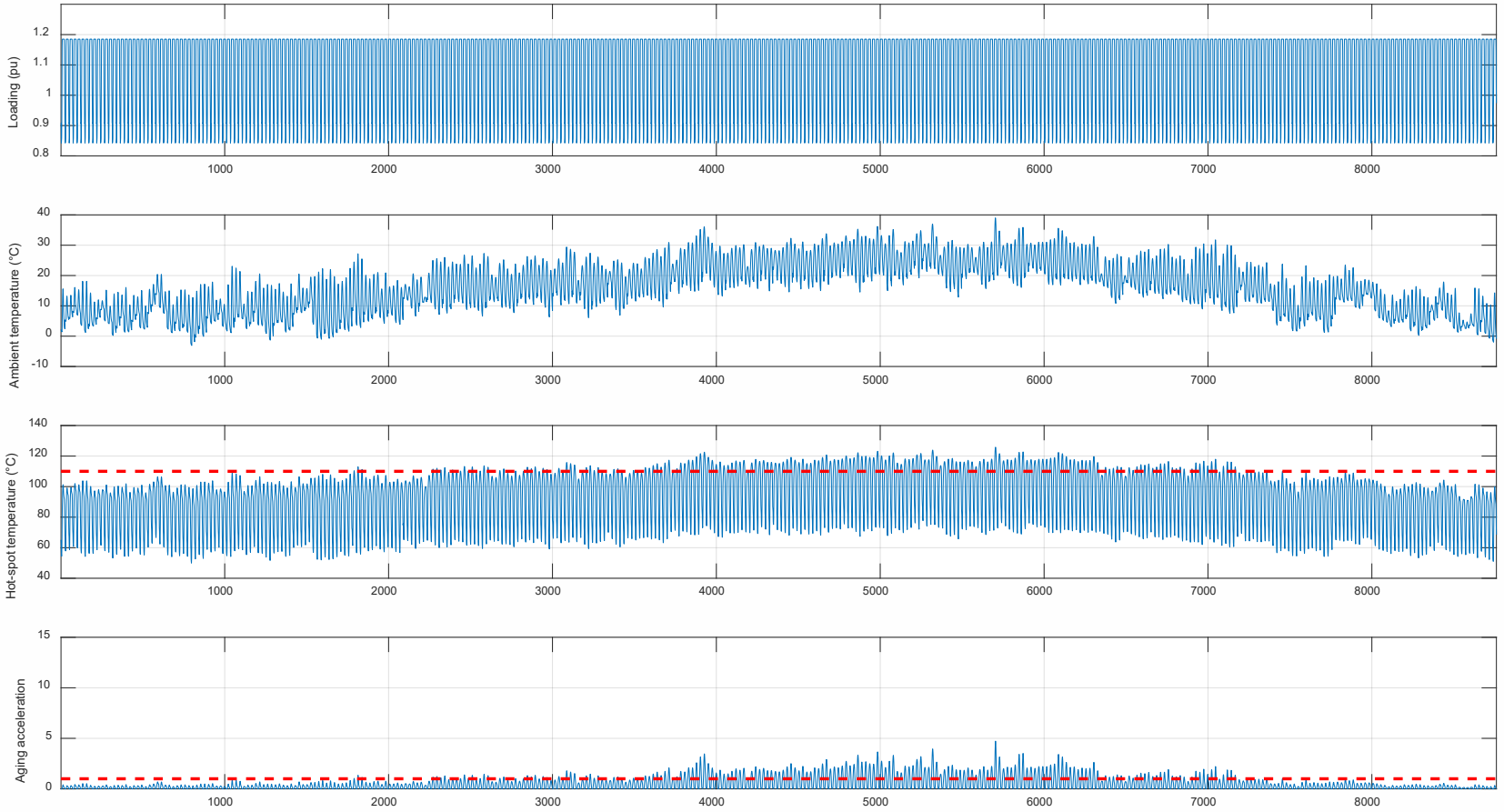
Thermal Analysis Theory

Overload Capability (2/3) - Operator-selected maximum flow (590 MVA)



