Strategies for Maintaining Electrical Distribution Equipment

by David Morte

Executive summary

This paper examines the benefits of various strategies for electrical distribution equipment maintenance. Different approaches to equipment maintenance have varying effects on safety, service continuity, power infrastructure optimization, equipment protection, energy efficiency, efficient spare parts management, and the total cost of asset ownership.

Introduction

Why maintain electrical distribution equipment?

Carrying out field maintenance on electrical distribution equipment provides four important benefits.

1. Increased safety: protecting people, equipment and goods

One of a plant manager's most crucial responsibilities is to ensure the sustainable development of their business. Plant managers are obligated to adopt all available measures technically and economically available to them to minimize the risk of unwanted events, such as those that harm personnel, assets, or the business, while following international standards for environment, health, and safety.

Some electrical distribution equipment is designed to minimize the risk and severity of accidents or process breakdowns, such as circuit breakers, fuse-contactors, etc. The highest priority of maintenance is to ensure that role is performed.

2. Availability enhancement: maximizing service continuity

Maintenance maximizes uptime. Maintenance is commonly conducted on scheduled outages during off-peak business periods, thereby mitigating its impact on operations with less disruption to activities, and less stress is generated.

It takes less time to perform proactive maintenance than emergency repair (immediate corrective), while mitigating the risk of emergency shutdown, where the consequences of even an hour-long production shutdown can be enormous.

Figure 1

Financial impact of one hour's production shutdown
(Source: Contingency Planning Research and Schneider Electric)

Application	Loss(*) in €
Health establishment	Human lives
Stock market transactions	6,500,000
Credit card sales	2,600,000
Petrochemical	100,000
Plane ticket booking system	90,000
Mobile phone network	40,000
Automobile	30,000
Pharmaceutical	30,000
Food processing	20,000
Cement	15,000

* Direct and indirect costs of no availability

Annual industrial losses due to power infrastructure disruptions reach 10 billion euros in Europe alone. *(Source: Leonardo Power Quality initiative – European Copper Institute)*

3. Aging asset performance: CapEx optimization

Considering the significant costs of equipment acquisition (CapEx), plant managers want their electrical distribution equipment to run safely for longer with maximum availability. Stress accelerates equipment wear (aging), shortening endurance. When wear is under control (within functional limits) endurance is secured or even extended.

4. Exploitation cost efficiency: OpEx optimization

Without maintenance, industries suffer emergency shutdown situations that cause

- **spare parts** to be purchased at a premium. Maintenance can cut these costs by reducing faults within complex parts and using efficient on-site spare parts management.
- **labor** to be purchased at a premium.
- **process shutdown costs** (no production, ramp-down/up production, waste, etc.).

However, these are only the visible operating costs. Maintenance helps ensure **energy-efficient equipment.** Research shows that unmaintained devices are less energy efficient. Wear and tear causes stress to components, which diminishes devices' energy efficiency over time, and wastes energy while in operation.

Modern and up-to-date maintenance practices have become a vital competitive advantage thanks to their use in early detection by identifying problems before they require a major repair. Knowing when scheduled outages will occur also allows managers to staff accordingly. It delivers a unique opportunity to achieve more rigorous cost controls.

Carrying out maintenance that is professionally executed by highly qualified technicians is a unique opportunity to optimize Total Cost of Ownership (TCO), and both CapEx and OpEx, creating more value for businesses by enhancing availability at lower operating costs.

What is the impact of a maintenance strategy on the TCO of electrical equipment?

