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Blueprint

Transformer monitoring: A strategic blueprint for wind farm success

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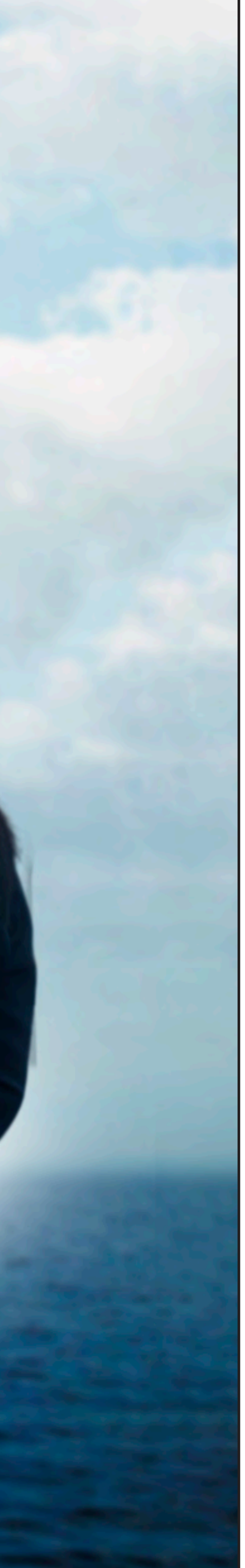

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Introduction

As the renewable energy market continues to grow, so does the need to understand asset availability and optimise operation and maintenance strategies.

Asset Managers are now facing the challenge of identifying and investing in the right technologies to deliver insights into asset health to reduce risk and maximise performance.

A key asset within a wind farm is the power transformer which connects the wind energy generated to the electricity grid.

Transformers generally function as a single point of failure, which means that undetected failures can result in plant downtime and loss of revenue. Understanding the risk to the transformer in real-time, is critical.

Transformer monitoring improves transformer reliability by providing early warning to developing faults. This enables operators to prevent failure and reduce risk to operations.

Transformers generally function as a single point of failure, which means that undetected failures can result in plant downtime and loss of revenue

CONTENTS

Regulatory motivators

There are 4 main areas where potential revenue costs from lost generation, increased overheads or regulatory penalties could impact either a project owner or OFTO.

- Lost revenue from failure to export energy
- Unplanned maintenance or repairs
- Increased insurance premiums
- Regulatory penalties and cost of replacement energy for forward commitment of energy contracts

Transformer risk profile

Much of the recent focus for improving availability and profitability has been focused on subsea cabling because of the issues with the technology, manufacturing, and installation. Another major single point of failure which has often been overlooked is the main step-up offshore transformer and the step-up onshore transformer that connects to the grid, as shown in Figure 1.

The standard approach to transformer redundancy

In other parts of the energy sector transformers normally have what is referred to as an n-1 redundancy which means typically twice the amount of capacity is sized and split over two transformers. Half of the energy is exported through each transformer to keep the amount of load to within normal parameters and to discourage running transformers 'hot' nearing their normalised capacity.

The challenge for wind operators

This standard is not universally observed across the wind sector leaving some operators extremely exposed to a risk of transformer malfunction or breakdown. Typically, transformers can take up to 6 months to order and replace, although at the time of writing, with current global supply chain conditions this is closer to 18 months. A failure in the offshore or onshore step-up transformer could potentially have catastrophic commercial effects in terms of regulatory penalties for lack of availability and cost of lost generation.