Unit overloaded at 120% at all time

Ambient temperature varying over time

Hot-spot temperature above limit (red line) when Ambient is high

Aging accelerating factor jumps up to 5 when hot-spot over limit

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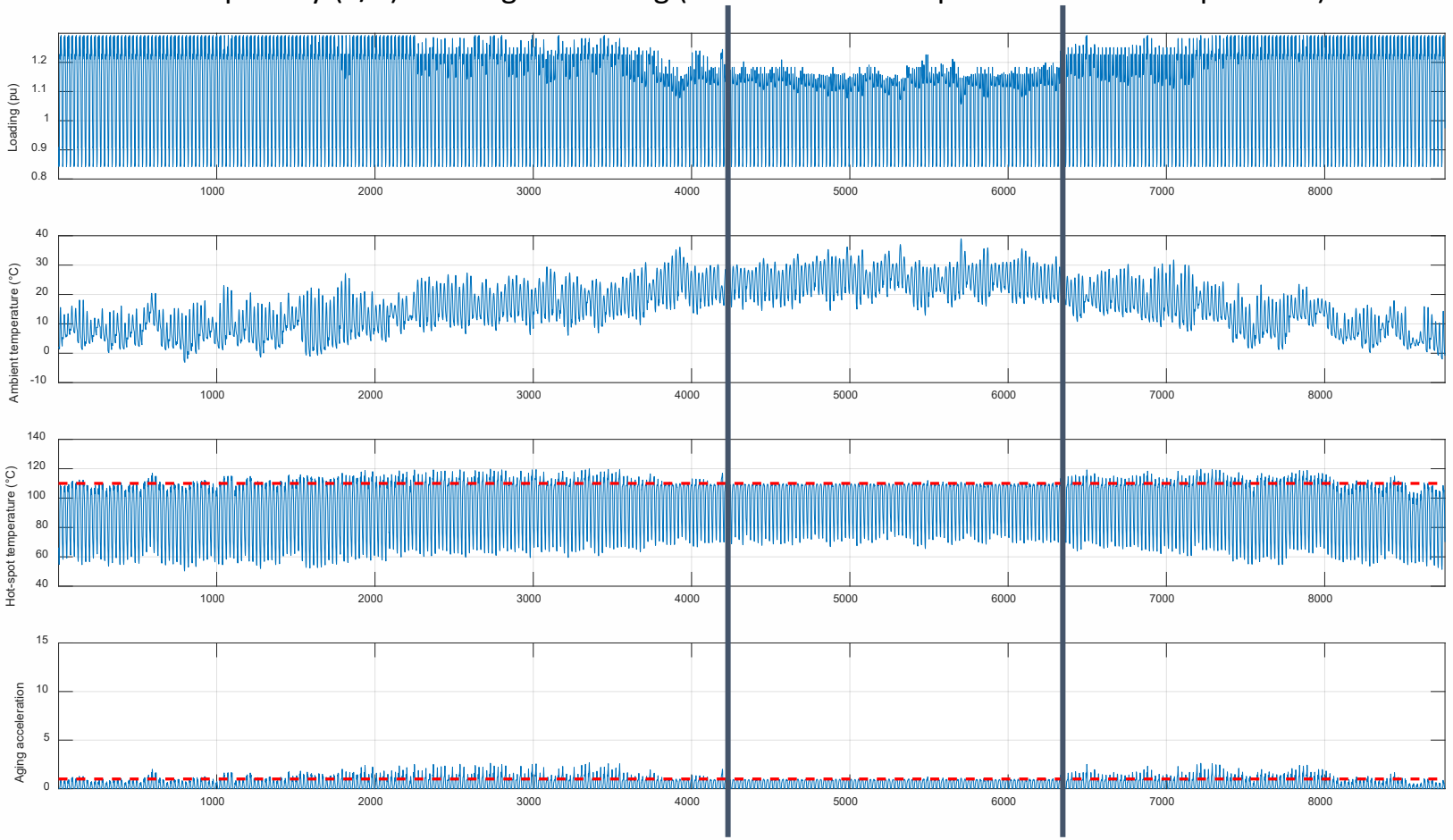
Thermal Analysis Theory

Overload Capability (3/3) - Intelligent loading (maximum MVA depends on amb. temperature)



Unit overloaded between 140% and 110% depending on hotspot limit

Ambient temperature varying over time

Hot-spot temperature kept close to the limit (red line) at all time

Aging accelerating factor acceptable with intelligent loading

Note that CoreTec only enables the operator to do intelligent loading by providing the data to make informed decisions about overloading, and does not actually control the loading of the transformer