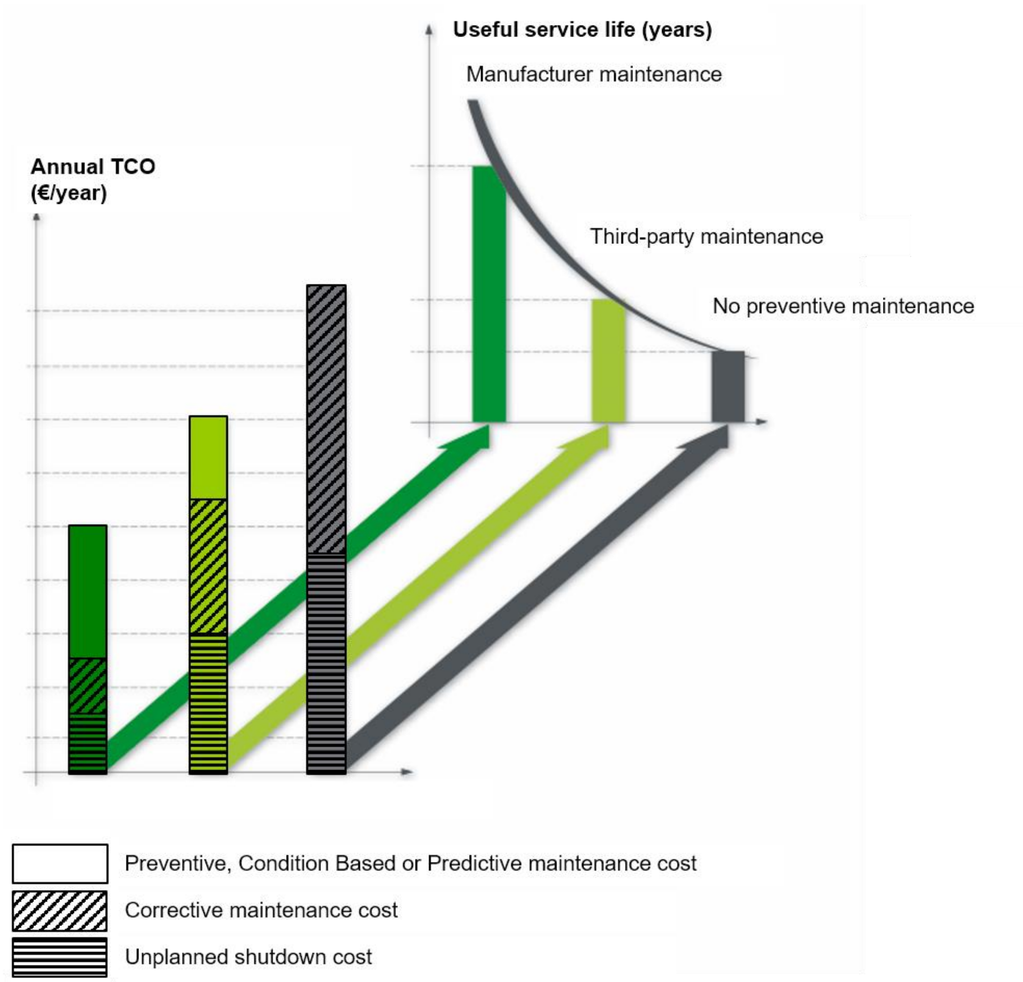

Figure 2

Example of complete annual costs for a MV switch protection cubicle

Maintenance results when delivered by a manufacturer:

- Annual TCO is lower because the useful service life of equipment is longer.
- Preventive, condition based (on-demand or continuous monitoring) and predictive (condition based with advanced analytics) maintenance practices improve equipment reliability and reduce costly corrective maintenance and unplanned outages that result from equipment failure.

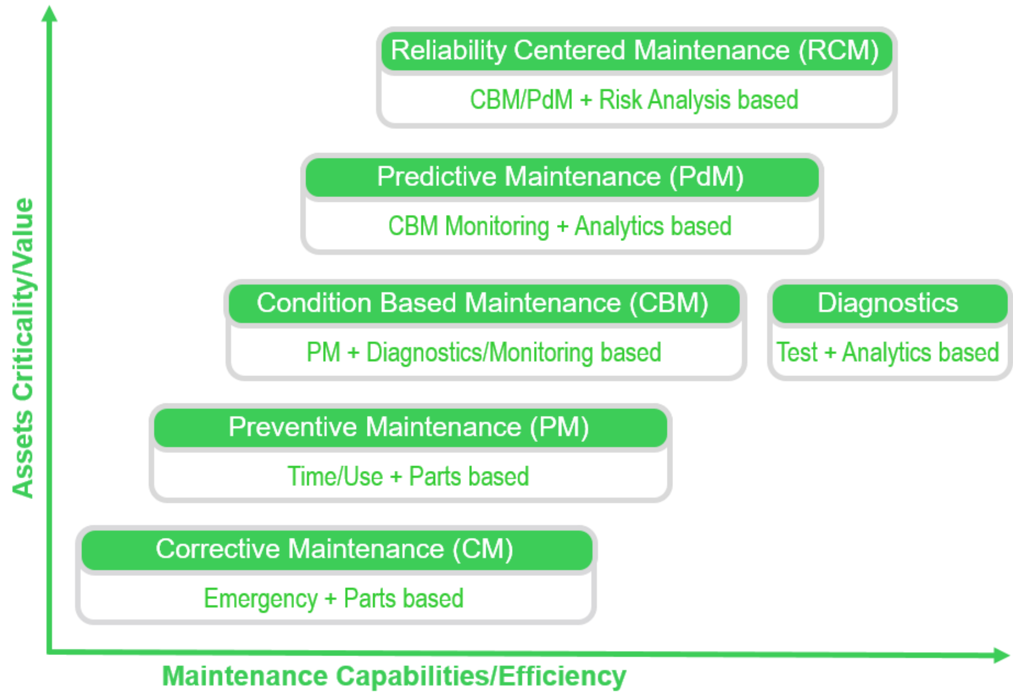

Figure 3

Maintenance capabilities

Maintenance types

Corrective maintenance

Corrective maintenance is a run-to-failure approach that simply lets equipment run until something breaks. This results in either of the following:

