June 2021

WHITEPAPER

Building a resilient T&D network

Improving T&D system reliability and grid resilience with real-time condition monitoring

Executive summary:

Today's transmission and distribution (T&D) utilities face a growing number of challenges, from increased regulatory pressure, new and changing environmental regulations, to evolving technologies, aging and obsolete infrastructure, and greater customer expectations. In addition to these challenges, utilities must confront the impacts of climate change that manifest as more frequent, intense, and extreme weather events occur.

Overview

With the huge growth of renewable energy and distributed energy generation (DER), grid resiliency becomes even more important as grid infrastructure continues to age. These complexities put greater pressure on T&D utilities to deliver a reliable, sustainable, and resilient grid for our swiftly changing times.

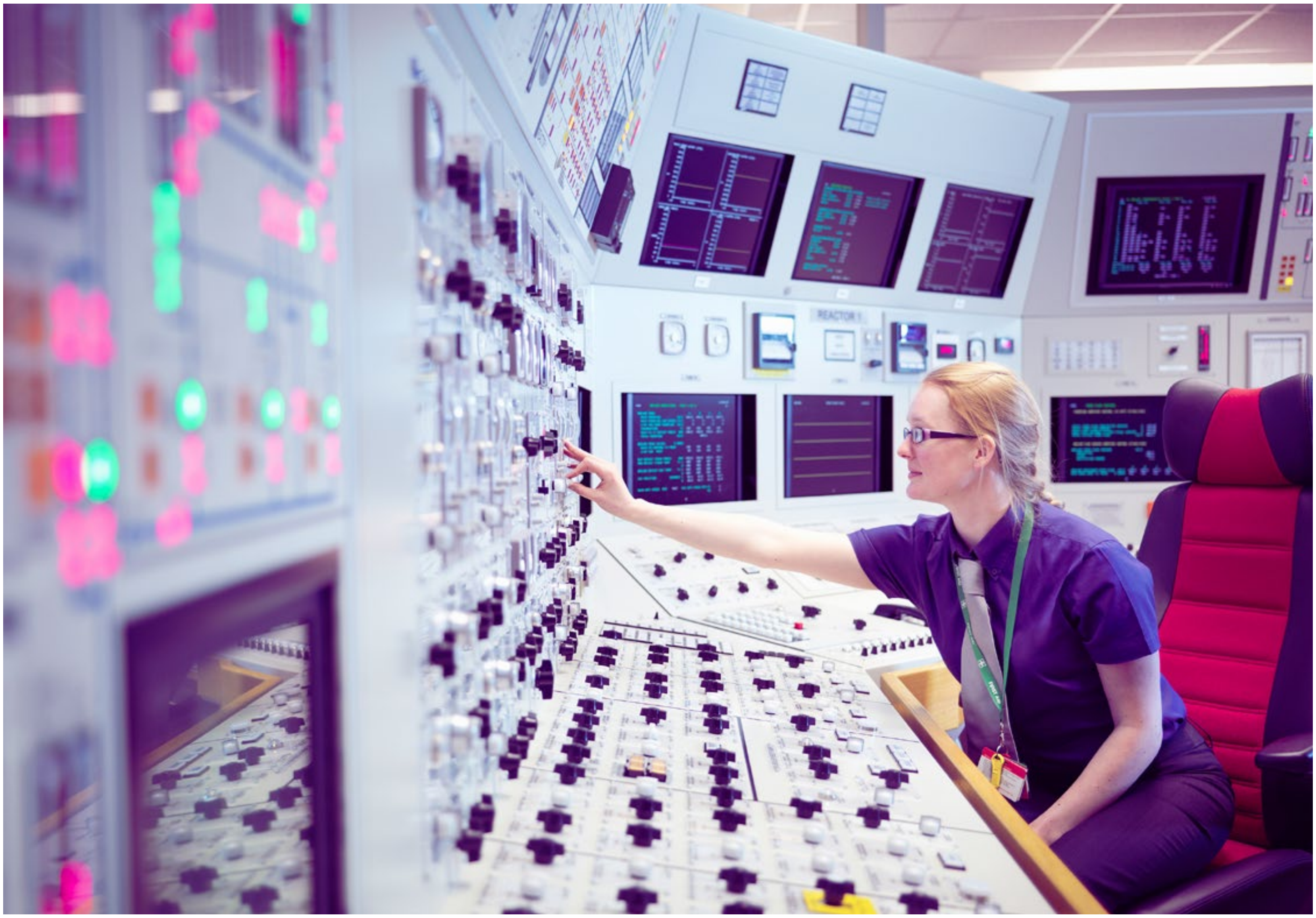
Though T&D companies must contend with financial constraints and more rigid regulatory requirements, these aging networks need enhancements. Many T&D utilities have streamlined their processes, cut operating expenses, particularly by adding new devices for remote monitoring and controlling equipment. The new devices, help make utility systems more resilient without the need for major capital investment.