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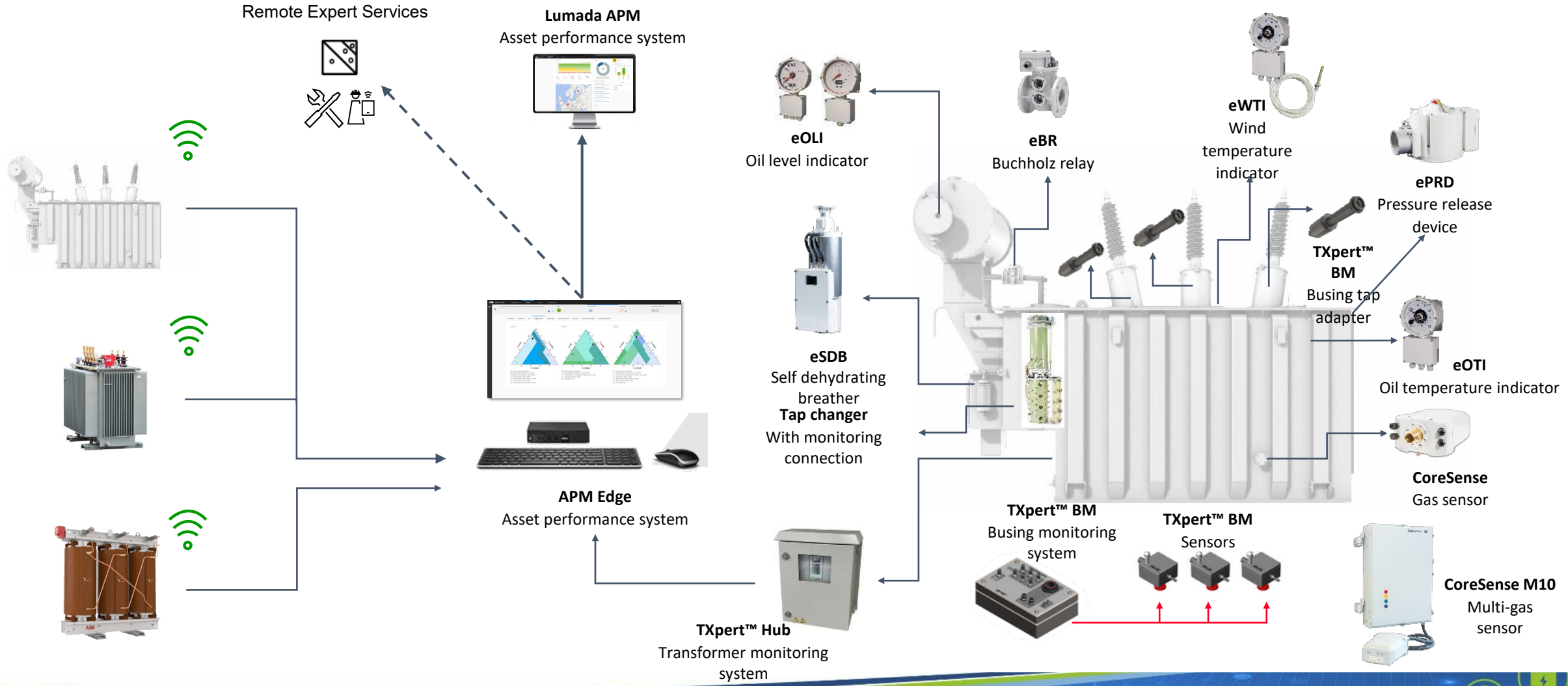
TXpert™: Transforming performance



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HMI capabilities

01

Local HMI

Local 7” touch screen using the integrated HDMI port

02

Portable HMI

Web server integrated into CoreTec application will render the HMI as a web page on a laptop or tablet

WIFI access allows for wireless local access

03

Remote HMI

Web server integrated into CoreTec application coupled with wide area connectivity over fiber optic Ethernet or cellular allows remote management

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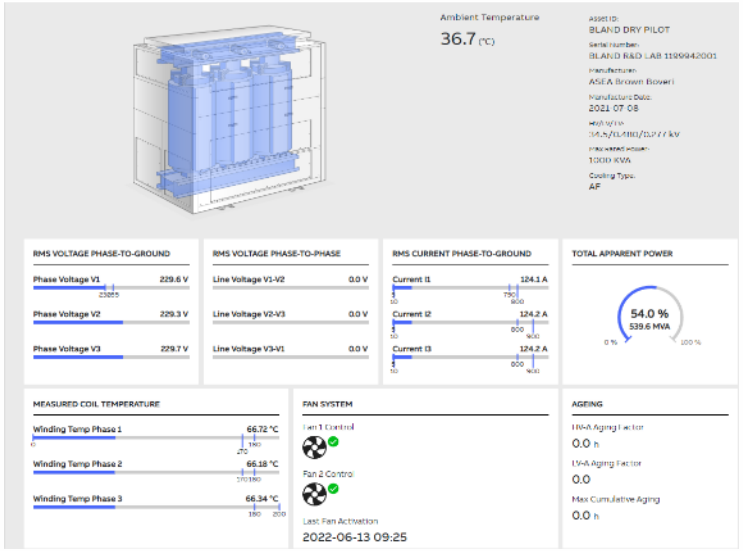
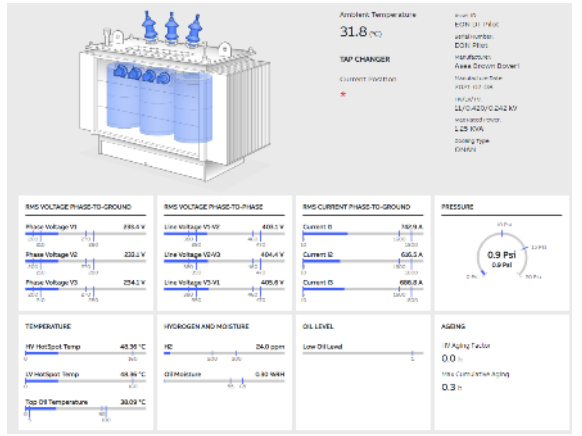
TXpert Hub and CoreTec 5 GUI

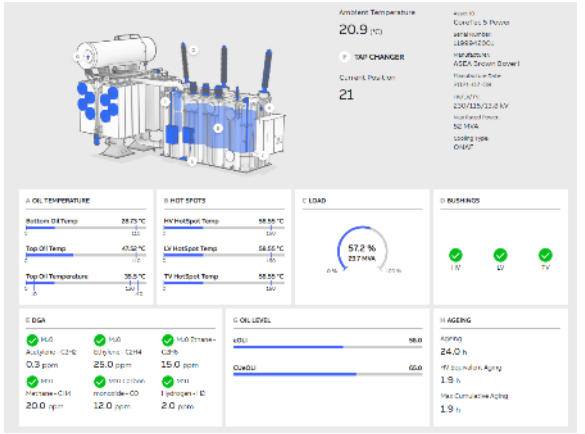
Transformer configurations

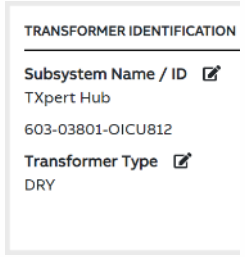
CoreTec 5 can be configured to operate with Dry, Distribution and power type transformers. Selectable via system page