- **Immediate** corrective maintenance. This restores the required function of a faulty item immediately after the fault is recognized. Often, a simple faulty function causes a costly process shutdown. Sometimes, the required function can only be restored for a limited interval at which point a complete repair is carried out via deferred corrective maintenance. The goal of immediate corrective maintenance is to restore normal operating conditions in the shortest restart time possible.
- **Deferred** corrective maintenance. This restores the required function of a faulty item after:
    - Immediate corrective maintenance or preventive maintenance. In both cases, equipment diagnostics are required for fault recognition, localization, cause identification, and the appropriate solution.
    - On-site condition maintenance or equipment diagnostics. In both cases, the failure has already been recognized for correction, and just a final function check is conducted to verify that the item can perform the function to its original performance level.

Electrical distribution original equipment manufacturers are often the best, delivering the most cost-efficient corrective solutions thanks to:

- Know-how in particular technologies, work protocols, testing methodologies, equipment manufacturing processes, etc. This enhances reliability and safety after intervention.
- Direct access to supplies of manufacturer spare parts for both active and discontinued equipment. This guarantees the shortest resolution time and lowest overall cost.

Preventive maintenance

Preventive Maintenance (PM) is carried out at periodic and predetermined intervals or according to prescribed criteria and is intended to reduce the probability of failure or the degradation of the functioning of an item and its costly immediate corrective intervention. However, it still requires substantial labor and heavy spare part inventory management on site.

Preventive Maintenance consists of the execution of a sequence of predefined activities (work instruction) such as: visual inspections, functional checks (electrical, mechanical, electronics), and work on mechanisms with proactive parts replacement to minimize component degradation and extend the life of equipment.

Preventive maintenance can be categorized in three levels according to execution complexity:

Exclusive maintenance activities
Conducted by equipment manufacturer services only and supported by rigorous execution protocols, as it strongly impacts equipment performance:

- Checking/disassembling/degreasing/greasing/reassembling/checking the circuit breaker operating mechanism
- Checking/disassembling/degreasing/greasing/reassembling/checking closing and opening springs of the circuit breaker

Advanced maintenance activities
Conducted by equipment manufacturer services or highly qualified technicians with demonstrated qualifications obtained and certified by manufacturers:

- Checking/disassembling/degreasing/greasing/reassembling/checking of moving and withdrawable parts
- Bus-bar inspection (tightening, chalking, cracking, signs of heating)

Basic maintenance activities
Conducted by equipment manufacturer services, highly qualified technicians, or customer personnel trained by manufacturers:

- General state with simple visual inspection, without device disassembly (cleanliness, oxidation of supporting structure, etc.)
- Functional testing

Activity complexity	Who		
	End-User	Services Partner	Manufacturer
Exclusive			■
Advanced		■	■
Basic	■	■	■
	PM Basic	PM Advanced	PM Exclusive
	Preventive Maintenance (PM)		

Figure 4

A simple categorization of Preventive Maintenance (PM) according to the levels of complexity of conducted activities: PM Basic, PM Advanced, and PM Exclusive

Preventive Maintenance is conducted during a scheduled shutdown to minimize its impact on business operations. This practice is also named predetermined maintenance, when these interventions are scheduled and conducted based on time intervals and/or the number of units in use, but without any previous equipment condition investigation.

Again, electrical distribution original equipment manufacturers are often the best choice, delivering the most cost-efficient preventive solutions because they have deep understanding and experience as well as direct access to a supply of spare parts.

Condition-based maintenance

The next level of maintenance maturity and effectiveness is condition-based maintenance (CBM). Its goal is to enhance equipment reliability, keeping it as close to its optimum condition as possible. It's the extension of preventive maintenance with testing and analytics (equipment condition diagnosis) and/or continuous monitoring and the ensuing maintenance actions.

This is possible thanks to functional diagnostics either on-site (scheduled or on-demand) or continuous. These identify symptoms of an undetected malfunction or equipment degradation before the fault occurs (not detected with preventive maintenance), giving focus to the preventive work on underperforming functions, to be more effective.

On-site condition maintenance is condition-based maintenance with on-site diagnostics. These deliver the greatest breadth and depth of device condition assessment based on real data about core equipment features. They replicate rigorous manufacturing quality control routine tests using work protocols and tools (hardware and software), capable of detecting the faulty part.

Conversely, condition-based maintenance that has continuous monitoring with online connectivity delivers skin-deep diagnosis based on remote data analysis with algorithms emulating equipment behavior for early indication (alarming) of failure symptoms, without precise faulty part detection. On-site and continuous monitoring are complementary.

When a malfunction is detected and parts for immediate correction are not available on the premises, on-site condition maintenance schedules immediate or deferred corrective maintenance, according to fault severity and/or equipment criticality, to restore its original performance level during the most convenient time.