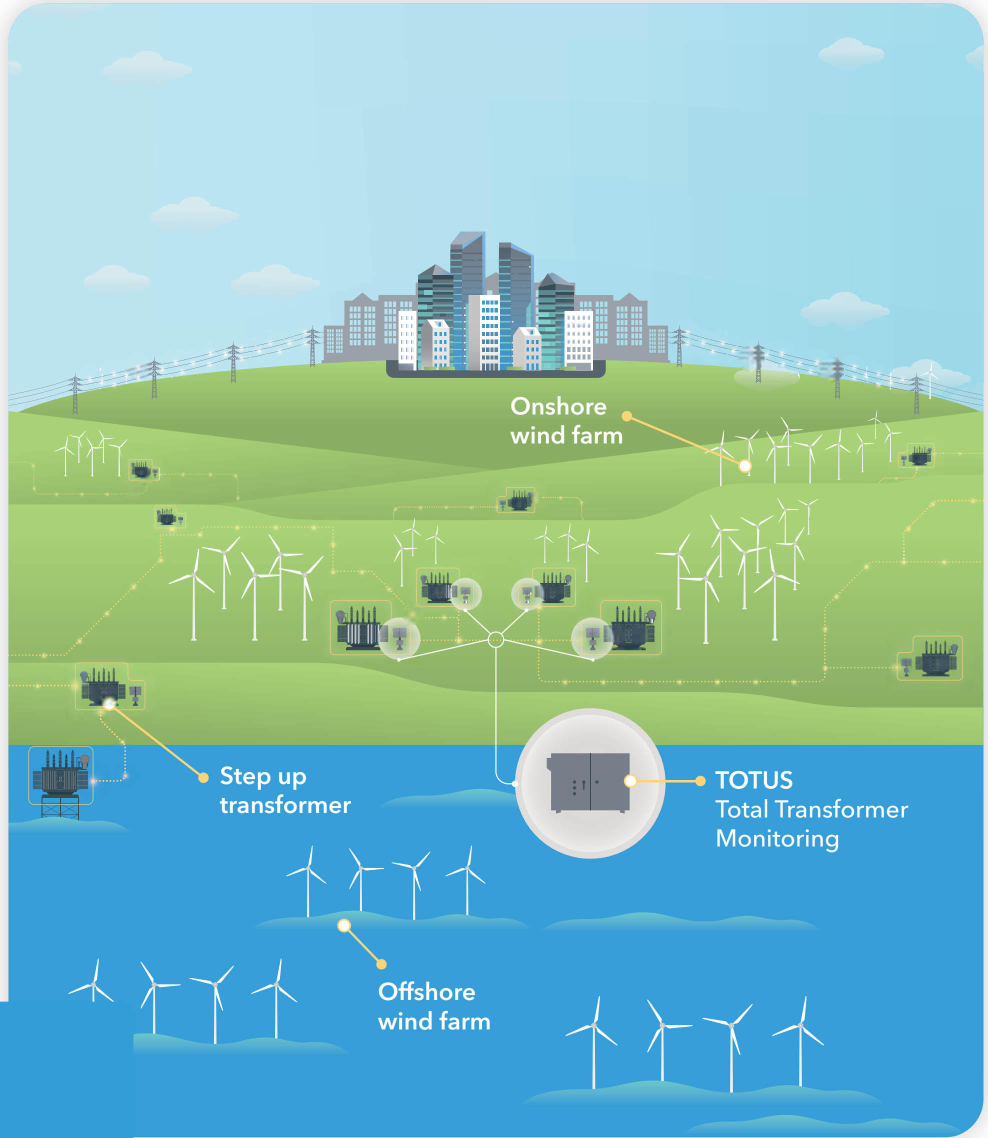
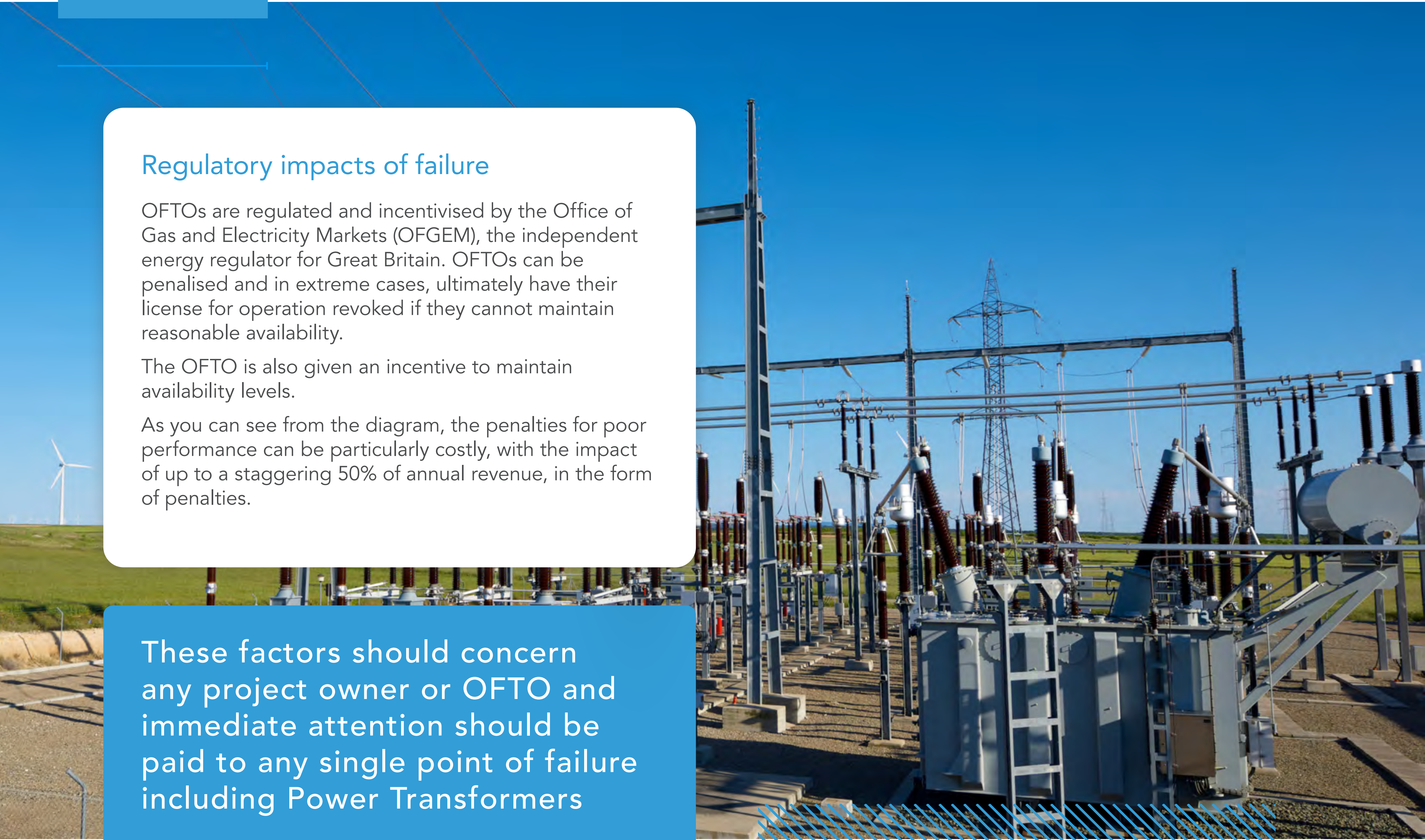


Figure 1 – A transformer is the single point of failure between offshore wind farm and electric grid

> Another major single point of failure which has often been overlooked is the main step-up offshore transformer and the step-up onshore transformer that connects to the grid



Regulatory impacts of failure

OFTOs are regulated and incentivised by the Office of Gas and Electricity Markets (OFGEM), the independent energy regulator for Great Britain. OFTOs can be penalised and in extreme cases, ultimately have their license for operation revoked if they cannot maintain reasonable availability.

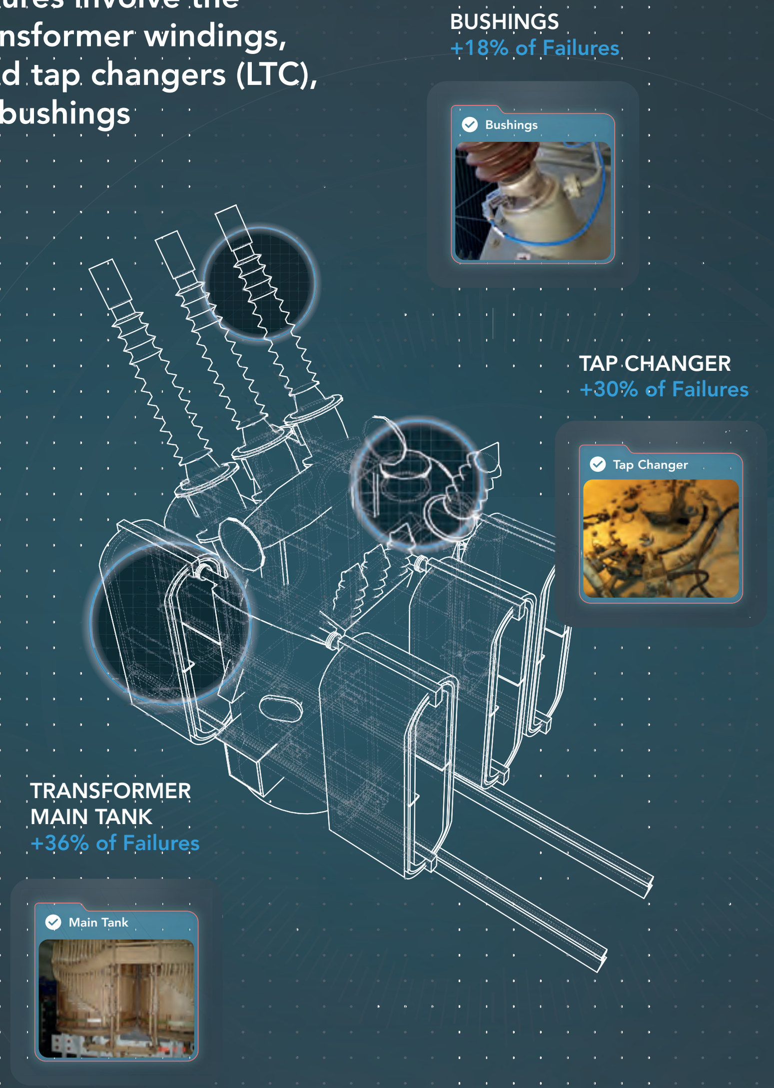
The OFTO is also given an incentive to maintain availability levels.