Each transformer type has a specific dashboard configuration









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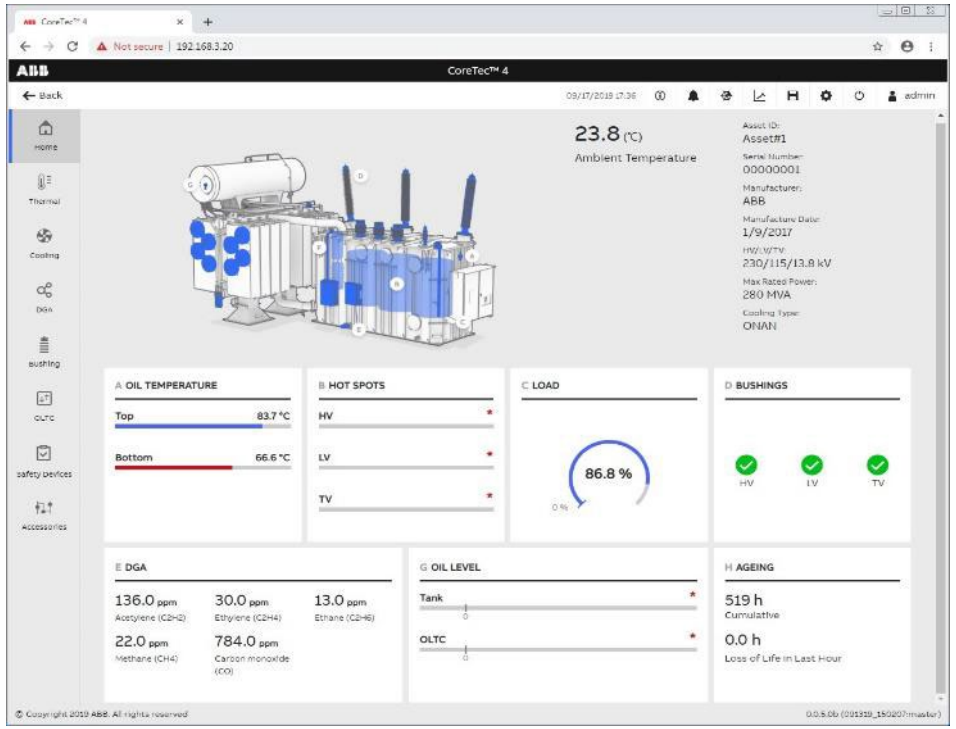
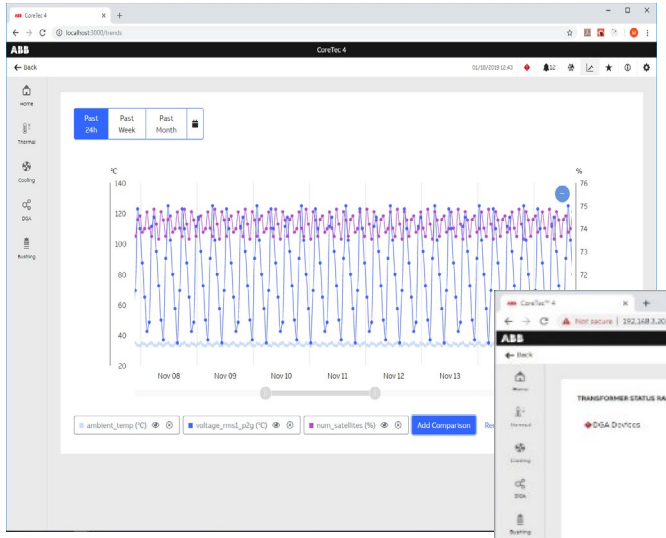
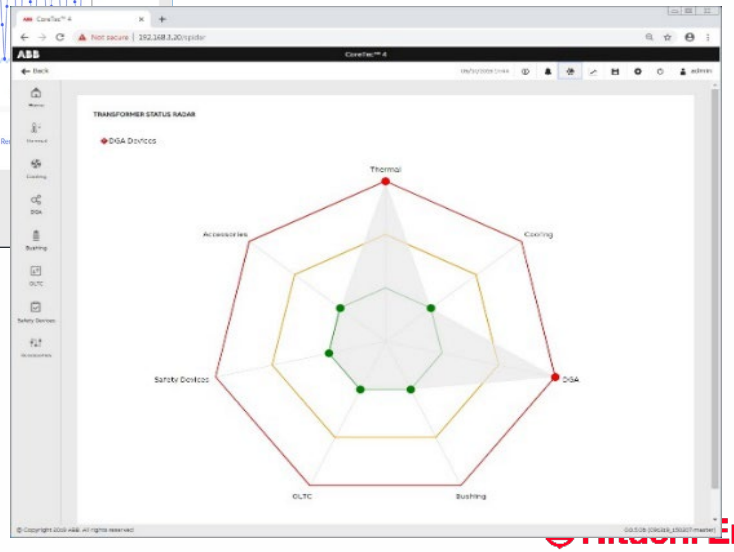
CoreTec™ 5 class leading user interface







