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How predictive maintenance for circuit breakers optimizes safety, reliability, and costs

by Markus Hirschbold

Executive summary

Circuit breakers require regular maintenance to ensure electrical safety, comply with safety regulations, and avoid costly facility downtime. Typically, this maintenance is performed at regular intervals, which do not account for usage patterns or environmental conditions. This paper explores how IoT and analytic technologies enable a condition-based, predictive approach that can increase levels of safety and reliability while tailoring maintenance to optimize costs.

Introduction

In the past, circuit breaker service and maintenance were typically reactive or preventive. Reactive (or corrective) action occurs when devices are run to failure. Preventive action happens at pre-determined, periodic maintenance intervals of normally 1 to 2 years, or in some cases when predefined thresholds are reached. Preventive approaches were adopted in an effort to increase the mean time between failures (MTBF) and, in turn, maximize safety and avoid unnecessary facility downtime.

To further improve the MTBF and, at the same time, optimize maintenance costs, there is a growing need to transform the maintenance strategies for circuit breakers. A condition-based, predictive approach can tailor the time intervals between inspections, servicing, or replacement. Intervals are determined based on the type of circuit breaker, conditions, and the operational and financial goals of the facility. The premise of this strategy is to create predictive models that represent breaker aging and associated failure risks. These models are based on a variety of operational and environmental parameters.

By implementing these predictive models using available sensor and software technologies, facility teams can track risks in real-time and generate automated reports that indicate circuit breaker health and the need for maintenance or replacement. This information helps:

- reduce the risk of failure, which can improve safety and avoid downtime
- improve the efficiency of maintenance services and, in turn, optimize spending

This paper presents a framework for implementing and maintaining a predictive maintenance strategy; it includes an overview of operational and environmental breaker aging conditions, monitoring and analysis system requirements, and example calculations and reports that help simplify decision-making. The recommendations can improve breaker maintenance in any facility, whatever its size, sector, or geographical location.

Figure 1

Any facility can improve breaker maintenance programs by moving beyond preventive schemes to a more predictive approach.

What causes a circuit breaker to age and require maintenance?

Operational conditions

One of the primary causes of breaker aging is the degradation of internal mechanisms from the number of open and close operations and tripping operations on current overloads or short circuit conditions. The service life of a circuit breaker is typically specified by a number of operating years or operations, whichever is reached first.

However, the level of interrupted current during each operation increases the impact on the breaker's contacts and further accelerates aging. The related wear is broken down into two categories:

1. **Contact (electrical) wear:** The wear of the contacts resulting from the breaker operating under various interrupt currents. For example, breaker contacts may wear by over 30% in case of a short circuit interrupt at maximum fault current.
2. **Mechanical wear:** This is the result of mechanical stress aging mainly caused by the number of operations, but does not consider contact wear.

The relationship between these two factors is illustrated in **Figure 2**.