As you can see from the diagram, the penalties for poor performance can be particularly costly, with the impact of up to a staggering 50% of annual revenue, in the form of penalties.

These factors should concern any project owner or OFTO and immediate attention should be paid to any single point of failure including Power Transformers

Where is the risk?

80%+ transformer failures involve the transformer windings, load tap changers (LTC), or bushings



Chapter 2

What to monitor and why

The step-up transformers located both on the offshore substation and those onshore connecting to the wider transmission or distribution system are critical part of an offshore wind project. If the key components of these crucial assets are not in good working order, the wind farm will be unable to transmit energy to the wider transmission system, leading to an erosion in availability incentive performance. Traditionally, these assets are visually inspected for degradation, and specialist equipment is used by operators to manually inspect substation infrastructure, such as transformers to check for unusual changes in operating behaviour. These are often done on a periodic basis, with no consideration for the actual condition of the transformer itself. The process is manual and can give inconsistent or misleading results due to human error, inconsistencies in reading methods, or other sample retrieval inconsistencies, especially in relation to manual transformer oil sampling.

Adopting online continuous monitoring would alleviate all the negative effects associated with periodic manual inspections.

Why do transformers fail?

Although power transformers are static machines, with a relatively simple working principle, they are complex assets, as they are made up of several materials, such as copper, iron, solid and liquid insulating materials like paper, wood, porcelain, resin, and oil. Such materials are prone to different failure modes that can affect the main tank, bushings, tap changer, oil conservator, cooling system, etc. Combining these elements and ensuring they last for their entire design life is not an easy task.

During operation, transformer components are constantly subjected to various stresses including:

- Electrical
- Thermal
- Mechanical (vibration)
- Chemical

These stresses can lead to the formation of defects inside the transformer; often referred to as faults.

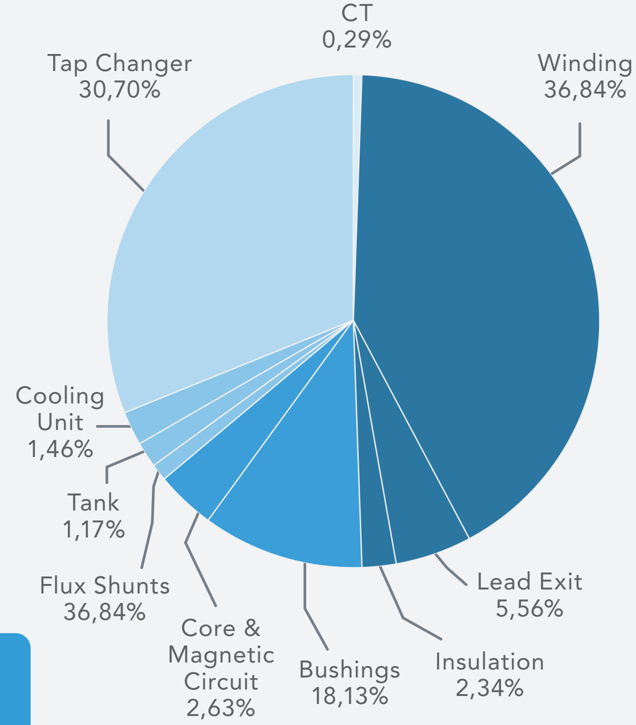
The transformer is the main artery through which power is delivered to the transmission network from a wind farm; a transformer failure likely results in significant downtime for the entire wind farm.

When considering transformer failures, some components are more likely to cause transformer failures than others. According to data published in the CIGRE 642 Transformer Reliability Survey, the components most likely to be involved in transformer failure are:

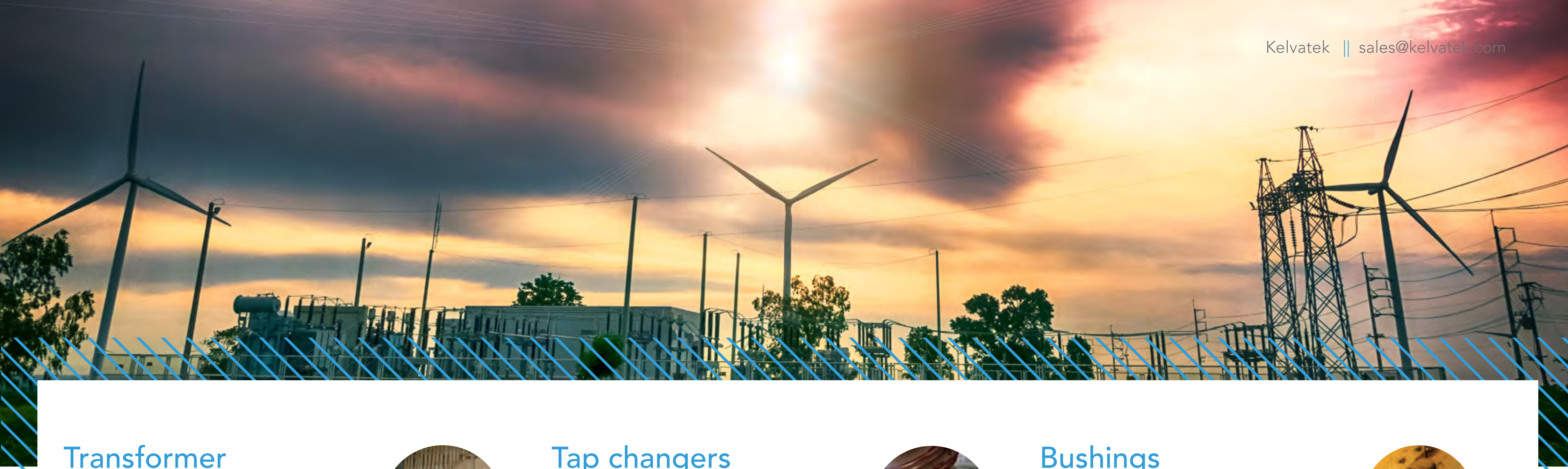
- Transformer windings
- Bushings
- On-load tap changer

As mentioned in the previous chapter, wind farms are motivated by both energy market access to sell their energy, and by incentives around power availability. Any fault modes could be a potential threat to this as wind farms are often located offshore or in geographically remote areas to access.

Figure 3 – Proportion of components attributed in substation transformer failures (all transformers rated >100kV). Adopted from CIGRE 642 Transformer Reliability Survey.