The web interface provides a visually intuitive integrated dashboard for the vital signs of a transformer

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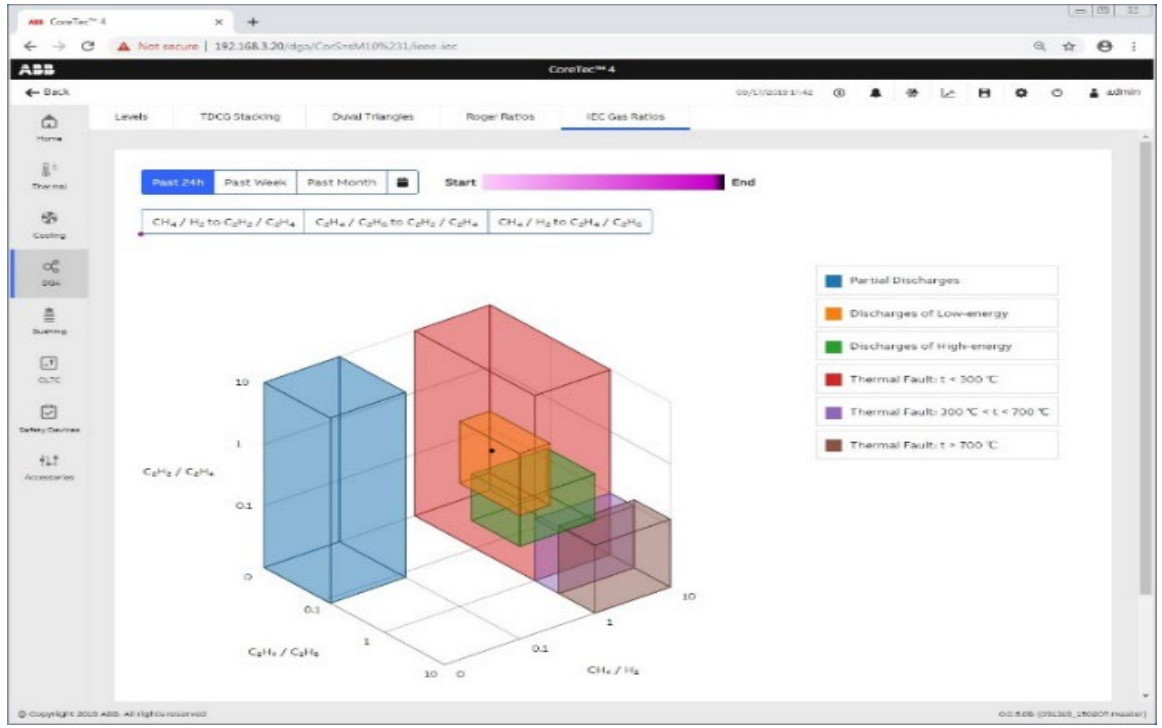
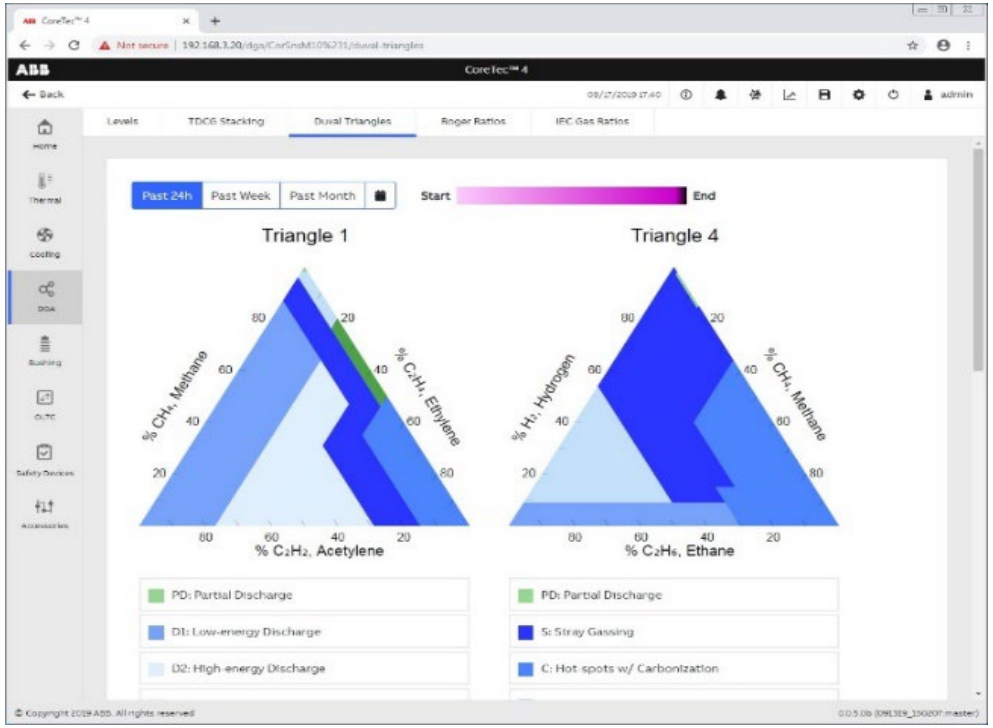
Automated DGA analysis