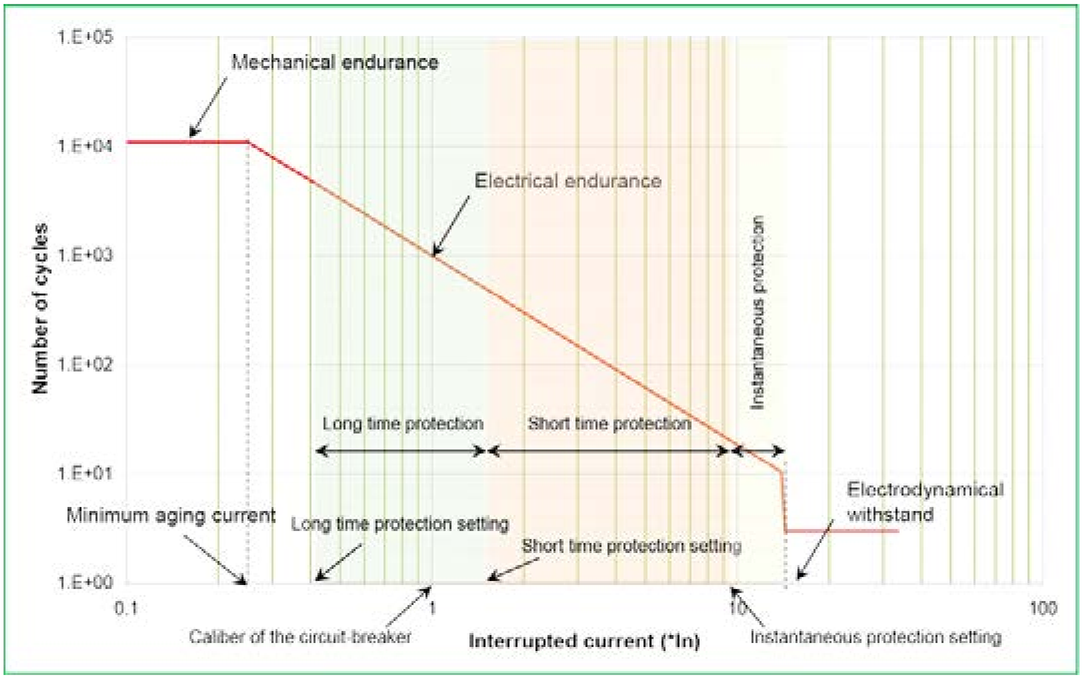


Figure 2

Example of circuit breaker endurance curve illustrating the relationship between interrupted current and the maximum number of operation cycles for which the contacts are rated. The current is given as a fraction of the nominal current of the circuit breaker.

The data indicates that high interrupt currents significantly reduce the lifespan of the breaker (specified the number of cycles of operation). Also, circuit breaker aging is not impacted by current if the interrupted current is below the minimum aging current specified for the device. Under this condition, lifespan is based solely on the mechanical endurance of the device.

To optimize the service life of a circuit breaker, systematic checks and periodic maintenance must be conducted. In determining the best times to do these checks, additional aging influences should be considered.

Environmental conditions

Breakers are required to operate safely and reliably in a number of different environments. Especially harsh environments can present additional stresses that accelerate breaker aging. These can include:

- **High operating temperatures** resulting from a combination of the ambient temperature, the effect of excessive power harmonics, and the load level of the breaker
- **Corrosive atmosphere** due to humidity, salt gases, or oil **(refer to Table 1)**
- **High amounts of dust**
- **Mechanical vibrations**

The presence and severity of these conditions may require breaker servicing more often than would be done using a time-based strategy.

Table 1

Circuit breaker aging due to corrosive atmosphere.

Corrosive atmosphere	Influence	Appearance	Consequences
Humidity	• Corrosion of metal surfaces. • Deterioration of dielectric qualities of plastics. • Deterioration of electronic components, in particular • SMCs and silver-coated components. • Degradation of optoelectronic components.	• Appearance of red rust on iron, white rust on zinc. • Blue deposit on copper, black deposit on silver. • White traces on case. • Appearance of dendrites on electronic boards. • Erosion of copper tracks. • Oxidation of connectors of integrated circuits mounted on supports.	• Increase in friction. • Risk of mechanical breakage resulting in non-operation of mechanisms. • Increase in contact resistance (clusters and main contacts). • Risk of a reduction in insulation. • Short-circuiting of circuit resulting in non-operation of control unit protection, measurement, indications and communication functions. • Breakage of components. • Poor contact with integrated circuit support.
Salt	• Corrosion of metal parts and surfaces. • Phenomenon accelerated by high temperature and relative humidity. • Proximity to ocean increases these influences.	• Oxidization.	• Increased resistance of disconnecting contacts exposed to air. • Excessive device temperature rise. • Short-circuiting of circuits resulting in non-operation of the trip unit. • Increase in friction.
SO_2 Sulphur dioxide	• Corrosion of silver, aluminum, and bare copper. • Phenomenon accelerated by high temperature and relative humidity.	• Blackening of exposed silver surfaces. • Appearance of dendrites on electronic and power circuits.	• Increased resistance of disconnecting contacts exposed to air. • Excessive device temperature rise. • Short-circuiting of circuits resulting in non-operation of the trip unit.

Corrosive atmosphere	Influence	Appearance	Consequences
H_2S Hydrogen sulfide	• Sulphurization of silver, this phenomenon is accelerated by high temperatures.	• Major blackening of exposed silver surfaces. • Appearance of dendrites on electronic and power circuits.	• Increased resistance of disconnecting contacts exposed to air. • Excessive device temperature rise. • Short-circuiting of circuits resulting in non-operation of the trip unit.
Cl_2 Chlorine	• Corrosion of metal parts.	• Oxidation. • Inter-granular corrosion of stainless steel.	• Increase in friction. • Risk of mechanical rupture. • Breaking of stainless-steel springs.
NH_3 Ammoniac	• Attacks polycarbonates, corrodes copper.	• Cracking of polycarbonates. • Blackening of copper.	• Risk of rupture. • Increased temperature rise.
NO_2 Nitrogen oxide	• Corrosion of metal parts.	• Oxidization.	• Increased temperature rise.
Oily atmospheres	• Attacks polycarbonates.	• Cracking of polycarbonates.	• Risk of rupture. • Increased temperature rise.