Without correction, thermal and electrical faults can progress to the point of causing serious damage to the transformer. In many instances this can result in permanent damage or failure



Transformer windings

The risk

Transformer windings are the most likely component to be involved in a transformer failure; an estimated **~37% of failures.**

The impact

The operational conditions within wind farms can impose additional stresses on the transformer windings, which can increase the risk for winding faults in wind farm transformers. Operating periods under high load, mixed with periods of intermittent/variable load occur more frequently in wind generation due to the variable nature of wind energy. This can increase the risk of electrical faults in the transformer.

Tap changers

The risk

Tap changers are the next most likely component to be involved in transformer failures; an estimated **~30% of failures.**

The impact

Like transformer windings, the on-load tap changer may be more stressed in a wind farm installation. Periods of variable loading and changing load may require the tap changer to operate more frequently in order to regulate the voltage. More frequent use imposes more wear and tear on the mechanical operating mechanisms in the tap changer.

Bushings

The risk

Bushings are typically present in onshore substations however they are not always present in offshore wind installations as many offshore platform transformers are terminated directly by submarine cables. When bushings are installed, they are the third highest component involved in transformer failures, **an estimated 18% of failures.**

The impact

For coastal transformers, exposed to the elements, the saline air around offshore installations can increase the risk of contamination on bushing surfaces, which can lead to electrical discharges and stress on the bushings.

> More than 80% of transformer failures involve the transformer windings, load tap changers (LTC), or bushings. Effective online monitoring systems should be capable of detecting emerging faults in these components

Online monitoring systems for power transformers

Online monitoring systems for power transformers integrate sensors installed on transformer components, with powerful processing and remote testing technology to provide early detection of thermal and electrical faults in the transformer.

They are often accompanied by suites of analytical and visual software to allow for easier understanding of the condition of an asset remotely.

Dissolved Gas Analysis (DGA), which detects gases in oil due to electrical and thermal faults, is the most effective method for online monitoring of the transformer windings and LTC. For monitoring of the transformer bushings, online measurement of the bushing leakage currents can detect degradation in the bushings. Online partial discharge measurement can be used to detect defects producing electrical discharges in the windings or bushings.

Online Dissolved Gas Analysis (DGA) monitoring

The challenges of DGA

Faults in the transformer windings can produce high temperatures or electrical discharges in the transformer oil, causing it to degrade. Faults may develop for a variety of reasons such as inadequate cooling, or poor electrical connections. Conversely, faults that produce electrical discharges or arcing inside the windings, can develop due to contamination in the transformer oil. Both thermal and electrical faults cause gassing in the transformer oil. Many of these gases are combustible (including hydrogen, carbon monoxide, with various hydrocarbon gases) and at high concentrations inside the transformer. These can pose a risk for direct failure of the transformer.

At low concentrations before reaching a critical level, these gases can be analysed to diagnose the type of fault present inside a transformer. This method of analysing the relative concentrations of gases generated in transformer oil is known as Dissolved Gas Analysis (DGA). DGA is an effective method of diagnosing faults in transformer windings and the LTC.

Benefits of online DGA monitoring

Most DGA is performed by retrieving samples of oil removed from the transformer and sending to a chemical laboratory. However, for high value transformers, especially those in remote locations such as offshore wind installations, continuous online monitoring of DGA can provide significant value.

With many onshore and offshore sites often in remote and unmanned locations, visits to the wind farm for maintenance or data gathering can be costly and time-consuming. Online transformer monitoring solutions with advanced communication and alarm capabilities can alert Asset Managers of any potential faults before they become critical. This helps them to prioritise, and plan interventions and maintenance, reducing the need for unplanned site visits and the associated costs.

Another key benefit from online DGA systems compared to manual sampling and laboratory measurements, is that with this method it is possible to monitor what operating conditions influence gassing in the transformer. For example, if gassing occurs in response to high loading or high temperatures which is common in wind generation, online DGA provides actionable information to the Asset Manager. It may help to inform adjustments to the transformer cooling system, or to manage and limit the transformer's loading until repairs can be made. This ability to limit loading in order to defer maintenance is beneficial to a wind farm operation.

Methods for monitoring DGA

The most well-known method for DGA on gases extracted from transformer oil is by a technique called Gas Chromatography (GC). This method of DGA is the most common method performed in chemical laboratories where it has been used for over 40 years. For online DGA, GC systems have some drawbacks due to their maintenance requirements. They require routine replacement of consumable gas containers, used for carrier and calibration of the testing. To address the maintenance drawbacks of this method of DGA, alternative optical techniques were developed in the industry for online DGA monitoring. These methods significantly reduce required maintenance, whilst providing sufficient accuracy to diagnose problems in transformers. This is a significant benefit for offshore wind installation due to their limited accessibility. The two most common optical methods for online DGA monitoring are;

1. Non-dispersive Infrared Spectroscopy (NDIR),
2. Photo Acoustic Spectroscopy (PAS).

Both methods are described further in the following sections.

DGA methods

Non-Dispersive Infrared Spectroscopy (NDIR)

Non-Dispersive Infrared Spectroscopy (NDIR) is an entirely optical method for online DGA measurement. Being entirely optical, NDIR alleviates disadvantages associated with online GC-based systems and their maintenance requirements. NDIR online DGA systems work based on detecting interactions between infrared light and gases.

One of the drawbacks with NDIR-based online DGA is that it is slightly less accurate and can detect fewer gases than GC-based systems. However, NDIR-based systems still perform well in providing early detection of faults, and they tend to be lower cost than GC systems. Therefore, when installed on less critical power transformers, NDIR-based online DGA can provide a more cost-effective solution, whilst requiring significantly less maintenance than GC systems.

Photo Acoustic Spectroscopy

Photo Acoustic Spectroscopy (PAS) is another optical method for online DGA and like NDIR avoids disadvantages associated with GC-based systems and their required maintenance. As a mature technology which has been available for over 20 years, many users of transformer monitoring systems have transitioned to PAS systems.

Like NDIR, PAS is capable of measuring concentrations of hydrocarbons in gas extracted from transformers by manipulating interactions between infrared light and gases in the transformer oil. However, unlike NDIR which measures the gas concentrations directly using optical filter, PAS detects acoustic emissions produced when the gases are excited by strobing infrared light. Photo acoustic spectroscopy is able to achieve similar accuracy and performance as online GC systems without the high maintenance. Given the proven accuracy and reduced maintenance benefits of PAS based online DGA, it is a popular choice for online systems, especially on high value or highly critical transformers, or on transformers in remote locations such as wind farms and offshore platforms.

Bushing monitoring

Bushing monitoring is implemented using a special sensor that is installed on the bushing test tap. Most high voltage bushings are equipped with a port which is normally used for offline diagnostic testing on bushings, but it is also an ideal point of connection for online monitoring. With sensors installed at the capacitance tap, it is possible to measure the electrical currents which pass through the bushing during the transformer operation. Under normal operational conditions, the currents in the 3-phases of bushings are balanced. However, if a fault develops in one of the bushings these currents become unbalanced, and the bushing monitoring will indicate the anomaly.

