SECURING THE AVAILABILITY OF ELECTRIC DRIVE TRAINS WITH PERFOMANCE BASED CONTRACTS

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Abstract - The paper focuses on two areas: the availability of critical production processes and effective service cost handling in electrified drive train applications. It also highlights the significance of time as a metric for measuring service efficiency and performance, as it is closely linked to business performance and serves as the basis for proposed Key Performance Indicators (KPIs). The concepts of TR3 (time-to-react, time-to-repair, and time-to-restart) are introduced to describe the performance of data-based life-cycle services. Furthermore, the paper proposes the concept of a downtime-duration cap to quantify the impact of services on unpredictable, off-specification events.

To achieve superior results in availability, the paper emphasizes the importance of digitalization supported by event-based predictions. The right combination of product and service items forms the foundation for KPI-based availability. Additionally, the paper highlights the significance of service contracts for specific applications, such as turbine replacement, hydrogen production, power-to-power, and carbon capture application, in alignment with sustainability requirements.

I. INTRODUCTION

Advancements in design and quality assurance have significantly improved the reliability of industrial machinery over the past 40 years. The widespread adoption of monitoring and protection systems has created a data pool that enables analysts not only to identify reliability improvements but also to make observations about current issues and the effectiveness of data processing systems and processes in understanding and addressing these problems.

II. FAILURES

Taking electric motors as an example, catastrophic failures are almost solely caused by off-specification events, the majority of which result from overvoltage, ambient vibration and chemical corrosion. Spares and emergency repairs serve as the primary mitigators of catastrophic failures and protect against extended downtime of critical infrastructure. Standard monitoring and protection systems, which are widespread across industries offer effective means of detecting operational condition out of design range or anomalies. Proper and regular maintenance helps to identify issues in a timely manner and ensures that the machines are operated according to specifications.

When it comes to addressing these rare anomalies, equipment operators may not have access to skilled personnel with the necessary experience and tools to provide comprehensive support at all levels. While these anomalies occur infrequently, their impact on production and associated business losses can be significant. It is crucial not only to detect and understand the severity of the problem in a timely manner but also to have access to spare parts and qualified personnel capable of remedying the issue. Although it may seem reasonable to always have the right team available, given the rarity of some faults, it is difficult to justify, from a business perspective, the feasibility of maintaining dedicated personnel.

Machine vendors, supported by a robust digital infrastructure and in-house trained experts, can leverage their capabilities on a large scale to support machine operators. By analysing failure statistics, they can prioritize the prevention of catastrophic failures as the primary risk to operational availability. From the perspective of operators, the most important aspects are preventing catastrophic failures from occurring and minimizing the downtime required for preventive measures, such as repairs or component replacements. Operators may also request the ability to safely extend the operation of a damaged machine as close to potential failure as possible, to maximize production despite the emerging risk. For that to be possible an effective service organisation must be able to detect the earliest occurrence of events indicating future problems like catastrophic failures, monitor the severity of the damage along the way and provide a reliable indicator for the last moment before catastrophic damage. Preventing the occurrence of a catastrophic failure is important to help reduce collateral damage to humans and equipment. Staying in the context of motors such failures to be prevented are for example short-circuits in electrical systems or shaft cracking.

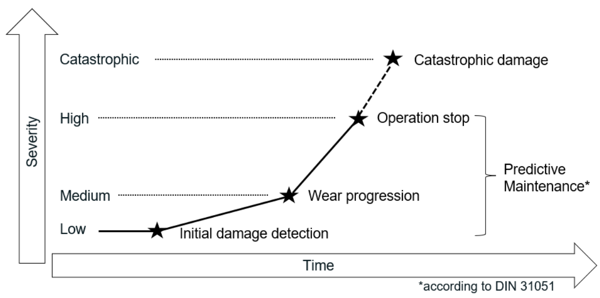

Fig. 1 Sequence of events

We believe that the knowledge and experience accumulated by service organizations of machine vendors over decades of operation, along with their connections to research and development and engineering departments, provide a strong foundation for understanding failures in terms of their root causes and progression over time. This expertise enables them to establish an infrastructure that can at scale effectively detect and monitor the progression of wear leading up to an impending failure. With this approach, operational interventions and remedial actions can be implemented at the latest possible moment at minimum risk of unexpected surprises and disruptions.

III. MACHINE LEARING

One of the critical applications of data processing and artificial intelligence (AI) lies in predicting equipment failures. The primary objective of data-driven prediction is to utilize measurement data collected during machine operation to estimate the point in time when a machine or its components are most likely to fail, resulting in operational downtime. This capability enables operators to receive timely notifications, allowing them to arrange necessary repairs and procure spare parts, or even prevent failures entirely. Consequently, the adverse impact of downtime on business operations can be minimized.