Table 1 (cont'd)

Circuit breaker aging due to corrosive atmosphere.

For more information

Refer to the IEC 60721-3-3 standard.

Based on these influences, the IEC 60721-3-3 standard specifies four environmental classes that describe different kinds of rural, urban, and industrial zones. For each class, the standard defines specific levels of corrosive gases and their level impact on switchgear equipment, from 'negligible' to 'high.' The standard also provides circuit breaker installation instructions for each class, and recommendations for preventive maintenance. This can range from following a standard maintenance program and more frequent periodic checks.

Human error and its potential effect on maintenance and reliability

A study done by CIGRE suggests that the probability of a circuit breaker failure event is higher in the same year as unlicensed (end user or third-party) maintenance activities have taken place.[1] In other words, while OEM services maintenance increases the MTBF, and in some cases unlicensed maintenance, may be the cause of increased failure risk or reduced MTBF. It follows, then, that reducing unnecessary maintenance work is desirable, not only for the sake of mitigating servicing costs, but also to reduce the risk of unlicensed maintenance-related breaker failures.

[1] Evaluation Of Failure Data Of HV Circuit-Breakers For Condition Based Maintenance

Reactive, preventive, or predictive maintenance?

Traditionally, circuit breaker maintenance has been done on either a reactive (corrective) or preventative basis. Neither offers full safety, reliability, and cost benefits of a predictive approach.

Reacting when something fails

Reactive maintenance essentially allows breakers to run until they fail, which may be appropriate only when a shutdown does not affect productivity or safety. It means that resources are not expended until something fails, so it could be seen as a way to minimize maintenance costs.

However, the reactive method can also result in:

- Unpredictable downtime
- Additional damage and costs due to secondary equipment failure
- Shorter equipment life, resulting in more frequent replacement
- Increased demand for spare parts

For more information

Refer to the CSA Z463-1 guideline.

Preventing failures with regular checks

Preventive maintenance performs periodic checks to reduce the probability of failure or deterioration in the operation of a system. These checks are done at either predetermined intervals or according to prescribed criteria.

According to the CSA Z463-13 guideline on maintenance of electrical systems, this approach 'is most usefully applied to equipment that does not run continuously…and in circumstances where personnel have the knowledge, skills, and time to perform the preventive maintenance work.' Following the recommended periods specified by the manufacturer helps extend equipment life, as well as component and serviceable part lifecycles.

Typically, the manufacturer-recommended intervals for maintenance vary based on environmental and operating conditions. National or international electrical and safety organizations may also set forth maintenance intervals, such as the US-based NFPA organization's recommendations in **Table 2**.

Table 2

Circuit breaker maintenance interval recommendations excerpted from table L. 1 of the US NFPA 70B guideline. Manufacturer recommendations can differ.

Item / equipment	Task / function	Interval
Air circuit breakers, medium voltage		
Insulation	Visual inspection / clean Electrical tests	Annually 3 years
Contacts	Visual inspection / clean / adjust Electrical test	Annually 3 years
Arc interrupters	Visual inspection / clean Electrical test Air-puffer operational check	Annually 3 years Annually

Table 2 (cont'd)

Circuit breaker maintenance interval recommendations excerpted from table L. 1 of the US NFPA 70B guideline. Manufacturer recommendations can differ.

Item / equipment	Task / function	Interval
Air circuit breakers, medium voltage		
Operating mechanism	Visual inspection Operational check / adjust	Annually Annually
Trip device circuit	Operational check	Annually
Air circuit breakers, low voltage		
	Visual inspection / clean / adjust Electrical tests	Annually 3 years
Vacuum circuit breakers		
	Visual inspection / clean / adjust Contact checks / vacuum integrity Electrical tests	Annually 3 years 3 years
Molded-case circuit breakers		
	Visual inspection / clean Mechanical test Electrical test	3 years 2 years 3-5 years

By understanding your application, you can choose the most appropriate interval for time-based interventions. Most importantly, failures are minimized, translating into maintenance and capital cost savings. It is estimated that preventive maintenance saves from 12% to 18% annually over a reactive approach.