IEC ratios



Duval triangles



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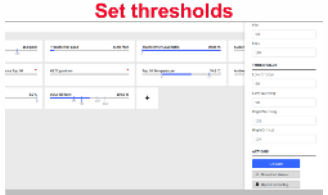
Remote monitoring: Flexible communication options and structure

Set thresholds

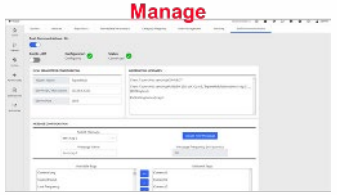


Set fully configurable thresholds

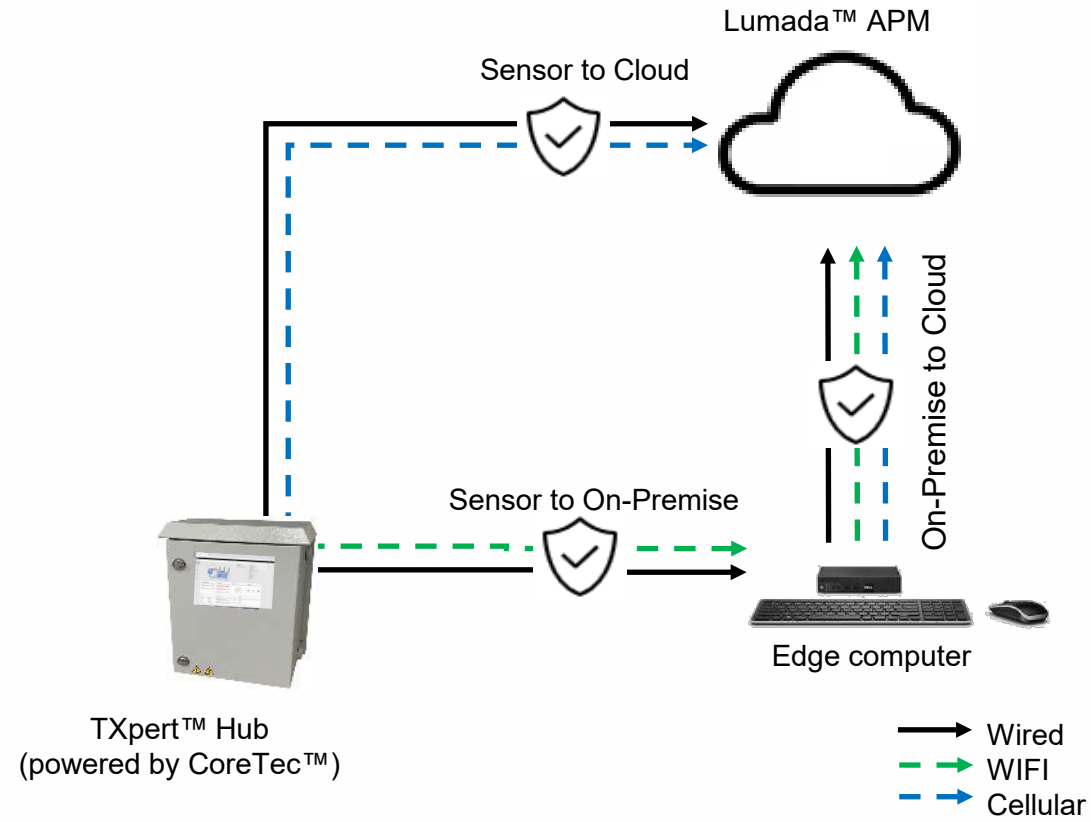
View Alarms

Get the status of the system

Manage



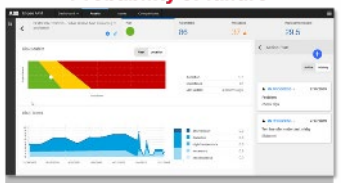
Get notified when a visit only it is needed



Manage assets

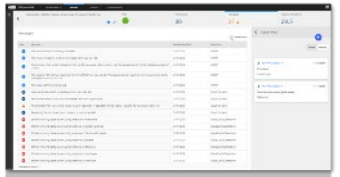
Manage your fleet, optimize maintenance

Probability of failure



Analyze risks, classify by likelihood of failure

Expert recommendations



Call to action, recommended maintenance

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Remotes services to help reduce downtime

