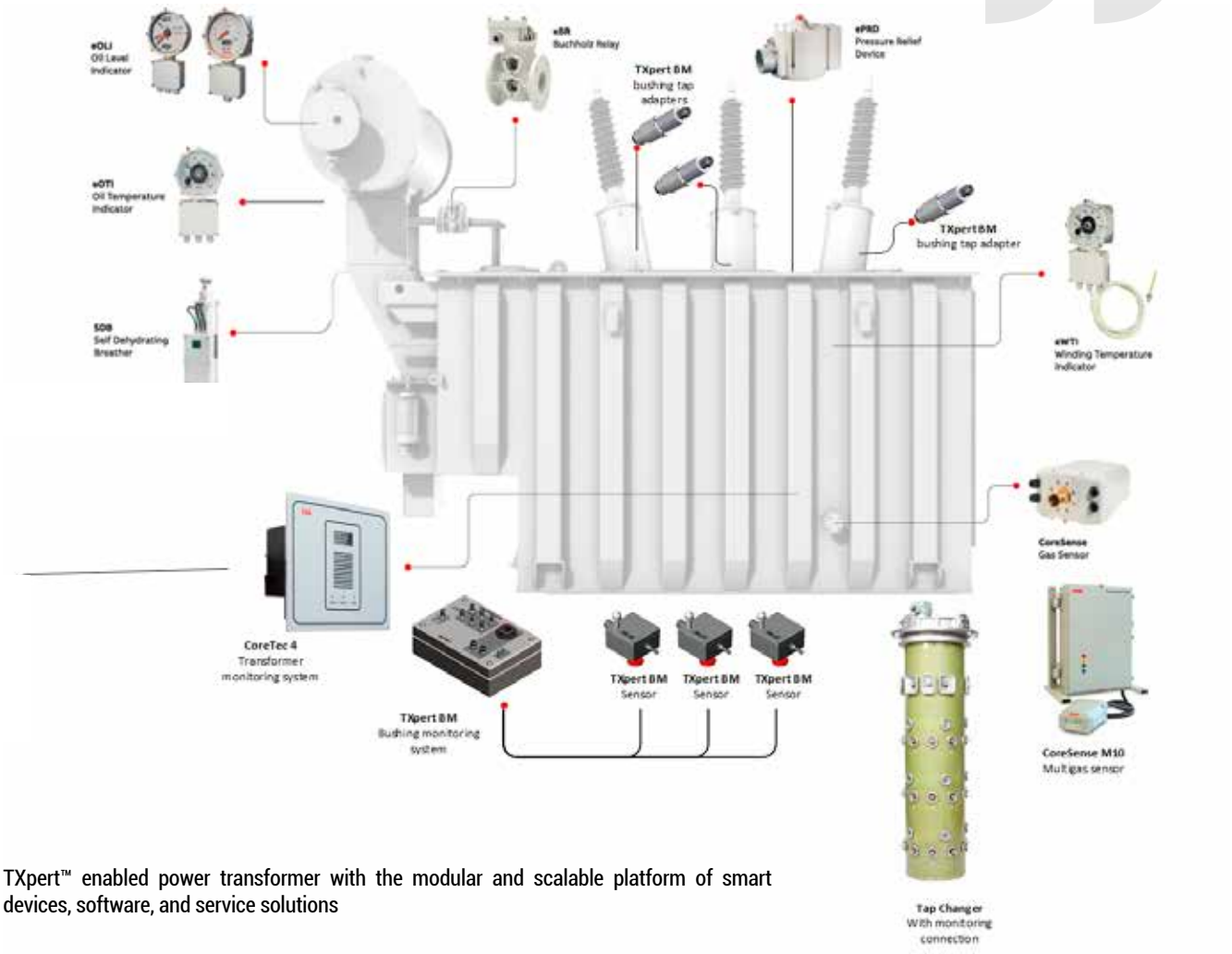
Operators can no longer afford to follow a simple time-based maintenance strategy, which is the reason why they implement more sophisticated condition-based maintenance strategies



TXpert™ enabled power transformer with the modular and scalable platform of smart devices, software, and service solutions

Fleet digitalization for increased reliability and maintenance optimization

The power transformer is the most important asset in an electricity grid. During their operational life, power transformers are subjected to thermal, mechanical, and electrical stresses, which lead to increased transformer aging. In addition, electrical network operators around the world are facing an increasingly aged population of power transformers in their grids—the average transformer age is approaching 40 years, and replacement costs run into millions. Most transformers that are currently in service were fitted with basic sensors, which at best only provided alarms after the condition of the transformer had already started to deteriorate. Due to this, evaluating transformer health is a complex and challenging task.