Cigre 755 estimates ~30% of bushing failures lead to explosion or fire at the transformer and approximately 1-in-5 lead to prolonged outages greater than 30 days

Online Partial Discharge monitoring

What are Partial Discharges (PD)?

Partial Discharges (PD) are localised electrical discharges or 'sparking' pulses of current that can occur inside the transformer windings and bushings. Partial discharges degrade the insulating oil and cause damage to paper materials inside the transformer and bushings.

Impact of PD on transformers

When persistent partial discharges occur inside the transformer windings or bushings over a prolonged period they degrade the insulating oil quality, and can cause permanent damage to the paper insulation materials by causing carbon tracking on paper surfaces. This degradation affects the transformer's ability to sustain high voltages and failures can occur.

The basics of PD monitoring

Partial Discharges in power transformers may be detected online in a multitude of ways. The most common method for online PD detection uses an electrical sensor installed at the bushing capacitance tap. For convenience, the exact same sensor, as used in Bushing Monitoring, may also be used for PD monitoring. It is possible to monitor PD and Bushing Monitoring leakage currents simultaneously. Although connected at the bushing, online PD may be used to detect electrical faults occurring in the bushing or the transformer winding.

PD and the risk for wind operators

In wind power transformers, the intermittent generation can lead to dynamic thermal changes in the transformer and changes in the electrical properties of the transformer oil. These fluctuations increase the likelihood of partial discharges and electrical faults, which could lead to increased maintenance above and beyond the industry standard, and risk potential downtime or reduced generating capacity.

Impact of PD on transformer windings

Figure 4 – Carbon tracking appearing on a portion of the transformer winding after oil removed. Presence of tracking indicates that PD activity was present on the winding in this location.

Partial Discharges could lead to increased maintenance above and beyond the industry standard, and risk potential downtime or reduced generating capacity

Through Fault Current (TFC) monitoring

Why monitor TFC?

The purpose of TFC monitoring, relates to the fact that transformers may be exposed to external faults on the transmission network. These events impose high electrical and mechanical forces on the transformers windings and can cause winding movement, deformation, and disturb the mechanical bracing. If the bracing is repeatedly disturbed from re-occurring through faults, eventually the winding may not have sufficient mechanical strength, and a failure can occur. Some studies have estimated that in ~22% of transformer failures, the root cause of failure is due to TFC.

TFC monitoring cumulatively tracks the energy from through faults that a transformer has been exposed to. TFC data can inform Asset Managers when internal inspections of the transformer may be advisable based on a history of the transformer being exposed to TFC events.

Impact of wind operators

Transformers for wind generation are required to have Fault Ride Through (FRT) capability to maintain stability of the power grid during fault events. This requirement differs from normal substation transformers, which may trip off to isolate a line fault. Therefore, transformers in wind generation are required to endure more stressful through fault conditions which may affect their long-term reliability, this again leads to a greater risk of availability to export power to the grid.

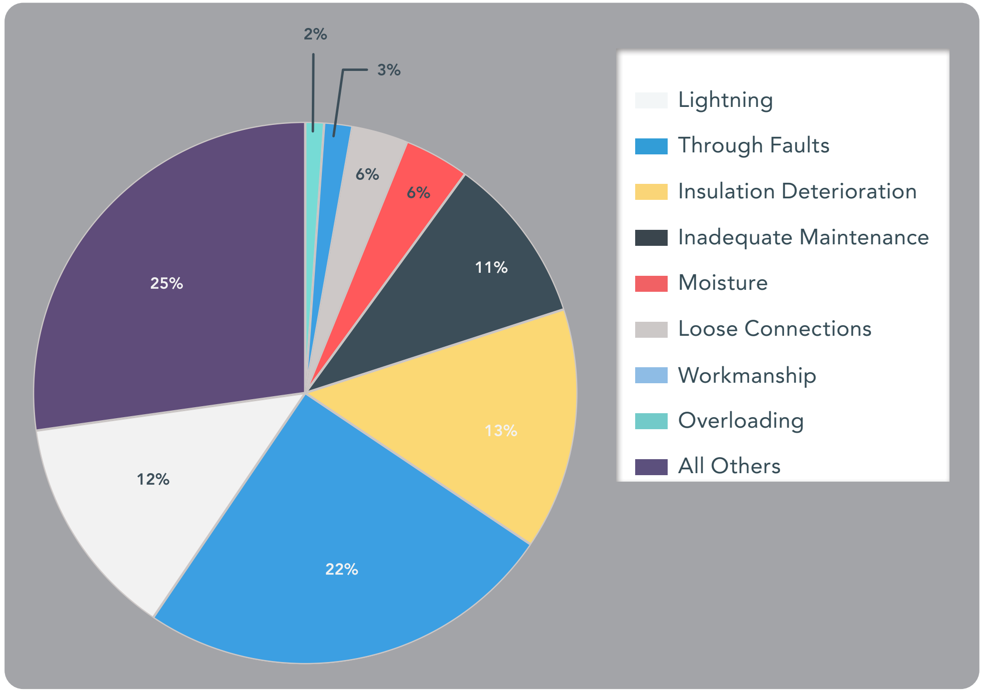


Figure 5 – Root causes for Transformer Failures

Studies have estimated that in ~22% of transformer failures the root cause of failures is from TFC - Transformers in wind generation are required to endure more stressful through fault conditions which may affect their long-term reliability

Cost benefits analysis

In this chapter we will consider the cost benefit analysis of utilising online transformer monitoring. As referenced in the previous chapter this technology, in its various different configurations is a cost-effective solution when considered in the context of a high value transformer asset failure. The ability to remotely monitor your transformer assets and act on accurate information has considerable financial benefits.

How to determine the ROI?

A Return On Investment can be evaluated by examining published literature on the rate of transformer failure, applying this to a lifetime average installation of a power transformer and then calculating the impact of downtime over the lifetime of a wind farm.

The load duration curve for maximum and minimum export potential can be considered along with an average market value for the associated energy price within a given market. This gives you two outputs which can be considered together to make an investment decision for remote online monitoring. What is the probability of failure and associated costs involved with choosing whether or not to invest in online monitoring?