However, the disadvantages of a preventive model are it:

- Is a labor-intensive process
- Can result in unnecessary maintenance
- Can result in maintenance not being performed often enough, in the case of harsh environments

Predicting needs to optimize performance and costs

As discussed above, breakers used under accelerated aging conditions may need servicing more than what would be done using a time-based strategy. Though preventive maintenance takes into account manufacturer recommendations, including predefined levels of operational and environmental conditions, it does not take into account the actual day-to-day, minute-to-minute dynamic changes that occur.

Benefits of predictive over preventive maintenance

- Maintenance costs reduced by **50%**
- Unexpected failures reduced by **55%**
- MTBF increased by **30%**
- Machinery availability increased by **30%**

Source: ARC Advisory Group

According to CSA Z463-13, the fundamental difference between preventive and predictive maintenance is that the latter 'is used to define necessary maintenance tasks based on quantifiable material or equipment condition. Essentially, a preventive approach transcends failure prevention to enable failure anticipation.

The ability to quantify all real-time conditions affecting breaker performance gives service personnel the guidance to execute maintenance specifically where and when needed, avoiding unnecessary work and shutdowns. Maintenance of downstream equipment can be optimized, not driven by the upstream shutdown schedule. Finally, inventory parts can be ordered on-demand, helping to minimize inventory.

This condition-based approach requires a supporting diagnostic system. Options are available for on-site installation or as a managed service solution.

Embedded intelligence enables deep insight

You can think of breaker performance as somewhat analogous to a vehicle's tires. Tire wear results from a number of factors. Beyond simply logging the total distance driven, you need to consider the various conditions under which that driving has occurred. This can include the driving habits of the operator, the typical speeds driven, ambient temperatures, road conditions, etc.

In the same way, to successfully predict the health of a circuit breaker and when it should be serviced, it is necessary to monitor all parameters that contribute to its aging, both operational and environmental. These factors may be measured by sensors or estimated through some indirect measurement.

IoT technologies are now making a wealth of data available from circuit breakers and other locations throughout a facility's infrastructure.[2]

Smart embedded trip units **(see Figure 3)** can provide a range of breaker performance information over wired or wireless communication links, including operation counters (trips or openings), interrupted current profiles, contact wear, and electrical load data. Data is uploaded continuously and stored in a central power management database.

Other smart sensors are normally in place within a facility to measure and track environmental and mechanical conditions. This can include ambient temperature, corrosive gas levels, humidity, etc. This data can be made available from facility or process management databases.

In all cases, measurement can be performed over a short period of time or, ideally, on a more permanent basis over extended periods.

[2] Internet of things: 'interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies' - ITU

Figure 3

Example of low- and medium-voltage circuit breakers with digital capabilities.

Predictive analytics enables proactive service

Analytic applications are emerging that support predictive maintenance by integrating all measured operational and environmental data and determining various aging factors for different conditions.

Calculating failure risks

The analytic module makes calculations based on all collected data, determining relationships between different aging factors, statistically modeling failure risks, and ultimately helping maintenance personnel evaluate a circuit breaker's critical impact on the surrounding electrical installation and equipment. The analysis can be performed on a regular basis, such as once per month, or on an ad hoc basis when there is a problem caused by a potential disturbance.

Example of typical breaker aging calculations

We assume that aging is cumulative. We can calculate the relative aging with the following relationship:

$$\%Ag = \%Ag_0 + \sum_i \frac{\Delta T_i}{(TF)_i}$$
$$= \%Ag_0 + \frac{1}{TF_0} \cdot \sum_i \Delta T_i \cdot A_i$$

$\%Ag_0$: Aging at time t_0
ΔT_i: Time spent in under (i) operating conditions since t_0
$(TF)_i$: Time to failure calculated with operating conditions (i)
TF_0: Time to failure in nominal conditions. This value will be defined on a per device reference basis in the databases.
A_i: Acceleration factor for the operating conditions (i)

The overall acceleration factor is calculated using a function of the following factors:

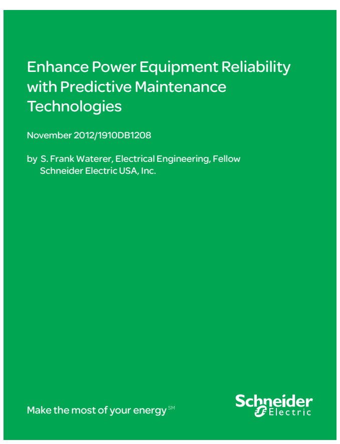
A_{SA}: Acceleration factor for salty atmosphere aging (e.g. proximity to ocean of <10 km = moderate, <1 km = high)
A_{CG}: Acceleration factor for corrosive gas aging
A_H: Acceleration factor for humidity aging
A_D: Acceleration factor for dust aging
A_V: Acceleration factor for vibrations aging
A_T: Acceleration factor for temperature aging

The temperature acceleration factor is estimated through a combination of ambient temperature, harmonics effect, IP (ingress protection rating) and load level of the device.