Digitalization is a crucial element that initiates changes in the whole transformer lifecycle, how they are designed, operated, maintained, or decommissioned

It is imperative to concentrate on transformer maintenance. Operators can no longer afford to follow a simple time-based maintenance strategy that mitigates risks by doing everything, every year, for all transformers. Instead, they must implement a more sophisticated condition-based maintenance strategy: carrying out more maintenance for high-risk transformers than for low-risk transformers. This requires reliable information about the status of transformers. The risk of a sudden transformer failure entails not only huge replacement costs and downtime but is also hazardous to the environment and human life.

Power transformers must, therefore, go digital. Digitalization is one of the main trends in transformer innovation, imperative not only for the provision of a set of digital products and solutions but also for making a whole ecosystem available for the user to manage their assets and the operation of their systems. Digitalization is a key element, initiating changes in the whole transformer lifecycle, how they are designed, operated, maintained, or decommissioned, and reshaping relationships between users and manufacturers with new business models.

One of the most important ways that transformers can be more sustainable and resource-efficient is through digitalization and by implementing technology that reduces their failure rate, increases maintenance intervals, and extends their lifespan. This can be achieved with condition-based lifecycle management instead of traditional time-based management. In addition, and crucially, digitalization solutions must be applicable to both existing and new equipment. The ability to retrofit digitalization to the existing installed base is essential, given their current predominance in grids.

The TXpert™ ecosystem provides a complete range of digital products and services that provide intelligence about the status and performance of the transformers

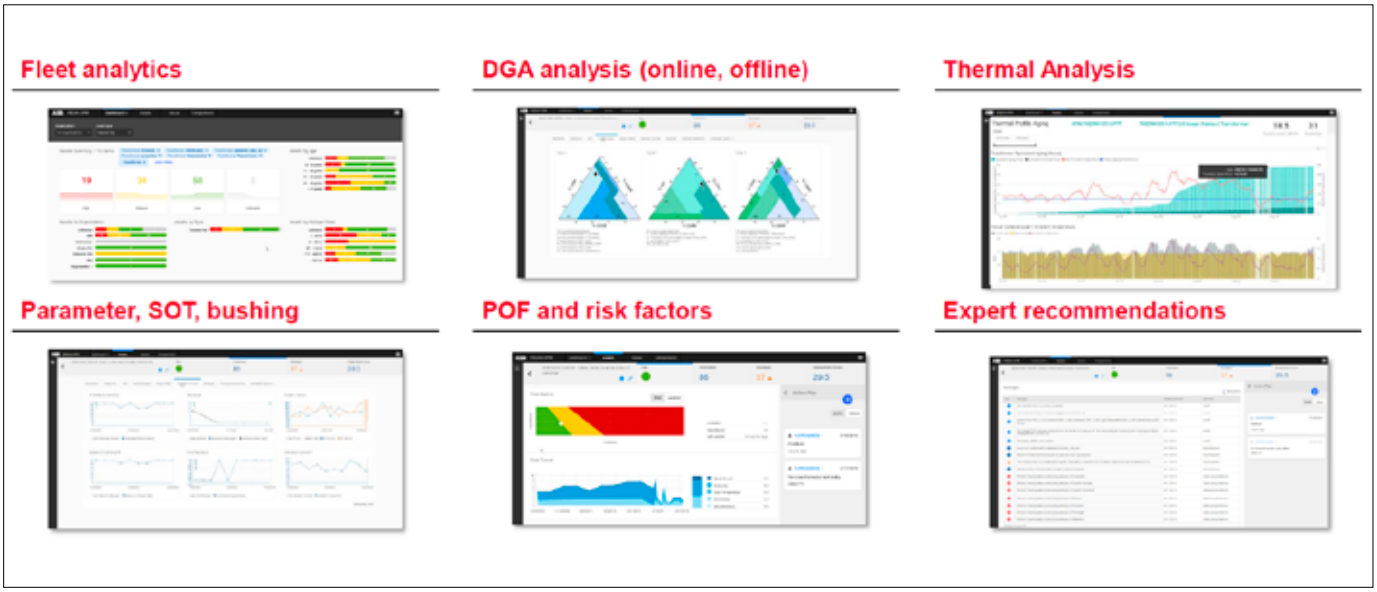
TXpert™ Hub and TXpert™ Ready CoreSense M10 multi-gas DGA sensor

Digitalization determines a maintenance strategy and permits the leveraging of sensing and monitoring of transformers to help make transformers reliable in their performance. It can also be conceptualized as safety by design wherein sensing, and monitoring can prevent failures and massive damage to the environment and increase its productive lifespan.

Digitalization is fundamental to enhancing transformer performance—helping to reduce costs, optimize operations, and enabling a more sustainable energy future. That is why Hitachi ABB Power Grids developed TXpert™, which is a complete ecosystem of open, independent, and modular digital solutions combining products and services for transformers that work together and perfectly with other existing equipment—regardless of the manufacturer.