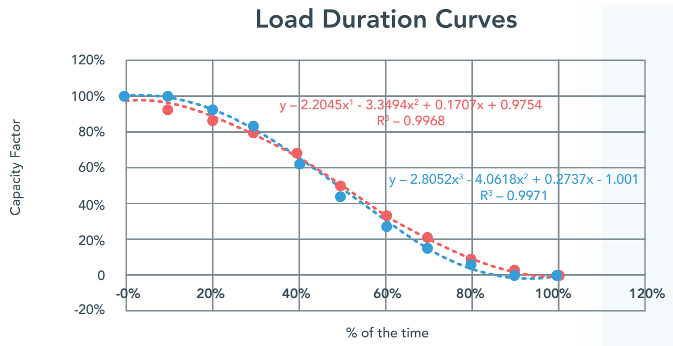
An offshore wind project with an installed capacity of 500 MW can lose up to

£4m

for a failure that lasts up to 6 months

or as much as

£220k for a repairable 7-day failure



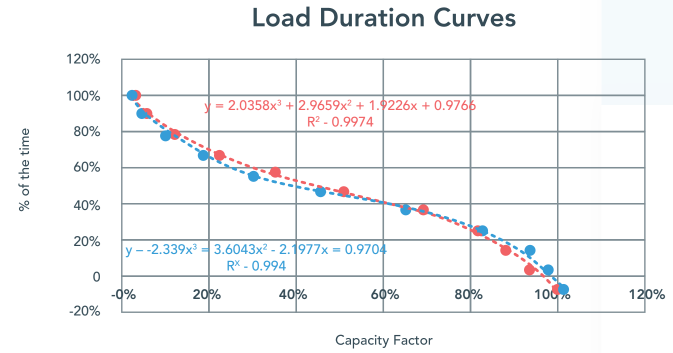


Figure 6 – load duration curves showing the amount of time typical offshore wind farms are at a given output

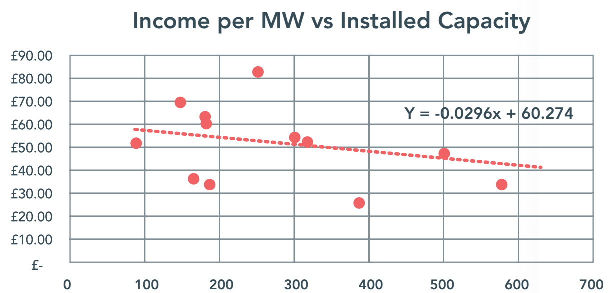


Figure 7 – OFTO Income calculation usually driven by the size of the farm vs the market price for energy

The business case

In this case we have used publicly available information for an offshore wind installation to formulate a high-level business case for remote online transformer monitoring.

The following inputs have been considered:

- Balance of plant
- Commercial market price
- Annual risk of transformer failure
- Repair & replacement time

We also considered some typical load duration curves for offshore wind farms from publicly available data.

Assumptions for the business case

We have used a representative 500 MW wind farm project, with a 5 MW individual turbine size with 2 onshore substations each with a redundant transformer and an offshore substation with a redundant transformer. Transformers, if they experience a catastrophic failure can take 6 months to replace, in many cases longer.

The numbers

With all of these parameters considered a wind farm could be exposed to a conservative estimate of £4 million in lost revenue due to a reduction in export.

Payback period

The average cost of a solution in the market, is less than a week of downtime over the wind farm lifetime of 25 years for a project owner, and less than a day for an OFTO. This does not take into account operational savings made from moving to a condition-based maintenance strategy, or the potential positive impact on insurance premiums.

Operational considerations

The data from transformer online monitoring can provide significant operational benefits.

Many manufacturers have often arbitrary lifetime periods and maintenance schedules, but due to the flexible and dynamic use of power transformers, and the highly variable nature of their operating conditions and use, these can often be unsuitable for a particular power transformer and its associated assets. The extra insight from remote online monitoring provides benefits above and beyond, ensuring the transformer remains available for exporting energy.

Some of these benefits relate to optimisation or deferring of maintenance, while others can relate to dynamic conditions in the electricity grid, such as requirements for temporary overloading of the transformer.

Optimising maintenance

If for example a transformer had a known fault condition or defect internally, online monitoring may afford the possibility to manage the transformer operating conditions in order to slow the progress of damage to the transformer. For example, if the fault generates more gassing at high load, it may be possible to use the monitoring data to limit loading below the threshold where gassing is occurring. Alternatively, it may be possible to make adjustments to the controls of the transformer cooling system. This can allow the transformer lifetime to be optimised providing power over longer periods between maintenance.

Controlled overloading

Due to the current political and economic situation of today's competitive pricing for energy, low carbon energy sources are becoming a more responsible source of electricity in the UK's energy mix. This places increased pressure to produce as much energy as possible when the generation opportunity is available. This can lead to transformers being under increased stress from a higher load target. A higher load results in higher heat being generated from the transformer causing the transformer insultation to age more rapidly. This can reduce the asset's life and result in downtime of the plant to allow Asset Managers to conduct regular manual inspections to assess the level of degradation.

With transformer online monitoring of parameters, such as the transformer load, top oil temperature, cooling performance, and moisture-in-oil, it is possible to generate a 'digital twin' model of the transformer in order to offer safe, controlled overloading of the transformer. This is possible with the online monitoring data processed using the 'digital twin' model. The model projects the duration the transformer may be overloaded before reaching it's critical hot-spot. This could lead to damage without effective online monitoring.

Benefits relate to optimisation or deferring of maintenance, while others can relate to dynamic conditions in the electricity grid, such as requirements for temporary overloading of the transformer

The role of data

Power transformers are highly specialised assets that require detailed knowledge to interpret and understand the data an online monitoring system provides. Without the integration of software that both summarises and visualises this data into consumable information asset managers risk being overwhelmed by the data that these solutions can output. With all of this in mind an energy sector wide data mandate has been produced by the UK government, the data agenda for the wind energy sector has never been clearer.

With transformer online monitoring of parameters, such as the transformer load, top oil temperature, cooling performance, and moisture-in-oil, it is possible to generate a 'digital twin' model of the transformer in order to offer visibility of the various monitored transformer components.

The following principles have been set out as generic challenges to the entire energy industry and these principles apply to handling complex asset data for power transformers.

Digitalisation of the energy system

Transforming the energy system to make energy industry participants more efficient.

Maximising the value of data

Making data discoverable, searchable, and understandable where commercially appropriate.

Visibility of data

Establishing common standards for data exchange making it easier for participants to interact within commercial frameworks.

Coordination of asset registration

Establishing asset registration compliance criteria to improve the reliability of data and improve the efficiency of data collection.

Visibility of infrastructure and assets

To allow for the effective planning, connection, and development of new projects these principles must be considered when preparing an asset monitoring strategy for high value assets such as wind farms, and the associated balance of plant.