To proactively manage changes, T&D companies are adopting best practices around reliability, resiliency, asset and maintenance management, outage management, renewable energy integration, and smart grids. One such best practice, Asset Performance Management (APM), improves asset reliability and availability through data capture, integration, visualization, and analytics.

APM also includes asset risk management, reliability-centered maintenance, predictive asset management, and condition-based management. Because the success of APM programs depends on the proper operation and correctly applied maintenance of critical assets. T&D companies are rethinking their traditional time-based maintenance or scheduled maintenance practices and turning toward condition-based maintenance (CBM).

Traditional utility maintenance programs are centered on calendar-based strategies. Unfortunately, scheduled maintenance is not driven by an asset's actual condition but by time, age, or wear. In many cases, companies incorrectly maintain equipment, perform maintenance too early, or worse, after the equipment has failed.

CBM uses real-time asset monitoring to detect anomalies, track asset health, mitigate potential failures, minimize downtime, maximize available resources, eliminate unnecessary maintenance, and trigger the right maintenance at the right time.



CBM also enables T&D companies to better prepare for unplanned outages. By minimizing forced outages, CBM plays a role in reducing the risk of losses or fines for poor system reliability, unscheduled sustained outages, and blackouts. CBM ensures that grid assets only perform within their operating context, especially important for those assets that are nearing or past the end of their useful life. By feeding operations and non-operations data collected in a PI System™ into enterprise asset management (EAM) and computerized maintenance management systems (CMMS) systems, such as SAP™ PM™, IBM™ Maximo™, and DNV™ Cascade™, CBM can help utilities build upon the utility companies' APM programs which, in turn, result into a more resilient grid.

This white paper will look at the challenges T&D companies face and the market forces driving demand for a shift to more proactive maintenance strategies. Next, it will examine how CBM works, and how new maintenance strategies offer a more efficient and effective alternative to planned maintenance methodologies. Finally, this paper will look at how electric utility companies are deploying CBM with the PI System™, the industrial data platform of choice for the T&D industry.

Electric utilities address new challenges

The electric industry is transforming rapidly. Most changes are related to the introduction of renewables, distributed generation, micro grids, distributed energy resources, battery storage, distribution automation equipment. The growing demand for operations data for advanced analytics is changing the way the T&D industry does business. While maintenance and asset health do not attract the public's attention like headlines about alternative energy or electric vehicles do, a growing number of asset managers realize that new maintenance strategies play a critical role in equipping T&D companies to meet today's and tomorrow's challenges.

The following three major trends demonstrate that the value of CBM lies not just in lower maintenance costs but extends also to improved grid reliability and resilience. CBM also enables improved asset management decision modeling through Asset Performance Management (APM) programs.

Moreover, by moving from reactive to proactive strategies, T&D companies will use data and subsequent insights to drive action far beyond simple equipment maintenance. When T&D companies leverage real-time asset data in conjunction with other forms of operations data, managers can use a single source of truth to develop new asset and maintenance strategies. These include capacity and system planning, resilience planning, storm hardening, linking to ERP/EAM/CMMS systems, and reducing overall operating costs.

1. Improved grid reliability

Current regulations levy heavy penalties on utilities for poor system reliability, which includes excessive and extended outages due to failing equipment and slow response times to system outages and emergencies. Every utility's primary concern is creating a reliable grid that optimizes return on investments for stakeholders as well optimizes benefits for its local customers. As demand for higher reliability and quicker response to outages increases, available capital is decreasing. This critical need for high availability, mixed with a distributed infrastructure, demands new approaches to optimizing asset health and tracking maintenance needs.