Its applications involve the most critical assets where failure significantly impacts uptime, asset longevity, safety, process output quality, or involves major corrective maintenance intervention costs. This level of maintenance is an easy-to-implement and cost-efficient solution.

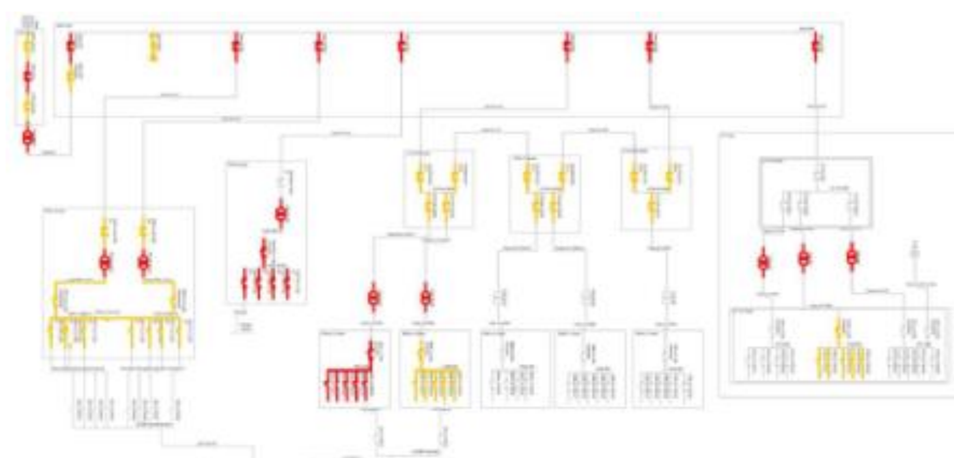

Figure 5

Critical equipment must be identified in order to give it special care and avoid failures that would significantly impact business operations.

Facility equipment criticality mapping is a strategic asset for any business, plant or maintenance manager. It's the maintenance manager who is ultimately responsible for budgeting maintenance activity while optimizing equipment exploitation costs and enhancing safety and reliability.

This asset criticality mapping should drive a tailor-made maintenance program supported by Enterprise Asset Management (EAM), often integrated within an Enterprise Resources Planning (ERP) information system, to efficiently purchase and schedule field maintenance services.

Electrical distribution original equipment manufacturers with diagnostic solutions are the best positioned to deliver superior performance with on-site condition-based maintenance because:

- Inspection, work on mechanisms, testing, and data analytics are conducted with integrated hardware and software, securing efficient and reliable data management.

- The availability of the original equipment functional specifications database is a unique aid for diagnosing whether equipment is maintaining its original performance level.
- Field service representatives have expertise in equipment warranties and the best recommendations to keep equipment in optimal condition.
- They possess experience from an extensive equipment installed base under the most extreme and diverse operating conditions.
- Information about manufacturer equipment obsolescence dates and their spare parts availability are essential data to anticipate future facility evolutions (extensions, upgrades, retrofitting or renewals), prepare a proficient modernization plan, and forecast the corresponding facility annual budgets to answer future business needs.

On-site Condition-based maintenance initiates repairs during the preventive work only when needed, based on functional diagnostics, eliminating failure risk with worn parts' replacement, excluding the need to fix functions without degradation. Consequently, it is more cost effective than regular preventive maintenance, which replaces spare parts proactively (time or use based) through targeted predetermined maintenance without condition assessment.

Original equipment manufacturers are the best positioned to deliver on-site Condition-based maintenance solutions because of their advanced functional diagnostics that allow them to keep equipment in optimum condition, mitigating failures and thereby extending their lifespans.

Diagnostics

Equipment diagnostics consists of an equipment core functions assessment that carries out functional testing on kinematics, electric parts, and electronics. Data is organized and analyzed for a comprehensive and crafted diagnosis based on multivariable correlation. If a malfunction is diagnosed, it recommends an immediate or deferred corrective maintenance according to fault severity and/or equipment criticality to restore its original performance.

Equipment diagnostics becomes a natural, complementary and effective solution to on-site Condition-based maintenance, when critical equipment serves highly demanding downstream processes that require permanently enhanced levels of availability.

Consequently, a higher level of monitoring is a must to warranty an ultimate level of reliability and service continuity. This is a circumstance when more results in less. Increasing the frequency of on-site Condition-based maintenance won't necessarily achieve the expected effect. Preventive maintenance operations won't deliver the level of reliability that comprehensive diagnostics with data analytics and data trend assessment can.

By adding equipment diagnostics between two consecutive on-site Condition-based maintenance interventions to existing maintenance programs, the best balance between enhanced reliability and exploitation costs is achieved.