Data modelling

Correct data modelling is an essential part of any business that wishes to leverage an effective data strategy. Establishing a data description will support analysis and understanding of your data requirements and how each of these interact with business-as-usual processes. This delivers a few key benefits:

- Cutting costs and providing a faster time to a minimum viable product
- Understanding and improving business processes
- Reducing complexity and risk
- Improved collaboration between core business functions and third parties

Collecting data to drive a condition-based maintenance strategy

The data collected from an online transformer monitor should be a mixture of data from sensors which monitor to detect the degradation in the transformer, along with sensors that monitor the operating conditions. This is important because many times the degradation (e.g. gassing in oil, or partial discharges in a bushing) is related to the operating conditions. (load & temperature). A list of common transformer monitoring inputs / parameters are listed below:

Inputs for transformer condition monitoring:

- Dissolved gas analysis (DGA) monitoring
- Moisture content in oil
- Bushing Monitoring (Capacitance and Tan. Delta)
- Partial Discharge Monitoring
- Transformer temperature monitoring (tank surface temperatures, radiator, and internal winding or oil temperature sensors)
- Through Fault Current Monitoring
- Voltage harmonics
- Transformer tank vibration monitoring
- LTC operating mechanism monitoring (motor torque currents, vibro-acoustic)

Inputs for monitoring of operating condition:

- Ambient/environmental monitoring (ambient temperature, humidity)
- Transformer load
- Transformer oil temperature
- Operating voltage

The link between condition based maintenance and data management

A condition-based maintenance strategy and data management are inevitably interconnected. Collecting and analysing near real-time data can transform the way a business operates by only performing targeted interventions when they are needed and reduce environmental impact by eliminating unnecessary visits. Data provides the information and insight that enables improved capital allocation, condition-based maintenance, the achievement of performance incentives and increased ROI.

To build these capabilities means introducing sensing capabilities across key assets in the wind farm asset base, and the ability to capture, store, tag and normalise data, transforming it into actionable information.

The value of actionable insights

The ability to combine near real-time data with historic information provides the ability to analyse trends, forecast investment, and predict equipment lifecycles based on actual usage. Many devices, such as Dissolved Gas Analysis monitors, have been acting as asset monitors for many years, enabling Network Operators to build a detailed picture of performance and reliability of assets over time. By combining asset histories with current data, the data analytics landscape can become a foundation stone for progress towards a condition-based maintenance strategy.

Online monitoring benefits for asset management

In this chapter we discuss the beneficial impact of leveraging a coherent sensor, online monitoring and data strategy and how this can impact the normal operation of a wind farm.

Life extension

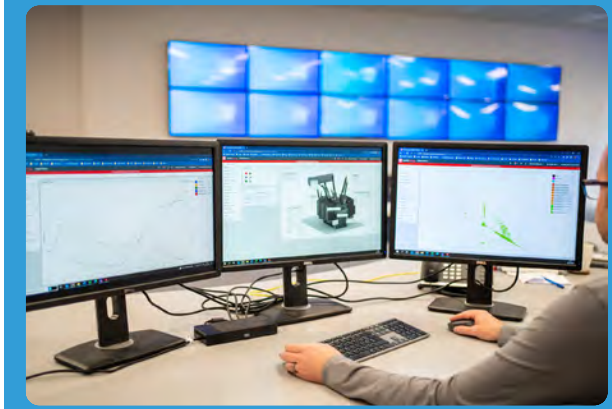
In some situations, it may be necessary for system operators to operate transformers with known defects that are not repairable for prolonged periods of time due to replacement or spare transformers not being available. In these circumstances, online monitoring can play an important role in assuring that transformers defects do not worsen and similarly to examples in the previous section, online monitoring can enable management of the transformer operating conditions to extend its service life.

Asset health scoring

For conducting risk assessment and maintenance planning, many transformer Asset Managers utilise health scores or indices. These indices are typically used as a relative ranking in order to identify which critical transformers should be prioritised for maintenance, allocation of spares, or planned replacement. Traditionally, these health indices would be based on the transformer age, its operational history, along with offline diagnostic test data and information from visual inspections.

Online monitoring can provide valuable insight into the asset condition since the assets are exposed to stresses from operating conditions which are not present during offline testing. Online monitoring data is not commonly considered in asset health scores or condition indices, and the exclusion of online monitoring data in many cases can be due to uncertainty with how to interpret and assess some online data, e.g. partial discharge data. In other instances, it may be due to uncertainty with integrating the online data for transformer fleet assessment.

In a CIGRÉ publication by Camlin Energy an analytical method for computing transformer health indices using both online monitoring data and/or offline test data for power transformers is described. The method evaluates a condition index score based on offline diagnostic test data and online monitoring data. This approach to integrate online monitoring data into condition health scores for power transformer asset management provides multiple benefits. One benefit is that that the condition for a fleet of assets can be monitored in a consistent way utilising a centralised database or data historian that is populated by online monitoring data continuously and translated into a condition score or index for all monitored assets. Visual inspection data and/or offline test data can also be integrated and automatically populated into the calculation of a hybridised condition index which factors online with offline data. For fleet asset management, this type of system would provide the up-to-date current data for maintenance planning, and life cycle management planning for transformer replacements or spares.



Life cycle management – aging estimation

What is thermal aging?

With transformer online monitoring data, it is possible to track the thermal aging that the transformer insulation endures. This thermal aging is what is usually used to define the transformers end of life, which is directly related to the transformer paper condition.

Impact of thermal aging

When power transformers age to end of life, the transformer paper insulation becomes embrittled. When becomes so brittle that movements in the transformer winding caused from network disturbances can cause the paper materials to rip or tear, ultimately leading to a transformer winding fault.

Value of online monitoring

Online monitoring data for aging estimation can inform when the transformer should be replaced and may inform the early/projected sourcing of replacement transformers preventing the risk of transformers failing in service after surpassing their serviceable lifetime based on the paper condition.

Online monitoring data for aging estimation can inform when the transformer should be replaced and may inform the early/projected sourcing of replacement transformers

Aftercare, condition reporting and installation services

Many Asset Managers on a wind farm do not have specific specialisms for transformer codition assesment, instead choosing to leverage outside expertise and service provision

Choosing a supplier - key considerations

Many suppliers of transformer online monitoring devices would provide services for maintenance. Some online monitoring systems require routine maintenance tasks such as replacement of filters, and verification checks, whereas some monitoring such as GC DGA systems can require other maintenance to replace consumable gases for example. All of these maintenance services may be managed by the supplier. This is important to consider when choosing a supplier for this technology, as previously mentioned many wind farms are in geographically remote areas, visits to site should be minimised both from a cost and safety point of view.

Services overview

Services are also provided for technical support. The analysis and interpretation of some transformer online monitoring data can be a challenge for Asset Managers. Technical services to analyse data and identify defects, while providing recommendations and actions to remedy problems are extremely beneficial and drive efficiency.

Benefits of condition monitoring

Service condition reporting is vital to maintaining the health of the transformer fleet. Typically, a maintenance service will be performed on a fixed basis to take manual oil samples as well as an inspection of other transformer components such as windings and bushings. These can be an expensive overhead and an inefficient measure of true transformer asset health. Other approaches can be taken which leverage a mixture of expert knowledge & automated data collection.