Note: *Circuit breaker aging represents a statistical model for similar devices under similar conditions. Like any statistical model, the aging prediction is not 100% accurate 100% of the time. It simply provides an estimation of the increased probability of failure due to aging. For example, if a circuit breaker calculation shows aging has reached 100%, this does not mean that the device failure is imminent; it means that the probability of failure is increasing dramatically.*

For more information

For information on additional predictive maintenance technologies, refer to the following Schneider Electric white paper.


Enhance Power Equipment Reliability with Predictive Maintenance Technologies

November 2012/1910DB1208

by S. Frank Waterer, Electrical Engineering, Fellow Schneider Electric USA, Inc.

Make the most of your energy

Interpreting and acting on breaker aging information

The health of every circuit breaker is synthesized and then presented through regularly generated circuit breaker aging reports as well as a real-time view of breaker aging status through an HMI. Interpreting the content of this information enables faster and easier decision making by facility management and service personnel, which in turn guides service actions.

Breaker aging reports summarize data for all circuit breakers throughout a facility **(see Figure 4)**. Breakers can be categorized into aging levels representing their associated failure risk, such as critical, moderate, or minimal. A further drill-down analysis of all relevant system parameters helps detect any drifts in performance or significant trends. In this way, corrective actions required for devices at highest risk can be anticipated to ensure continuity of service and equipment safety.

Based on these risk categories and supporting data, personnel can prioritize the required maintenance actions for each group of breakers, scheduling the most convenient time to maximize service efficiency. For breakers at highest risk, maintenance can be performed much sooner than previously scheduled. For breakers at minimal risk, the maintenance team might decide to postpone a previously planned inspection, depending on local regulations allow for this.

Regular aging reports take into account changing conditions over time, and their effect on the health of each breaker. During each review cycle, maintenance teams can optimize their maintenance procedures in response to actual changes in breaker aging.

Circuit Breaker Aging Report - 7/23/2021

Breaker aging and wear summary				
Switchboard	Level	Breaker name	Breaker aging (%)	Contact wear (%)
Switchboard A 1	Critical > 50%	Breaker A38	32.5	99.0
		Breaker A39	22.4	86.4
	Moderate 30-50%	Breaker A1	40.6	44.0
		Breaker A6	44.8	32.8
		Breaker A19	37.6	43.0
	Minimal < 30%	Breaker A31	28.5	27.2
		Breaker A48	18.6	29.4
		Breaker A3	27.8	15.7
		Breaker A4	16.7	21.9
		Breaker A15	25.7	22.8
		Breaker A26	18.6	15.4

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Figure 4

Example of a circuit breaker aging summary report showing devices automatically organized by risk level categories.

For operational and environmental conditions that are highly variable, having a real-time display of key aging parameters helps identify any immediate critical conditions that need to be addressed. The HMI can be configured to display circuit breakers in functional groups throughout the facility, for example by building or process area **(see Figure 5)**. Simple status icons can give a quick indication if everything is running normally or if there are any potential high-risk situations.

When a critical status is reached for any breaker, service personnel can be alerted on their mobile devices, either by email or through SMS alarms. The HMI can then provide a fast drill-down capability to isolate the breaker in trouble and the specific condition(s) that are putting its reliability at risk **(see Figure 6)**. For example, this could be an unforeseen increase in contact wear or a local spike in temperature affecting a trip unit.

Armed with this data, the maintenance team can take quick action to either service or replace the breaker in question.