However, several challenges complicate this endeavour. Machinery varies widely in type and size, and failures of a similar nature across different types of equipment occur infrequently. Furthermore, effective quality assurance processes implemented by machinery manufacturers often ensure that failures are non-repetitive. In the case of electrical machinery, observable wear-related damage and failures are particularly rare and are typically mitigated by existing monitoring and protection systems. For the limited number of damage patterns that may develop gradually, machine learning techniques require extensive time horizons to collect sufficient data for effective modelling.

Despite the widespread adoption of data collection practices in modern plants and factories, it often remains unclear whether the gathered data contains information relevant for accurately identifying problems or predicting failures critical to machine operation. The feasibility of employing machine learning in industrial settings heavily depends on factors such as the type of equipment, the characteristics of damage and failures, the frequency of occurrences, and the relevance of the data in capturing pertinent information. Moreover, the cost and time associated with developing and maintaining such models may outweigh their potential benefits.

IV. DATA PROCESSING

Inefficiencies in machine learning for failure prediction can be mitigated in several ways: improving the quality of measurement data, incorporating relevant information inputs, and leveraging physics-based models.

Industrial equipment is fundamentally designed using physical principles that are mathematically expressed. These mathematical models incorporate a range of factors derived from accumulated experience and experimental results, providing a robust foundation for performance optimization and precise estimations in life consumption and damage detection.

Data collected through control and monitoring systems is often optimized to detect the most frequent symptoms of potential issues. However, this data is frequently insufficient for accurately identifying damage and predicting its progression, both in terms of the scope of damage and the lead time. Service experience with specific machinery, particularly insights gained from failure cases, serves as a valuable resource for understanding the stages of damage progression leading to failure. This expertise can be employed to identify critical informational inputs for models and to determine the most appropriate sensors for monitoring processes effectively.

Integrating information from diverse sources—such as sensors, measurement data, and human observations—and feeding it into damage models significantly enhances the quality of outcomes. When enriched with data containing relevant and precise information, factorized physical models deliver highly accurate and valuable inputs for decision-making.

V. DECISION MAKING

The identification of damage that may lead to future failure and the reliable monitoring of damage progression through the observation of sequential events significantly enhance the quality of predictive analysis. To transform raw data and computational results into actionable information that is readable for humans, an additional layer of processing is required. Automatic decision-making plays a crucial role in extending the lead time to failure by minimizing the time needed to convert raw data into meaningful information. A decision-making layer is responsible for interpreting and communicating results, and it must incorporate knowledge stored in a manner that eliminates ambiguity and bias. Establishing causality between observations and outcomes is essential for accurate interpretation, reduced analysis time, and precise, actionable recommendations.

VI. INFRASTRUCTURE

The key elements of an effective digital service infrastructure are a selection of tools and capabilities that enhance the serviceability KPIs. Among the most important ones are real-time observability, automated complex mathematical calculations, integration of various data types, automated decision-making and integration with operators' maintenance management system. These components must be tightly integrated to effectively support domain experts and responsible service providers.

Let's look closely at some of the most important ones. To enhance observability, on-site monitoring can be extended with dedicated sensors tailored to detect issues specific to the machine type and its mode of operation. This extension not only helps eliminate certain parts of in-person inspections but also enables the timely detection of potential catastrophic issues by pinpointing initial impacts. Vendors, with their deep knowledge of machine mechanics, can analyse the development of these failures and predict upcoming developments, allowing for effective planning of service activities.

Many analyses can be automated be reusing models originally applied for machine design. Those mathematical representations of machine physics, when fed with proper input can be indispensable in assessing the machines condition and life consumption of its most critical components.

It is important to note that diagnosing machine deterioration requires a hybrid approach. Long-term measurements taken during operation must be combined with measurements conducted during machine downtime.

A comprehensive digitalization solution incorporates not only long-term and service measurements but also incorporates human input and machine factory data.

Improvements in the quality of observability are further achieved by focusing on machine subsystems that are relevant for its availability and by measuring the components' performance and life consumption to predict their durability. Dedicated digital systems not only provide information on the potential life extension (in case of machines underutilization) but also enable identification of events leading to shortening of the life expectancy.

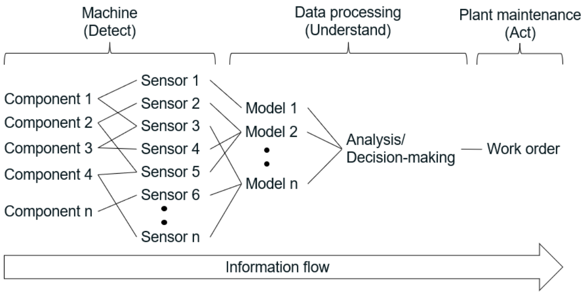

Fig. 2 Principal architecture for information processing

Modern digital solutions play a crucial role in enhancing the performance of service delivery by enabling a (near) real-time connection between the machine and the individuals responsible for its availability. The future of service delivery will be shaped by semi or fully automated systems that integrate measurements, inputs, and manufacturer information to accurately detect and analyse problems. By utilizing the results from Root Cause Analysis, these systems will be able to generate precise work orders that target the specific issue at hand

VII. PREDICTIVE MAINTENANCE

For modern, globally operating service organizations to be effective, they must possess an in-depth understanding of the machines and the processes in which those machines are involved, throughout their entire designed lifetime. This understanding is crucial across all three phases: design, operation, and maintenance. Each phase requires personnel with distinct skills, experience, and abilities to ensure successful outcomes.