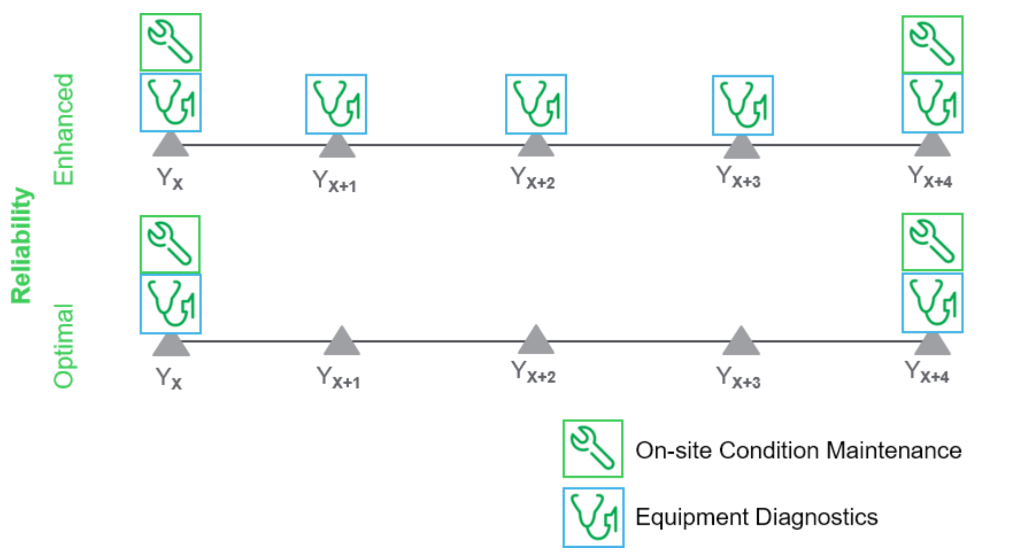

Figure 6

Critical equipment reliability can be enhanced with pure equipment diagnostic works to complement on-site condition maintenance

We again see that original equipment manufacturers are uniquely equipped to not only deliver advanced equipment diagnostic solutions, but also to build specific tools that keep equipment functioning optimally and maximizing their useful life spans.

The following level in maintenance efficiency is to integrate smart monitoring systems for real-time tracking and performance supervision of its critical devices and sensing parts' condition data. When following the principles of predictive maintenance, the plant manager gains a complete picture of equipment condition, and greater peace of mind when making critical decisions.

Predictive maintenance

Predictive Maintenance (PdM) is the pinnacle of maintenance management to minimize unscheduled downtime and reduce the overall cost of maintenance, while delivering full peace of mind over electrical distribution infrastructure.

It represents the application of the Just-In-Time (JIT) principle to preventive maintenance. It is a way to optimize, but not eliminate, regular field maintenance interventions that require shutdowns to a strict minimum with the Just-If-Needed (JIN) principle, by predicting and acting when equipment is about to fail.

This prediction and its consequent benefits requires investment in cutting-edge technologies:

- **Connected products** and equipment embed hardware to make it ready-to-connect and able to integrate sensor technologies with specific purposes. Brownfield components, equipment, and switchboards may benefit from similar features by being upgraded with add-on hardware for remote, continuous condition monitoring. That can include communication modules, sensors, and high-end control units that provide connectivity and generate data. For this purpose, new IoT technologies bring low-cost, easy-to-install, and reliable solutions under the most demanding exploitation conditions.
- **Edge computing** at the equipment level facilitates user interaction through better operational software interfaces, including web publication of operating parameters to interface with other systems, and in some cases, new self-diagnosis algorithms. Logically, green field equipment natively ready for IoT delivers a more comprehensive variety of data than upgraded brown field equipment.
- **Analytics and Services** around new or existing technical features, to the complete stack of new Internet of Things (IoT) technologies, are often delivered from cloud-based platforms where advanced analytics can merge and correlate a variety of data sources (big data), or blended with other subject expertise to generate even more value from data in a user-friendly way.

Big data analytics services with smart algorithms emulating equipment behavior (digitizing patterns to model similar devices) easily and automatically adapt alarm thresholds for each piece of equipment's individual operating conditions to indicate that a predefined wear threshold has been reached. They are known as Asset Performance Management (APM) systems, often sold as a service (APMaaS).

This requires a deep knowledge of how the equipment fulfils its function. That is, which are the relevant measurable data that need to be used to provide the right information to decide whether the equipment can continue to operate at optimum performance under multiple operating conditions?