1. Remote online monitoring

Monitoring equipment connected back to our experts

2. Remote Guidance using Augmented Reality

Inspection of proceedure and equipment at site

3. Remote Consulting

Reports for customer-gathered data

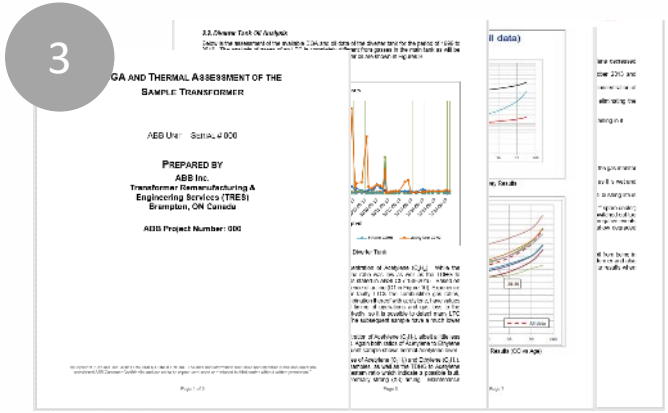
4. Remote troubleshooting

Temporary remote connection for fixing issues

1

2

3



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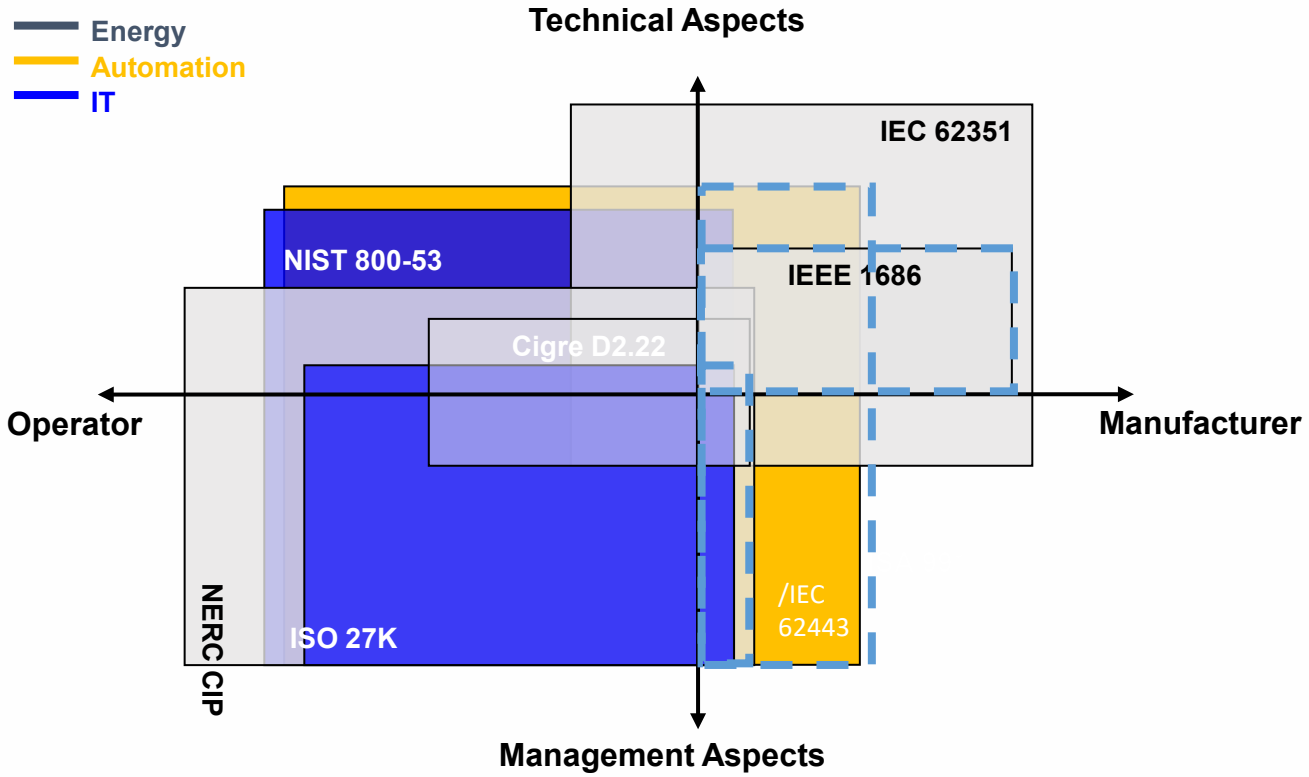
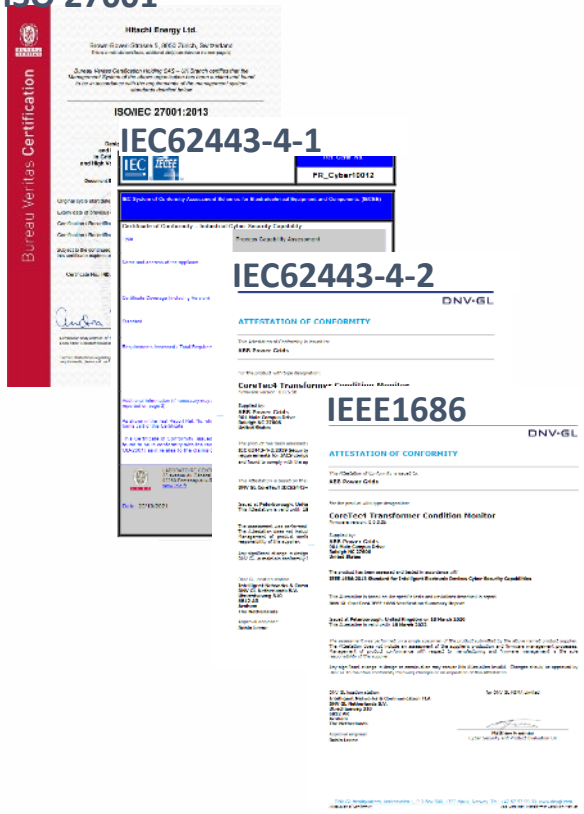
Cybersecurity – TXpert Hub certifications