By having a skilled team and utilizing both mechanical and digital infrastructure, service organizations can unlock new possibilities in terms of optimizing machine performance, reducing downtime, and improving overall operational efficiency. This comprehensive approach allows for proactive and effective maintenance, as well as the implementation of advanced technologies and strategies to maximize the lifespan and performance of the machines.

An extended monitoring system, coupled with digital solutions, provides valuable information that enables both local and remote service organizations to prepare and mobilize resources such as spare parts, tools, and personnel. Real-time communication facilitated by digital means allows for seamless coordination with external service providers.

Through co-monitoring the operation alongside the operator, vendor-based service providers can alleviate some of the burden on operators and quickly identify any anomalies that may arise. This approach, supported by tailored sets of sensors, improves the efficiency of anomaly detection by reducing the number of false positive alarms. Distinguishing and qualifying an anomaly as a potential failure triggers proactive activities within service organizations, raising awareness and bringing the affected application into focus. Precisely detecting the affected component and observing the sequence of events provides a buffer of time required for the mobilization of spare parts, tools, and personnel for emergency repairs.

When the system indicates an imminent risk of catastrophic failure, the operation can be halted, and the fully prepared and mobilized emergency response team can promptly address and remediate the problem. This streamlined process allows for efficient and effective maintenance, minimizing downtime, and maximizing the availability of the machine.

VIII. PERFOMANCE METRICS

Outage Duration Time (ODT) measures the performance of service delivery in problem remediation cases. Keeping this KPI low is the goal of every operator and service delivery organisation.

For better transparency it can be broken down into three subsections distinguished by the type of expertise and infrastructure needed to influence ODT.

Time to React - time required for important information to reach both responsible manager and supporting domain expert. It also considers the time needed to evaluate the information, understand the problem and propose a remedy.

Time to Repair – time required for a remedy to be applied

Time to Reinstate – additional time required for a specialized personnel member to recommission the machines and start production.

The ability to detect initial damages, understand the sequence of events leading to catastrophic failure, and observe the development of such failures empowers service delivery organizations to proactively mobilize and plan remedies well in advance. This proactive approach enables timely interventions and allows for the maximum utilization of the damaged machine until repairs are necessary.

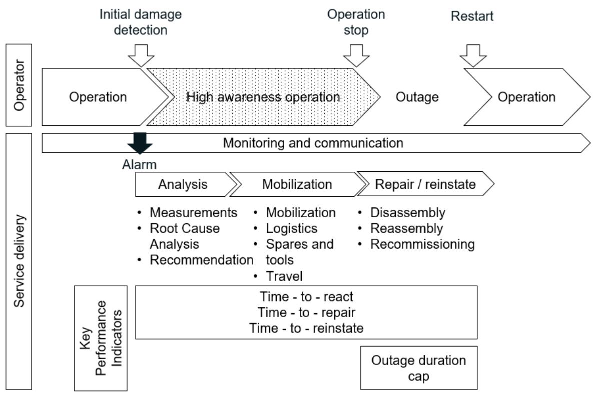

Fig. 3 Performance metrics in context of digitalized service delivery

By closely monitoring the machine and analyzing data, service organizations can identify early signs of damage or deterioration. This knowledge, combined with an understanding of failure progression, facilitates taking pre-emptive measures to mitigate risks and plan for necessary repairs or maintenance. This approach not only helps prevent unexpected catastrophic failures and costly downtime but also optimizes the utilization of the machine until repair is unavoidable.

IX. CONCLUSIONS

In this paper, we present arguments supporting the thesis that enhanced collaboration between plant operators and machine vendors significantly contributes to ensuring the operational availability of electrified drive trains. While spare parts management and emergency repair services play vital roles in addressing off-specification damage events promptly, digitalization enables the implementation of predictive maintenance strategies through task automation and global real-time communication.

The framework proposed in this paper demonstrates that long-term performance-based service contracts are likely to become standard practice across industries that rely on large high-voltage electrical drive trains—such as turbine replacement, hydrogen production, power-to-power systems, and carbon capture applications. This shift is driven by the substantial economic impact of equipment availability on the profitability of industrial production.

Given the increased reliability of electrical equipment and the infrequent occurrence of catastrophic failures, long-term outsourcing contracts between operators and machine vendors incorporating specialized service delivery organizations can be viewed as a viable business option. These contracts strike a balance between service costs and production availability, ensuring smooth operations and minimizing the impact of disruptions.

X. REFERENCES

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XI. VITA

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