2. Grid resilience and system hardening

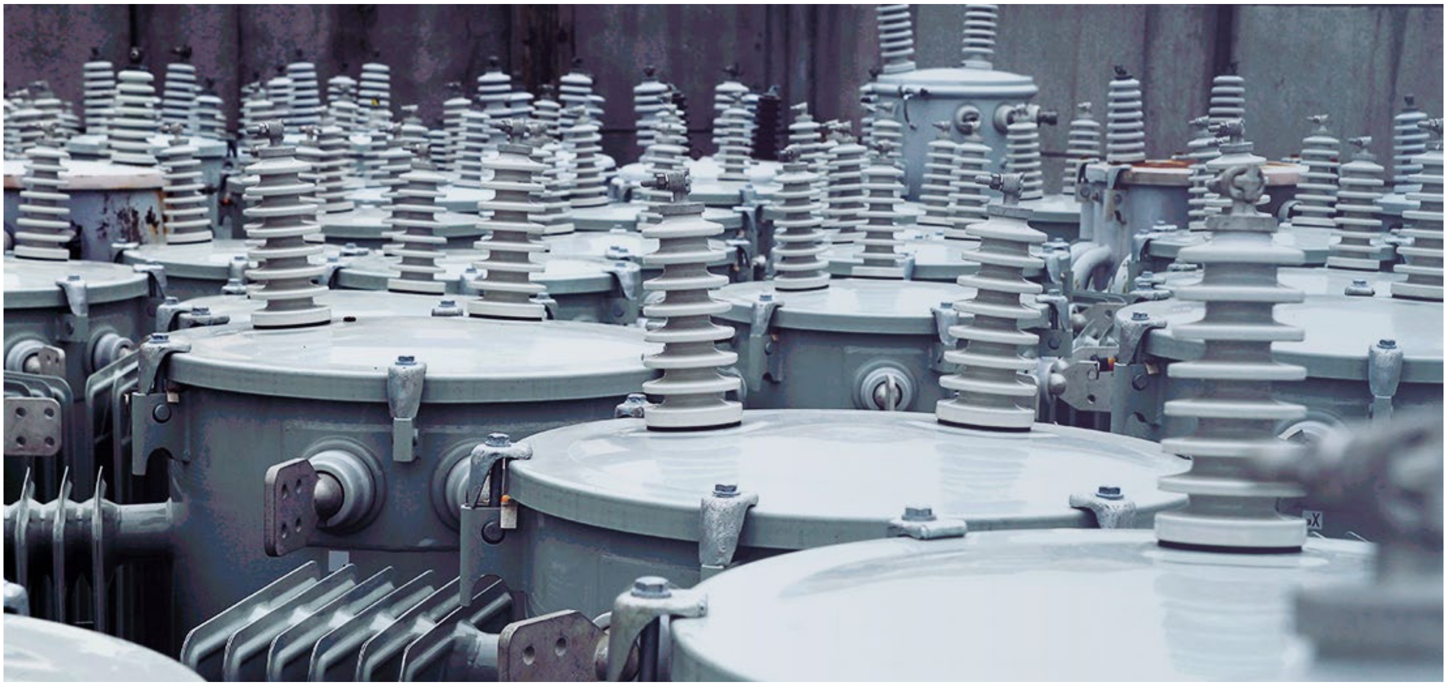
The impacts of extreme weather on utility infrastructure are forcing T&D utilities and regulators to take a more proactive approach to storm preparation, risk mitigation, and system hardening. Within this century, we have already seen a large number of record-breaking extreme weather events. These 21st-century natural disasters have not only occurred with an apparent increased frequency, but they also have had an increased magnitude and impact. These extreme weather events include hurricanes, floods, extreme cold and heat, drought, and snow and ice accumulations.

Clearly, the costs of recent extreme weather events are enormous. As we know with climate-related impacts, it is a matter of when, not if they will occur.

As the need for grid-hardening and resilience investments becomes increasingly apparent, and as the benefits from such improvements are being realized, utility companies must also recognize that identifying and addressing vulnerabilities to the system is an ongoing process.

In addition, they must be prepared to make risk mitigation investments cost-effectively, particularly as this new category of investments is typically viewed by the regulators with heightened scrutiny given the high costs of grid-strengthening programs, which do not necessarily provide immediate benefits. This capital-intensive initiative impacts available funds and resources on the operations and maintenance side of the utility companies.