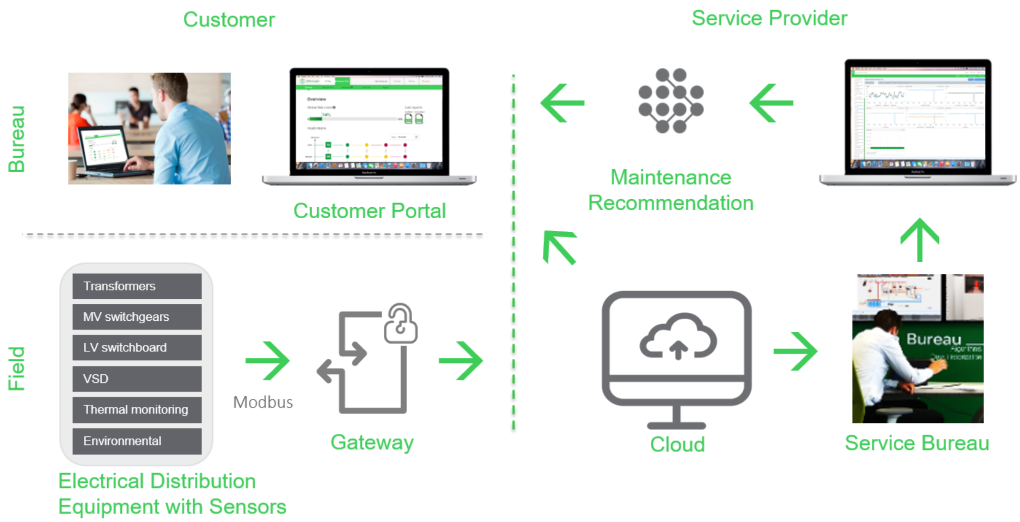

Figure 7

Predictive maintenance architecture to deliver asset performance management in electrical distribution infrastructure

APMaaS provides remotely early warnings based on skin-deep equipment diagnosis. A service bureau assesses data on behalf of the customer for validation and triggering work orders for those events where it is relevant to schedule upcoming field maintenance. Alternatively, equipment performance monitoring is reported via the cloud to the customer on a regular basis. On top of this service, customers benefit from the high level of manufacturer expertise (product support, subject matter experts, commercial life cycle, etc.) in a single point of contact.

APMaaS runs over an IT platform, either on premise or cloud based, that is integrated with a customer's Electrical Control System (ECS), Enterprise Asset Management (EAM), and consequently with plant ERP for planning the most convenient equipment-derived actions: spare parts management, field maintenance works (on-site condition, preventive or corrective), etc., as part of core processes to enhance business sustainability.

Predictive maintenance defines the new paradigm to enhance equipment condition and get the most from electrical distribution infrastructure. However, the ultimate step in maintenance efficiency is the integration of risk assessments with predictive or Condition-based maintenance practices, known as reliability-centered maintenance (RCM).

Reliability-centered maintenance

TCO optimization of electrical distribution infrastructure is the result of diverse and complementary initiatives including the following:

- Efficient spare parts stock management
- Efficient equipment obsolescence management related to maintainability
- Efficient maintenance management, predicting when a failure is likely to occur
- Efficient risk-based resource allocation

In the previously described maintenance practices we introduced the importance of reliability and its impact on an installation, along with criticality mapping. Now, we'll examine efficient resource allocation by equipment, based on risk analysis and process and equipment reliability studies.

Equipment reliability data is integrated into a risk assessment system that characterizes the installation ecosystem with advanced modeling systems. Later, simulations of all possible events in the installation are mined to generate the asset prioritization for maintenance resource allocation with the different market maintenance practices.

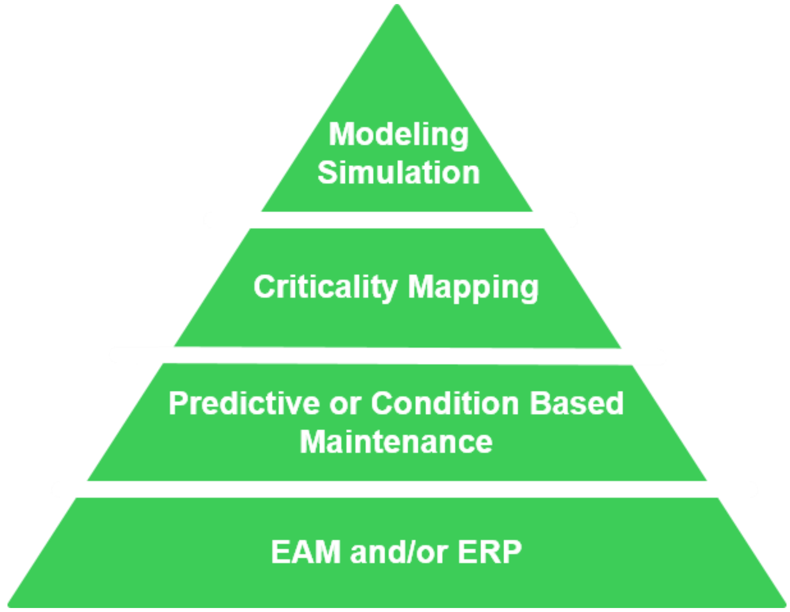

Figure 8

Competency pyramid required to deliver reliability-centered maintenance

These simulations and analytics can propose the most efficient and effective maintenance program possible based on:

- Equipment failure risk assessment defined by Mean Time Between Failure (MTBF), depending on maintenance practice
- Equipment impact to operations (downtime revenue loss, safety issues, repair costs, etc.)