The general approach to asset condition determination is merging of two criteria: highlighting condition/ performance of the weakest component and general asset condition. The first step of evaluation takes each analysed parameter and assigns it to one of the below Condition Groups. The Condition Groups are specific for each parameter and have following categories (inspired by CIGRE TB227):

CONDITION 1: Good

CONDITION 2: Normal for service

CONDITION 3: Long-term risk

CONDITION 4: Mid-term risk

CONDITION 5: Short-term risk

The final evaluation result can be presented in a format combining results of both evaluations. This is just one number, the higher the number, the worse the transformer condition. This simple presentation of complex analysis allows the ranking across a transformer fleet. This means a wind farm operator only needs to pay attention to the power transformers that need intervention.

The condition is evaluated from the combination of both on-line and off-line data. In particular, the following 4 groups of parameters are considered for the calculation:

1. DGA: dissolved gases: Absolute Gas Concentration (AGC) and Rate Of Change (ROC) (lab and on-line)
2. Oil quality: furans, colours, acidity, BDV (lab data), moisture (lab and on-line)
3. Partial Discharges and Bushing Monitoring: medium activity, severe activity, High Energy Events, relative variations of Bushing Capacitance and Tan Delta, PD
4. Models: moisture and bubbling, hot spots, ageing, apparent power, through-fault-current

Condition reporting - Driving decisions and actions

Recommended activities from condition reporting need to be clear and easy to understand and require limited technical knowledge of transformers, this allows decisions to be made quickly on what action to take and when.

More detailed outputs can be presented if wind energy operators have resident expertise in transformer assets.

These can be provided alongside recommended actions or without depending on the capability of the wind farm owner.

Advanced analytics spotlight

Advanced analytics can also be leveraged which take into account trending data from other data sources such as ambient temperature, vibration, transformer load, top oil temperature and winding hot spots.

A prerequisite for advanced analytics is to: provide an algorithm with Temperature and Load data from the monitoring system and the baseline configuration of the power transformer.

In cases where the baseline configuration of the power transformer is not available, algorithms can still provide meaningful results when considering data within recognised industry standards and average ranges for similar transformers reported in literature.

More than 80% of transformer failures involve the transformer windings load tap changers (LTC), or bushings

Conclusion

As the offshore market continues to grow rapidly in size, growth which is being heavily encouraged by the UK government, project owners and OFTOs will undoubtedly want to grasp this opportunity.

To comply with the highly regulated standards set out by OFGEM, and maximise ROI, the ability to avoid downtime is very important.

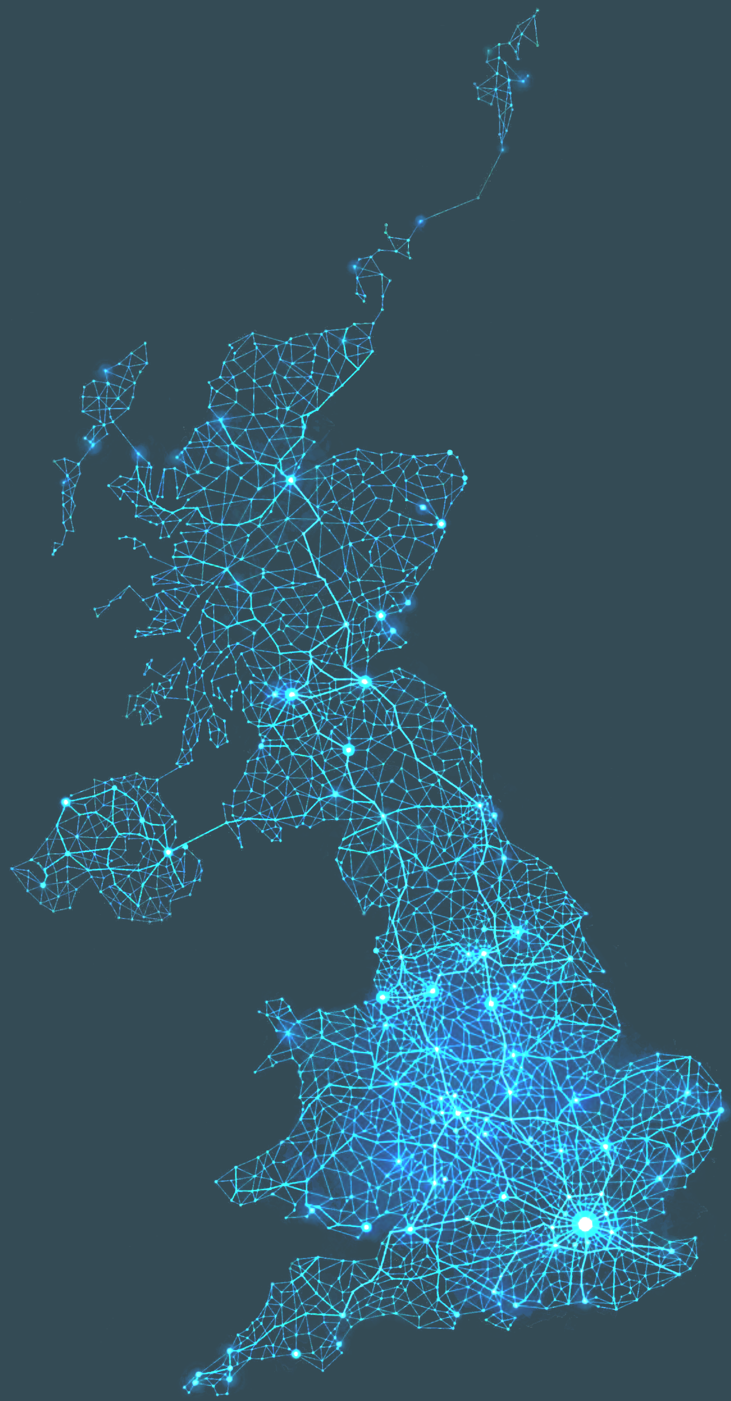
Throughout this blueprint we have explored the main considerations when investing in transformer monitoring solutions. We at Kelvatek are acutely aware of these key factors and their importance in choosing the best monitoring solution, we have built our own solutions around this, to ensure we provide the best outcomes for our customers.

We understand that sometimes the data can be overwhelming. At Kelvatek we provide a holistic transformer monitoring solution, not just a box. We offer the end to end solution supporting the management of your critical assets based on innovative sensing technology, together with software, data solutions and expert services. Our online monitoring solutions support you with the insights into the data which help you make reliable, informed and confident decisions.

Transformer monitoring solutions support asset managers to be proactive rather than reactive enabling interventions, ahead of time. This improves the reliability of the transformer, ensuring faults are prevented and downtime is minimised.

By adopting a transformer monitoring solution from Kelvatek we can provide you with critical insights to the health of your assets, work in partnership with your asset management and operations teams to provide asset owners reassurance that they are maximising performance of your wind farm.

Contact Details



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