By thinking beyond traditional planning frameworks and traditional maintenance methodologies, T&D companies enable a different sort of investment which includes a change in how the existing infrastructure is operated and maintained. Implementing best practice maintenance methodologies, such as CBM, strengthens the utilities' grid to perform more effectively when extreme weather events occur.



3. Extending asset life

Faced with rapid transformation, financial constraints, and increased regulatory requirements, electric utility owners are reluctant to make significant capital investments into asset replacement. Replacing equipment such as transmission towers, HV lines, power transformers, station switchgear, circuit breakers, and protection systems is expensive and resource-intensive. Extending asset life through the use of more proactive, or even predictive, maintenance strategies can give utilities more time to consider options without the hefty infrastructure costs.

T&D utility grid hardening initiatives changes focus on specific asset infrastructure investments and leaves other infrastructure to run beyond its expected life. This elevates the importance of maintaining assets optimally even beyond their expected life.

In addition, almost all life-extension business cases benefit from the use of real-time condition monitoring compared to engineering calculations alone. Most regulations governing life-extension applications require real-time condition monitoring.

More efficient maintenance strategies

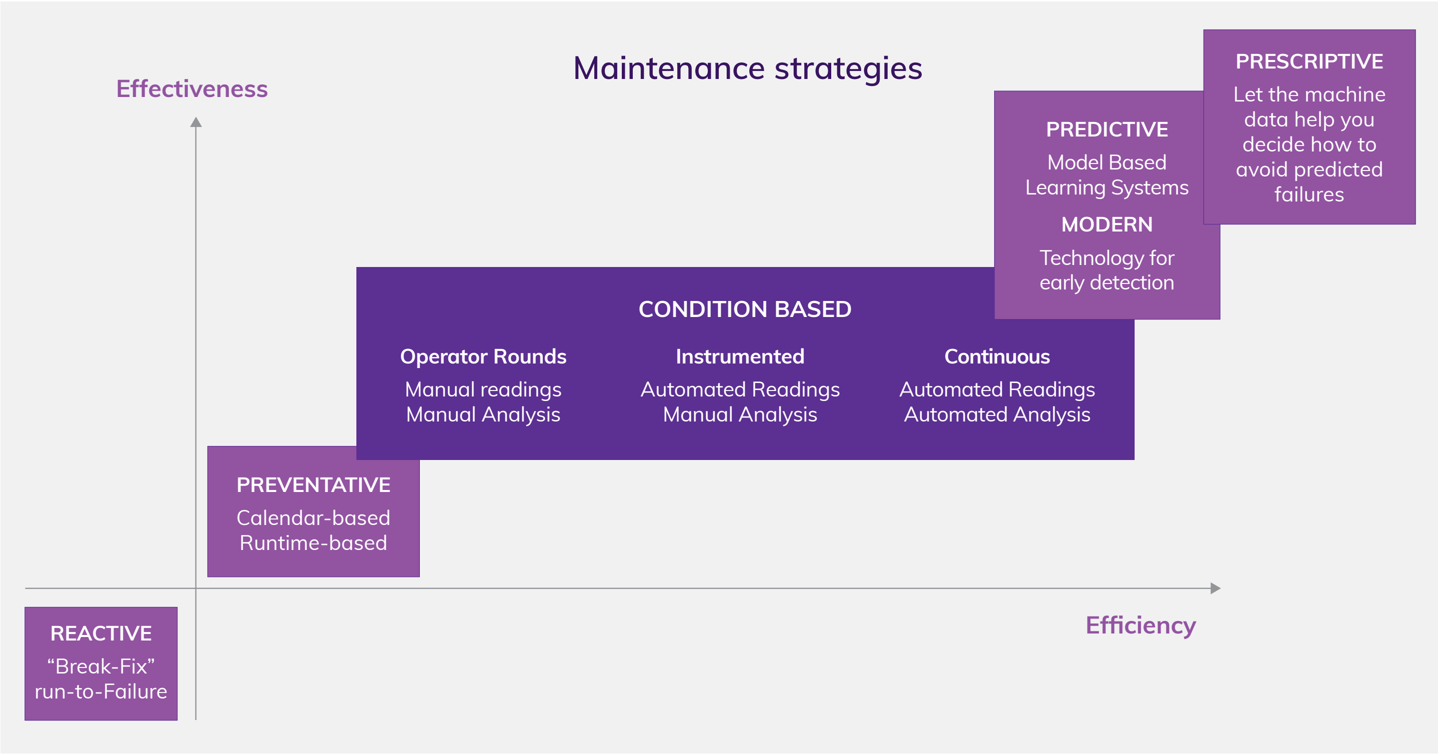


Figure 1. New maintenance strategies offer more efficient and effective alternatives to reactive approaches.