This practice aims to reach zero failures (100% availability) with a smart allocation of resources where needed. That is, more maintenance (effort) on high criticality equipment and less maintenance on less critical equipment. This requires new skills on risk assessment analysis and more capabilities in advanced software for facility modeling and simulation (Monte Carlo type or simplified failure tree).

Reliability-centered maintenance brings a new model to operate electrical distribution infrastructure within the context of digital factories solutions, from its ideation to its operation, with comprehensive facility modeling. Today, this new paradigm is reserved for green field industries with very critical continuous processes built under a disruption-free specification, because shutdown penalties impact business sustainability.

Lastly, this paper discusses a model that has strengthened the financial mindset in asset management and maintenance decision making. It will become the reference in asset intensive industries with heavy equipment investments. Decisions are commonly taken with economical value creation criteria driven by the finance manager with the maintenance manager's help. This is known as value-based maintenance and asset management.

Note: For a deep dive on reliability-centered maintenance, refer to the white paper titled Optimize power system reliability and maintenance costs through reliability-centered maintenance, by Charles Alvis and Joy Sonn McCandless.

Value-based maintenance and asset management

This methodology considers the four benefits of maintenance listed at the beginning of this paper—the drivers to create economical added value on existing equipment. This value can be easily calculated with the well-known discounted cash flow financial methodology.

Once the sources of value creation potential are prioritized (calculated), the organization can select the best mix of maintenance practices (reliability-centered maintenance, predictive maintenance, condition-based maintenance, etc.).

Plant managers should not implement just one practice, but rather they should take advantage of the many maintenance options. Consequently, to achieve this, the organization must secure some competencies and capabilities key to delivering the calculated value:

- Asset knowledge to ensure the equipment meets the performance in safety and availability requested by operations
- Asset management starts to plan its life extension (refurbish, replacement, renewal) when expected performance is not achieved
- Asset performance monitoring requested by operations
- Scheduling of field interventions that secures this performance
- Execution and verification of field work

The model proposes several KPIs to monitor previous capabilities' performance. These KPIs can later be benchmarked between industries and peers to detect areas of improvement, and drilled-down on low level PIs for finer granularity. Once the model is defined, its implementation starts with process mapping and later monitoring supported by business intelligence IT platforms integrated in the EAM system of the organization.

Maintenance periodicity

How to define the best periodicity

Electrical distribution original equipment manufacturers recommend conducting field maintenance activities on a regular basis for on-site Condition-based maintenance or preventive maintenance to achieve the benefits described at the beginning of this paper.

We have also introduced the different types of available maintenance practices because each equipment type is different (economic value, function, impact, reliability, lifespan), and each maintenance practice has its own benefits and costs.

Maintenance managers have the difficult responsibility to define or delegate to its services provider the best maintenance practice (on-site condition based or preventive) along with the periodicity for each equipment type. In an era of increasingly limited OpEx budgets, periodicity prescription directly impacts business profitability. The answer is often a simplification of reliability-centered maintenance.

This can be shaped in a simple spreadsheet or in an Enterprise Asset Management (EAM) system. To define the periodicity, the maintenance manager or the delegated service provider (manufacturer or services company) should have in mind the equipment's:

1. **Criticality** (minor, major, critical)
2. **Environmental conditions** (favorable, normal, severe)

1. Equipment criticality within the installation depends on two key factors:

- **Stress** level (low, normal, severe) is a result of process exploitation conditions of nature or origin:
    - electrical (load %In, interrupted current %In, operating cycles, harmonics %In)
    - mechanical (vibrations),
    - chemical (dust, corrosion)

    Each is worsened by the level of maintainability based on spare parts availability (emerging 3D printing technologies will mitigate this risk).

Figure 9

Example of factors and categorization to define the level of stress on electrical distribution equipment

	Stress levels (equipment)		
Risk factors	Low	Medium	High
Electrical origin			
Percent load (threshold % in)	<80% 24/24 hours	90% 8/24 or 24/24 hours	100% 8/24 or 24/24 hours
Interrupted Current (% In)	<40%	40%<X< 60%	≥60%
Number of operating cycles (cycles a month)	<30	30<X<60	≥60
Harmonics (% In, causing thermal runaway	≤30%	30%<X<50%	≥50%
Chemical origin			
Corrosivity (category IEC 60721-3-3)	3C1	3C2	3C3, 3C4 (no protection)
Dust level	Low (switchboard IPX4)	Moderate	High (switchboard IPXO)
Mechanical origin			
Vibration (continuous)	<0.2g	0.2g<X<0.5g	≥0.5g

- **Impact on installation reliability** (low, medium, high), where empirical estimations (measured by shutdowns, production losses, corrective intervention costs, process ramp-up costs, etc.) may be sufficient for simple cases. For more complex architectures involving backup sources, transfer mechanisms, etc., it is necessary to undertake a professional reliability analysis.