ISO 27001



Graphical representation of scope and completeness of standards from IEC62351-10

Hitachi Energy

Cybersecurity can only be achieved through coordinated efforts

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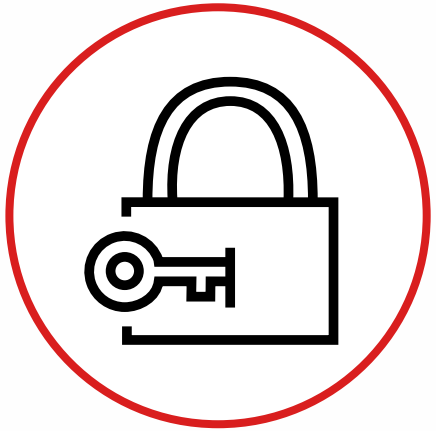
Cybersecurity features

Product development team is certified IEC 62443-4-1, meaning:
- Our products are developed in accordance to our "**Secure Development lifecycle**" (SDLC) Process
- **Products are developed from inception with cyber security in mind**
- The **Development team has the expertise**, are trained and/or follow written procedures

IEC 62443-4-1

Hitachi Energy is certified ISO 27001 which is a suite of information security standards :
- **Covers the management of information security**, not just IT / Technical Security. Includes asset management, HR security, Physical & Environmental security, etc.
- **Improved Risk Management**
- **Legal and Regulatory Compliance**
- **Preparation for Emergency / urgent Situations**

ISO 27001



Product is certified to IEC 62443-4-2, features:
- **Session Lockout** (Temporary/Permanent).
- **Network Segmentation**: product interface is not bridged with other systems
- **Denial of Service protection** in case of a malicious entity tries to overwhelm the product
- **Resource Management**: in case of a problem/crash, a watchdog will bring back the unit online
- **RBAC Account Management**: Admin can choose specific access rights per user and every user is unique. Also in accordance to **IEC 62351-8**

IEC 62443-4-2

Product is compliant to IEEE 1686, features:
- **No hidden access to the system or back-door**
- **Audit trail** (Secure Event Logs, e.g. Login, Time change, Config Change, etc).
- **Backup and Restore functionalities** if an event occurs, special procedure will allow for recovery of the system
- **Encryption** for access to the product: protects from "eavesdropping" from malicious entity

IEEE1686

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Digital Transformation: From Products to Services

Digital solutions for Hitachi Energy, 3rd party OEMs and Retro-fits

Digitally enabled solutions and services

- Digital Assets as enablers
- Asset monitoring & connectivity
- support customer digital experience
- Advanced analysis & optimization
- Data & knowledge Management

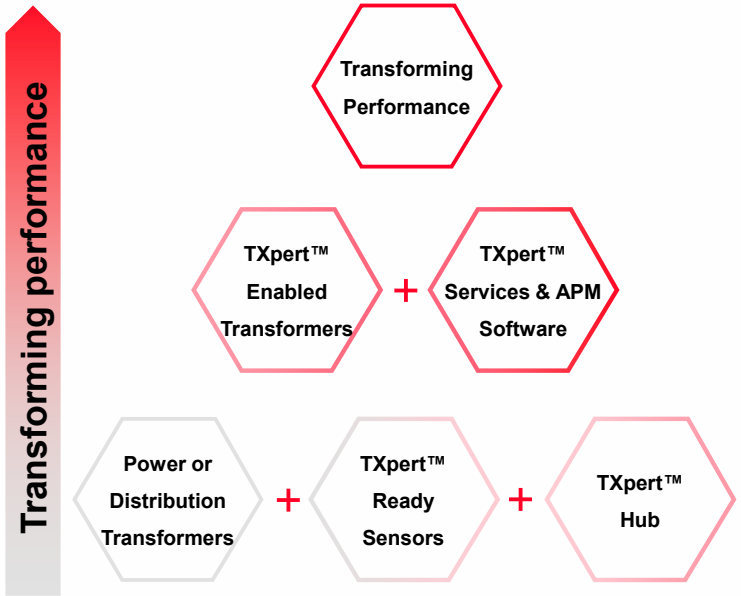
TXpert Ecosystem

A complete suite of products, software, services and solutions.

Manufacturer agnostic

Proven intelligence from experience

Optimization of transformer and grid operations and maintenance



Customer value

Multivendor digital ecosystem

Reduced costs and risks

Optimized operations

Extended life-cycle expectancy

Enhanced environmental performance

Hitachi Energy

TXpert is a multivendor software enabled ecosystem that combines the value of service and software, scalable offering to our suit customers needs, across the whole life-cycle

Thank you

Carlos Martín

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