Studies show that the average electric utility company spends more than 55% of its maintenance budget on highly expensive, reactive maintenance strategies, under which maintenance occurs only after an asset goes into a failed state. However, top-tier industry plants that utilize predictive technologies and proactive practices spend less than 10% of maintenance budgets on reactive strategies.

Alternative, more proactive maintenance strategies use corrective, preventive, and predictive processes in a complementary manner. These strategies leverage dynamic, real-time online asset monitoring using wireless and wired sensors. Subject-matter experts, consultants, and OEMs can analyze data for CBM to maintain assets or use predictive models to more accurately estimate asset life cycles. There is, however, no need to wait for sensors and online monitors to be installed across a fleet of assets; a utility company can start with whatever data is available, then build up and expand data models as more sensors and online monitors are installed and incorporated into the system. Predictive maintenance gives utility asset managers more insight into an asset's health and life expectancy, which in turn provides time to plan for capital replacements or system upgrades while maintaining system reliability and maximizing asset availability.

Today, leading utilities continue to leverage real-time and historical data collection and advanced analytics to expand the adoption of CBM processes to drive down the high cost of reactive maintenance strategies (Figure 1). CBM is generally defined as a set of maintenance processes guided by the collection of data on utility assets to ensure that maintenance is performed only when needed. Unlike calendar-based maintenance strategies, CBM leverages asset data to reconcile maintenance schedules with real-time asset conditions, organizational priorities, and changes in the operating environment.

A CBM program begins by monitoring asset parameters, then evaluating parameters in relation to limits, trends, and other asset data. Eventually, a successful CBM strategy ties real-time data to comprehensive work-management solutions.

Properly applied CBM implementations offer several advantages over calendar-based maintenance systems, including:

- Reduced capital costs by extending asset life cycles
- Lower maintenance costs because equipment that is operating well is not repaired or replaced
- Increased asset and system reliability through early detection and more rapid response
- Improved asset availability and utilization
- Minimizing unplanned outages by better predicting asset failures and end of life
- Optimized maintenance intervals and prioritization based on the current health and risk
- Improved spare equipment and parts management
- Introduction of failure-finding tasks for protective devices
- Asset Performance Management (APM) for asset replacement planning

Customer Story

Commonwealth Edison – Multi-asset analytics enable CBM

A number of years ago, Commonwealth Edison, or ComEd, used the PI System and Asset Framework to move away from calendar-based maintenance and toward predictive maintenance strategies. Sensors now alert teams when assets began to fail so they can take action. However, these insights show only the status of individual assets, not the company's vast distribution-automation (DA) schemes. Monitoring the thousands of DA devices in the system was a critical next step for improving maintenance strategies and enabling exception-based analytics.

ComEd's DA schemes work together and are responsible for isolating faults and restoring service. Service cannot be restored if a team member is in a state of alarm, so any outstanding alarms required review. Static reports showed all alarms, or points in time from the PI System, but these reports did not have team relationships. Alarms were vetted by two DA engineers and required a significant amount of time.

The company created a data flow that uses PI System and GIS location data fed into PowerRunner models to create graphical, exception-based reporting. Now, engineers can easily see the team's status and which alarms require review rather than the entire list. The reports show an in-depth view of five PI System data points and the state of the entire DA team, including prior reviews and any operator decisions. By moving to an exception-based model, engineers can easily understand how devices work together and quickly determine which alarms are critical so they can take appropriate action.

Earlier detection of impending failures

How do CBM and proactive maintenance strategies contribute to higher availability? In calendar-based maintenance strategies, asset replacement or repair have been historically driven by vendor recommendations or internal experience. If an asset's life cycle runs outside the historical projections, utilities run the risk of increasing costs by replacing or repairing the asset too soon or, worse, too late. Maintaining an asset too soon means that unnecessary costs and resources are used as well as introducing the risk of premature failures. If maintenance is performed too late and the asset fails catastrophically, this can cause anything from a safety or environmental issue to a major system outage or even a grid blackout. This emergency maintenance is by far the costliest restoration exercise.