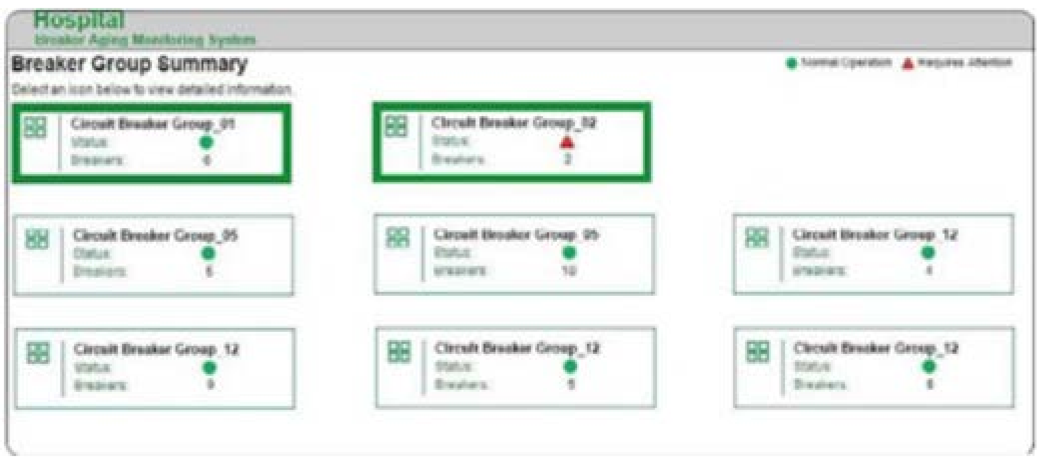

Figure 5

Example of a real-time circuit breaker aging status screen, showing breakers grouped by function or location, with buttons to enable quick access to more detail.

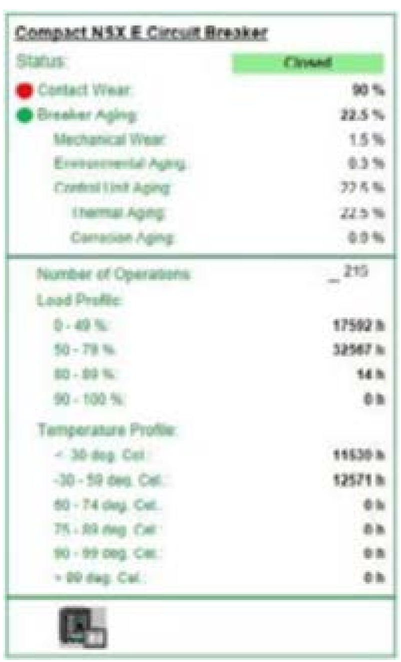

Figure 6

Example of a detailed breaker aging data screen for a single circuit breaker, showing the list of major aging factors and their current values, with an alarm indicated for contact wear.

Conclusion

"For large, expensive capital equipment…the cost of implementing a condition monitoring solution is easily justified. The most important benefit is an increase in revenues, which comes from maximizing uptime and efficiency of production machinery."

–Jan Zhang, IHS

The condition-based, predictive maintenance strategy outlined in this paper is designed to support failure risk models that take into account all operational and environmental conditions. This approach can tailor the time intervals of the inspection or service based on the specific conditions affecting each circuit breaker.

In less demanding applications or less harsh environments, this can help to extend the service life of equipment and reduce the frequency of inspections (dependent on regulatory requirements) as well as reduce repair costs. In more demanding or corrosive situations, it can help improve safety and increase meantime- between- failures of the main electrical switchboard.

Ultimately, a predictive strategy allows an organization to use a more fluid approach to asset management, dynamically adjusting maintenance work as needed. Continuously optimizing the performance of the electrical protection infrastructure will then, in turn, enhance facility-wide productivity and cost control.

Next Steps

To progress beyond a program of preventive circuit breaker maintenance to a more predictive approach, consider the following short- and long-term steps:

1. **Within the next few weeks –** Consult with an expert to help perform an audit and evaluation of your electrical protection infrastructure, including maintenance costs, operational challenges, and the availability of operational data from circuit breakers or power management system.
2. **Within the next 6 months –** Seek out a solution provider that can help you design a complete platform for predictive maintenance, including an IoT-based monitoring system to acquire any additional operational and environmental data needed. Determine whether an onsite analytics module or an outsourced service-based solution fits best with your business and goals.
3. **Within the next 12 months –** Implement the solution and use reporting and real-time data to begin optimizing your circuit breaker maintenance strategy, documenting ROI in terms of service and parts savings as well as instances of reduced risk to safety or productivity.

About the author

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Markus is responsible for offer creation of Schneider Electric's Power Monitoring software. He has held various key positions in R&D, Services, Power Quality, Project Management and Offer Marketing during his 23-year tenure at Schneider Electric. He has been Segment Director for Healthcare since 2009, responsible for the creation of electrical distribution and energy management solutions for Healthcare facilities. Markus holds in excess of 30 patents related to Schneider Electric hardware and software.

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