The TXpert™ ecosystem provides a complete range of digital products and services that provide intelligence about the status and performance of transformers. TXpert™ digital products are: TXpert™ Hub (CoreTec 4), a digital transformer monitoring and diagnostics device that is installed on the transformer to collect and analyze data from connected TXpert™ Ready sensors and to enable connectivity; TXpert™ Ready transformer sensors and monitoring devices that are qualified for connection to the TXpert™ Hub, devices from any manufacturer can be TXpert™ Ready; TXpert™ Asset Performance Measurement, flexible software solutions that provide access to the industry-leading APM software for operators, which is designed to enhance the functionality of transformer sensors and digital transformers.

The TXpert™ enabled power transformer is a modular and scalable platform with a full ecosystem of smart devices, software, and service solutions. It is a building block for digital substations, a future-proof investment, and includes state-of-the-art



TXpert™ APM analytic software for visualization, insights, and recommendations

cybersecurity—aiming to provide the world's first integrated solution for digitally enabled power transformers. In the future, Hitachi ABB Power Grids intends to enable all its power transformers with digital capabilities, allowing real-time remote monitoring and data analytics of its vital parameters. The transformer comes equipped with a digital hub that employs a portfolio of smart devices on a modular platform with plug-and-play capabilities.

TXpert™ Hub CoreTec 4 is Hitachi ABB Power Grids transformer monitoring device designed to aggregate, manage, and analyze data for a single transformer. It is retrofittable and continuously monitors connected oil temperature, load, and gas formation. Variations in these health thresholds are flagged by CoreTec 4 in real-time and can trigger advanced investigations when needed, not when scheduled. ABB is a pioneer in transformer monitoring, having introduced the first TEC system in 2001; the CoreTec 4 is the culmination of this legacy knowledge and experience.

Transformer sensing and monitoring are essential components of transformer asset management; by keeping a watchful eye on the most critical transformer components, operators can optimize their maintenance planning and spending.

The benefits of monitoring are substantial. A CIGRE study has shown that transformer monitoring can reduce the risk of catastrophic failures by 50 percent. It was shown that early detection of problems could reduce repair costs by 75 percent and loss of revenue by 60 percent. Furthermore, annual cost savings can amount to 2 percent of the price of a new transformer—approximately $40,000 to $80,000—can be achieved.

Based on in-depth knowledge and experience of more than 10,000 transformer assessments, Hitachi ABB Power Grids have built up an analytic model that can accurately determine the risk of failure of the transformer

Monitoring a transformer amounts to tracking variations of absolute values and trends of temperatures and electrical, mechanical, and chemical indicators. These measurements are collected with sensors installed on the transformer. Hitachi ABB Power Grids offers multiple sensors, including the CoreSense™ family of sensors for dissolved gas in oil analysis and the recently introduced TXpert™ BM Bushing Monitoring for both sum of current and voltage reference technologies. CoreSense™ provides a non-intrusive, retrofittable, maintenance-free, and easy to install solution for either flagging a potential fault with hydrogen measurement or performing a deeper analysis with the multi-gas version. Hitachi ABB Power Grids' and third-party digital devices can be configured to the TXpert™ Hub.

Based on their deep domain knowledge of transformers and more than 10,000 transformer assessments, Hitachi ABB Power Grids have built up an analytic model that can accurately determine the risk of failure of the transformer. These performance models are used within TXpert™ APM Edge and TXpert™ Hub to convert data from sensors into actionable information—so the performance model is at the heart of the company's digitalization offering. It is the performance model in conjunction with dynamic algorithms that have proven successful and are the backbone of the sensor information interpretation.

Earlier performance models and tools were implemented with the sole purpose of supporting human experts in assessing the operational risk of the transformer fleet. However, industry requirements now demand that the tools must constantly interact with the continuous stream of data from multiple sensors on a fleet of many transformers. This data can come from spreadsheets and databases containing data from offline measurements and other systems and online sensors deployed on transformers. As new sensors

TXpert™ APM fleet analytic software for optimizing maintenance spend and improving reliability

With the integration of operational and information technology, TXpert™ APM delivers a facility for the consolidation of all the asset information to provide intelligent insights on the health and risks to transformers

continue to be developed, the dynamic algorithms and performance models must be flexible and amenable to modifications to deal with new sensors and information. A variety of sensors and monitors are re-used today on different transformers within the same fleet.

The industry response in the power transformer sector includes the introduction of online smart sensors, design optimization, integration of transformer operational data, and on-site diagnostics. Utilities are creating new data centers as a part of their "smart grid" initiatives. New challenges and requirements arise, creating the need for sophisticated applications capable of handling massive amounts of data originating from new and aged assets, in order to support the few available experts. Models are needed to turn raw data into actionable information that can be used by asset managers and decision-makers alike.