When an organization begins collecting real-time data for specific equipment parameters, the asset's actual condition and operating context are always known and validated. In proactive maintenance strategies, real time asset behavior and context drive maintenance requirements. Condition monitoring is performed while the asset is operating, enabling utility companies to detect an impending failure, plan accordingly, and make necessary repairs in a controlled manner with minimal impact to the system and its customers.

A key tool used in understanding the selection of CBM as the right maintenance choice for a specific failure mode is the P-F curve. The P-F curve in Figure 2 shows the stages of failure of an asset. CBM is based on the principle that the P-F interval for an asset under a defined set of operating conditions can be determined, and then introduces the concept of an inspection interval which is less than the P-F interval (typically equal to half of the P-F interval). On that basis, the inspection or test that is capable of detecting the impending failure will be performed before the point of failure (F) (Figure 2), allowing time for maintenance to be planned (actions prioritized and planned, spares secured and repair work executed) before functional failure.

Point P represents the first possible point on the curve when an incipient failure can be detected. Through monitoring and intelligent filtering, system operators and maintenance managers can respond to any number of asset characteristics, such as a slight change in operating temperature, a sudden rise in combustible gases, an alarm of a leak, a change in power quality, an increase in losses or fluctuations in voltage and currentlevels.

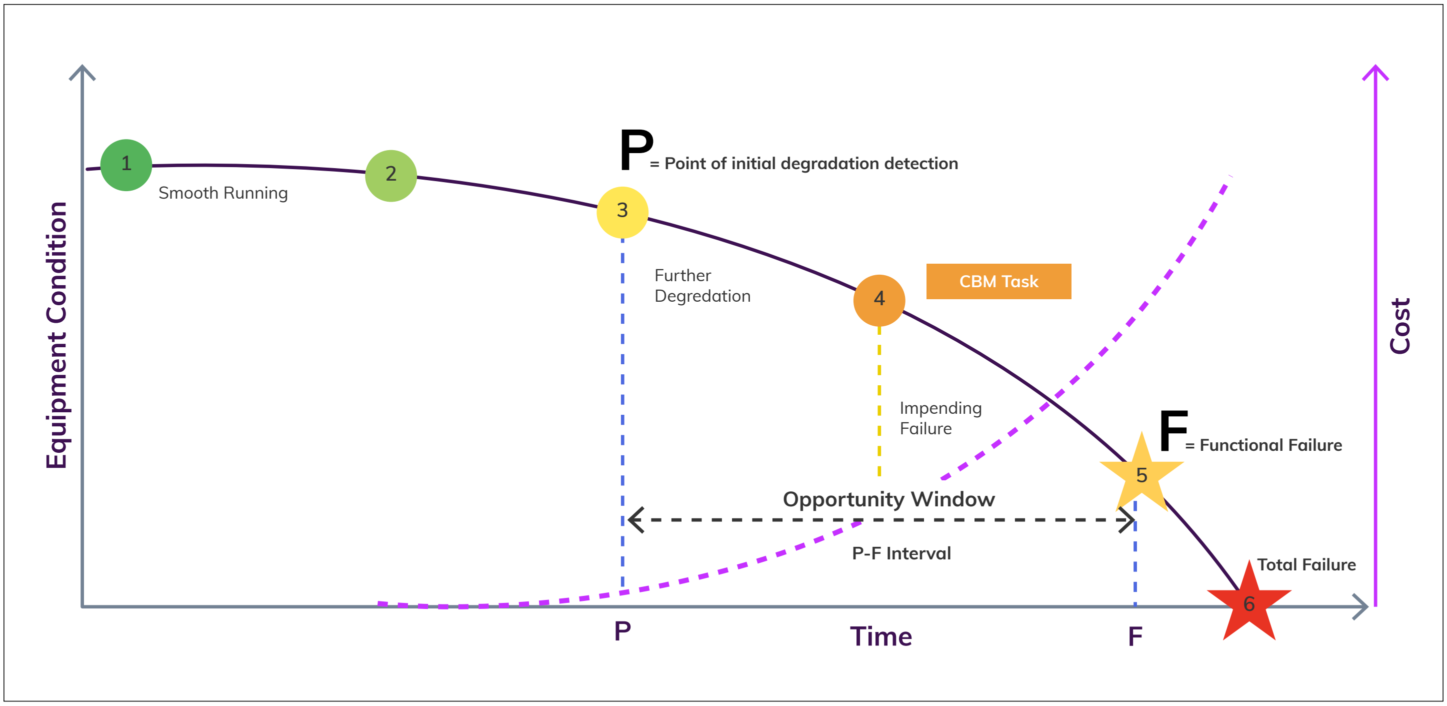


Figure 2: Asset condition degradation on the P-F curve.