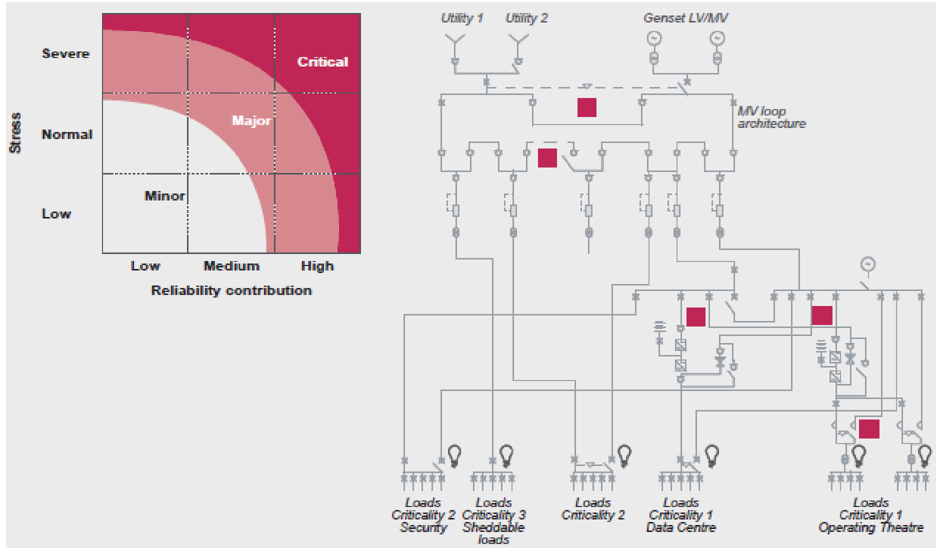

Figure 10

Asset criticality mapping

2. Equipment environmental conditions can be categorized according to the table below. Electrical room environments with extreme temperatures or significant temperature changes, or high humidity and salinity levels, speed electrical distribution equipment aging. This leads to a higher risk of equipment malfunction.

Figure 11

Categorization of electrical room environmental conditions

	Environmental Conditions (site/electrical room)		
Risk factors	Favorable	Normal	Severe
Temperature (average annual around/out of switchboard IEC 60439-1)	<25°C	<25°C X <35°C	>35°C
Humidity (relative)	<70%	70%< X <85%	>85%
Salinity (site distance from seaside and device without protection)	No salt mist (>10 km)	Moderate salt mist (<10 km)	Significant salt mist (<1 km)

It is strongly recommended to reduce the periodicity of interventions when operating under normal or severe environmental conditions such as the situations listed above and/or critical levels of criticality, enhancing the risk of failure. Any manufacturer should be able to deliver the maintenance periodicity for all use cases.

Consequently, for a given device, maintenance may vary substantially in terms of maintenance practices and their periodicity. An example of equipment periodicity with **critical criticality** under **favorable environmental conditions** can be defined as follows:

Figure 12

Example of maintenance periodicity for a "critical" asset working under "favorable" environmental conditions

		Who		
Maintenance Practices	Recommended Periodicity	Manufacturer	Services Partner	End User
On-site Condition	4 years	■		
PM Exclusive	4 years	■		
PM Advanced	2 years	■	■	
PM Basic	1 year	■	■	■

Spare parts

Every piece of equipment has an associated risk of failure (failure rate). While one can minimize risk by choosing high-quality electrical distribution equipment and performing regular maintenance**,** that risk can never be eliminated.

Using manufacturer spare parts according to the equipment manufacturer's recommendations, plant and maintenance managers can ensure equipment is returned to service in the shortest possible time, avoiding lost revenue, and safeguarding assets and business.

Logically, when spare parts are no longer available (obsolete equipment) the only solution to extend equipment service life is to carry out intense maintenance while planning for modernization.

Conclusion

Plant managers should strategically schedule and employ a variety of practices to maintain electrical distribution equipment and achieve their benefits: personnel safety, equipment and goods protection, service continuity, energy efficiency and efficient spare parts management to optimize the total cost of ownership of their power infrastructure.

About the author

David Morte is a Senior Marketing Manager in the Schneider Electric Field Services Electrical Distribution Business Unit. He holds a Bachelor Degree in Electrical Engineering and over the last 10 years has assumed numerous engineering and marketing positions within a variety of business units and operational divisions. As marketing executive, David Morte has continuously contributed to building and enhancing customer-centric business models with distinctive and sustainable customer and brand experiences. As an expert in strategic and operational marketing, he has recently developed a worldwide Field Maintenance Services offer portfolio.