A novelty introduced by the newly developed models is to make use of the same condition assessment algorithms that have been successfully applied offline for many years; transforming them into a powerful online tool which can operate in real-time incorporating "expert knowledge" and risk assessment capabilities, predictive capability based on maintenance and operation inputs, historical event data, and data from offline tests, simultaneously to the online data from monitoring sensors. The assessed risk level for each transformer can then be displayed either at a fleet level or at a transformer level.

In the context of transformer asset health management, a challenge that many industries and utilities face is in the understanding and tracking of the data generated by both online and offline measurements. Many organizations try to avoid unnecessary maintenance by utilizing a variety of mixed information from multiple sources, like inspection data, sensor trends/alarms, and industrial enterprise systems. However, most of the time, the collation, correlation, and interpretation of these data require human expertise, which, especially now, is a challenge given the scarcity of highly trained personnel.

Hitachi ABB Power Grids' solution to these issues is TXpert™ Asset Performance Management (APM). This solution combines decades of subject matter expertise in transformer manufacturing and maintenance with historical and real-time data analysis from transformer sensors. These continuous health and per-

formance insights prevent critical asset failures while optimizing lifecycle costs. With the integration of operational and information technology, this system delivers a facility for the consolidation of all the asset information to provide intelligent insights on the health and potential risks to transformers.

TXpert™ APM applies expert knowledge on all the assets mapped in the system. Each asset is also categorized according to its current health condition and expected life. The result is a priority-wise risk assessment of critical assets based on their probability of failure along with actionable intelligence.

Deployment of TXpert™ APM also provides possibilities for remote monitoring, enabling access to global experts who can help evaluate captured operational data and provide advanced diagnostics. These consulting services can assist in interpreting analytic results and recommend actions to mitigate identified risks. Such expert knowledge can assist in determining corrective actions and planning any required outage to minimize downtime.

In cases when online monitoring and the diagnosis indicate a possible transformer malfunction, one might need to drain the oil of the transformer and have a specialist enter the unit to perform an internal inspection. All this deems significant outage, risks, and considerable expense by the transformer owner.

In order to mitigate the above challenges, Hitachi ABB Power Grids has developed the TXplore™ system as a remotely controlled inspection "submarine." This automated inspection completely eliminates the need to put a human at risk and expose the transformer's internal structure to external contaminants. The inspection is usually performed within a day. Based on the findings by the submersible robot, a transformer design expert provides an analytical report that reviews any problems and contains recommendations for condition improvement or for bringing the unit in for repair. The company's expert services can help interpret and recommend, as well as implement an action plan to maximize utilization.

With this improved intelligence, companies can prioritize resources to take immediate action on the flagged assets. This allows organizations to optimize their operational and maintenance spend so as to maximize the capability of their assets and prepare for repair/replace decisions.

TXplore™ inspection robot being inserted into a power transformer

Hitachi ABB Power Grids can also partner with you to secure sustainable reliability of your transformer using Transformer Care - a range of long-term service agreements which bundle remote services

Cybersecurity is a critical factor for the success of digitalization. With its vast experience, the company can focus on security solutions and provide the best and most reliable cloud management. Due to a large number of digitalized devices, Hitachi ABB Power Grids demonstrates its first-hand experience with cybersecurity challenges.

Digitalization is part of an innovative contribution to sustainability—to enable the gathering of data on the installed base of transformers and predict the future in time. Effectively utilizing and retrofitting digitalization to assess the condition of the installed transformers on the fleet, to treat the potentially worst cases to avoid failure and prevent environmental and monetary disasters. Hitachi ABB Power Grids can also partner with you to secure sustainable reliability of your transformer using Transformer Care—a range of long-term service agreements which bundle remote services using TXpert™ monitoring solutions and agreed preventive services.

As the world's biggest supplier and among the earliest, Hitachi ABB Power Grids have extensive domain knowledge from manufacturing and successfully supplying thousands of transformers, along with the experience and ability to encompass that knowledge and serve as a partner for life for transformers. The drive to exploit and implement digital technologies would enable customers to address not just today's challenges but also those of tomorrow.

Stephen Pearce

Stephen Pearce holds a master's degree in Electrical Engineering from the University of Strathclyde in the United Kingdom. Over the past 20 years, he has held a number of management positions in Hitachi ABB Power Grids covering HV and MV Switchgear, Transformers, and has worked in a number of countries. Since 2016 he has taken the role of Global Product Manager for Transformer Service, which covers Hitachi ABB Power Grids wide range of transformer service offerings. He is based in the United Kingdom.