The F point represents the point in time where it reaches a state of functional failure (F), where it stops safely performing the function for which it was used before it finally fails completely. The time between those two points is the opportunity window for the organization to proactively prevent a total failure through maintenance or repair. The earlier the detection of the P on the P-F curve occurs, the more time maintenance personnel have to secure spares, schedule for equipment isolation and de-energization, and execute repair work before functional failure.

In every utility, unexpected or random failures are usually catastrophic. Not only do failures present the greatest risk to reliability, availability, safety, and the environment, but unexpected failures are also the most expensive to repair. In a CBM or proactive system, early detection of performance degradation not only reduces or eliminates the unexpected and unplanned costs associated with a reactive maintenance approach, but maintenance personnel also have more opportunities to plan maintenance activities and manage costs.

As depicted by the red curve in Figure 2, the cost of failure or impending failure will typically rise as the point of total failure is approached.

The value of continuous condition monitoring

The inspections and or tests performed at the inspection interval have traditionally been applied by maintenance personnel; testing with handheld instruments and sophisticated test sets and analyzers, recording the test results on paper or electronically. Although this method of periodic inspection and testing can be performed either offline or online, online testing and inspection is preferred because it involves little or no downtime of the asset.

With assets that are critical to the operation of the system, many technologies are now available for continuous online, rather than periodic online monitoring. Monitoring units and sensors are indicative of incipient failures. Referring back to Figure 2, the implication of continuous online monitoring is that the variability of manual interval testing can be eliminated, and its value becomes the sampling or reporting period of the applied online condition-based monitoring instrument or system, which will typically be in the order of seconds, minutes or tens of minutes rather than days, weeks or months.

As technology develops and continuous monitoring systems become smarter and more powerful, utility engineers are using the PI System to develop algorithms that utilize a combination of analytics, inputs from multiple online sensors, data sources, disparate systems, and advanced pattern recognition to create virtual instruments which have the effect of moving the point of initial degradation detection P, back up the P-F curve (see Figure 2), closer to the (undetectable) point of degradation. A maintenance approach using such multiple variables and analytics is classified as proactive maintenance.

Continuous condition monitoring, virtual instruments, and analytics help to minimize and eliminate the variability of inspection intervals which means that:

- There is more time and flexibility to manage an impending failure event
- The risk of the event leading to undesirable outcomes is minimized
- The consequences of the event are minimized

To maximize the potential of online condition-based monitoring, all of this data (continuous condition data, process data, and utilities data) needs to be in one place so that users can view an asset's performance history and current status holistically and so that more detailed algorithms and models can be derived to provide the earliest possible notification of impending asset failure.

Organization-wide impact starts with condition monitoring

The core of CBM is real-time condition monitoring, which supports preventative maintenance and can determine the overall health of assets. While condition monitoring does not require complex analyses or models, the benefits are great.

Maintenance personnel collect multiple pieces of test and inspection data from an asset, analyze the data by looking at rates of change or comparing values to a norm, and create an algorithm for a group of assets based on multiple indicators. From there, personnel can calculate a health score for each asset based on how it rates compared to other pieces of equipment in its peer group.

By comparing operating and maintenance histories of similar asset classes, T&D utility companies can make confident, data-driven recommendations that reduce inventory costs, prevent over-servicing, and improve overall operational variability. Real-time operations data collection can be highly useful not only for operations and maintenance programs but also for aiding in future capital expenditures and defining work-prioritization schedules.

Ultimately, early equipment-degradation detection can help utilities plan for equipment repairs and replacements and reduce the risk and time of an unplanned outage.

With industrial data-management software, such as the PI System, utilities can further make use of their existing installed smart equipment across their grid. This smart equipment collects data and information from the multitude of installed online monitoring devices. These devices include intelligent line monitoring systems, transformer DGA and bushing monitors, DC Systems, Protection and Communication equipment, Security systems, IR cameras, fault indicators, and distribution automation devices to name a few. When this data is collected and leveraged by real-time systems such as a PI System, it can automatically analyze large amounts of data and eliminate the need for manual monitoring. The PI System can detect anomalies in critical equipment very early in the performance-degradation process and help support operations by avoiding equipment failures and optimizing maintenance schedules.

CBM and proactive maintenance strategies can be easily scaled from pilot projects and individualized pieces of equipment to utility-wide asset class implementations. The PI System's highly scalable infrastructure, for example, enables T&D utilities to integrate system-wide asset class maintenance requirements into corporate management systems such as SAP's PM, IBM's Maximo, and DNV's Cascade.

Customer Story

Fingrid Oyj – Real-time condition monitoring saves €5 million

Fingrid Oyj is a Finnish electricity-transmission operator. The company's vast network spans 14,000 kilometers of transmission lines and more than 100 substations. Network reliability is critical, but the company had no way to monitor its vast network of assets. The distributed nature of the Fingrid Oyj's assets, along with numerous components, made it difficult to identify defects and low-performing assets.

The company deployed the PI System to enable real-time condition monitoring to optimize new investments and maintenance schedules. Using Asset Framework (AF), Fingrid Oyj created an asset hierarchy that served as a data foundation. The team created 13,000 AF templates and a hierarchy of substations organized equipment by type and grouped together its reserve power plants. This data structure enabled teams to visualize asset health in real time and receive nearly 500 notifications if assets were performing outside of set limits.

Real-time condition monitoring with the PI System has significantly improved operators' ability to detect gas leaks in circuit breakers and geographic information system stations. In addition, operators use a health-index tool to analyze large asset populations, such as switchgear, to optimize the timing of maintenance and equipment replacement.

Maintenance personnel uses the PI System daily to monitor assets. Right away, maintenance teams quickly identified two transformer faults before they presented a serious problem. Not only did the Fingrid Oyj avoid catastrophic failures, but repairing the transformers also saved the company €5 million.

Looking ahead: Building a resilient T&D system for future benefits

Today's Transmission and Distribution market demands that electric utilities deliver high reliability, a safe and resilient grid all at a low cost. However, many utilities still use multiple, disparate data systems, limiting visibility and leaving companies to rely on periodic equipment-condition assessments and reactive maintenance strategies. Reducing maintenance costs and preventing catastrophic failures hinges on proactive CBM-based techniques that leverage real-time operations data.

Not only can CBM reduce overall maintenance costs, but it can also impact processes across the enterprise. CBM data can inform asset management strategies and vendor performance reviews and enable root cause analysis techniques as well as environmental monitoring and regulatory compliance. As CBM strategies mature, T&D companies can optimize operations well beyond the control room to boost system reliability and grid resilience and optimize outage planning.

The PI System provides utilities with a single source of truth for operations and non-operations data. The PI System collects and manages information from multiple isolated sources across the enterprise and presents that data in a way that allows management, engineering, operations, and maintenance staff to share and analyze information. From there, they can work together to optimize operations and maintenance strategies, maximize asset life cycles, predict outcomes, and, ultimately, drive bottom-line results.

As the costs of remote monitoring gear and analytical software remain affordable, T&D companies will continue to adopt CBM as a best practice foundational to asset management programs.

The rolling out of CBM along with advanced analytics, using real-time performance data and predictive algorithms, has a direct positive impact on system reliability, reducing risk and lowering operating costs. It can help T&D companies prevent asset failures, concentrate asset management efforts on critical assets, avoid excess maintenance work or premature asset replacements, and grow and retain the valuable knowledge of in-house experts.

Many utilities are being more proactive, pushing to harden and modernize their grids and cybersecurity to boost efficiency, safety, reliability, and resilience. Regulators are considering major proposals to require upgraded systems as utilities prepare to spend huge amounts of capital to create a grid capable of accommodating new digital technologies and increasing amounts of variable power generation originating from the wind or sun. CBM is one of the most cost-efficient ways to buy utility companies more time during these times of change. CBM allows T&D companies to maintain their existing grids while obtaining the necessary capital to upgrade their infrastructure.