McDONNELL GROUP

Unplanned Outages:

Four Keys to Assessing Risk and Prioritizing Maintenance

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Classic preventive maintenance practices remain ingrained in the power industry culture in spite of the tremendous potential of predictive, condition-based, and reliability-centered alternatives.

Why is this still the case?

For one, preventive maintenance is considered easier. Equipment manufacturers commonly establish pre-determined maintenance schedules based on fixed time or cycle intervals. Their recommendations are readily plugged into today's computerized maintenance management systems as preplanned work orders. When the interval threshold is reached, a work order is automatically generated.

Consequently, preventive maintenance is also perceived to be cheaper. Planners, schedulers and technicians expend minimal effort, and no complex analytical skills, tools or technologies are required. But this is a false impression.

Conducting routine inspections, tests, maintenance and overhauls at pre-defined intervals ignores the many internal and external factors that influence an asset's true risk of downtime. Faults and failures come as a surprise when risks are not managed and adverse conditions are not brought to light. In addition, when the root cause of an unplanned outage remains a mystery, opportunities to improve the maintenance program are lost.

Condition-based, predictive maintenance has become significantly easier and more automated in recent years, and the cost to implement the practice is falling. Maintenance that is prioritized based on current asset conditions enables safer, more reliable operation and extends equipment life. Furthermore, maintenance labor is reduced when non-value added tasks are reduced or eliminated.

Power companies today rely on increasingly sophisticated equipment components such as transformers, circuit breakers and switchgear that are vital to reliable operation. It is components like these that benefit most by replacing or supplementing traditional maintenance practices with condition-based, reliability-centered strategies that are targeted, timely and effective, and more likely to prevent costly unplanned downtime.

Combining reliability-centered risk assessments, cost/benefit analyses, priority-driven condition-based maintenance, and root cause analyses is preferred to ensure optimally timed, efficient, and economical service. The outcome allows effective corrective actions as well as ongoing improvements to the maintenance program, equipment design, and risk assessment models. Together, this comprehensive approach forms the continuous improvement cycle that is essential to the power industry.

Limitations of Traditional Maintenance Practices

Time- and cycle-based fixed maintenance intervals contribute to crisis management and run-to-failure tendencies. When maintenance tasks are performed at set intervals, regardless of the equipment's current physical condition or environment, they may occur too soon to be of value or too late to prevent a failure. In fact, the odds of a routine task occurring just in time are slim.

For instance, changing good oil and filters costs time and money, but when the change comes too late, the consequences may be significant. "Breakdowns generate byproducts which contribute to faster breakdown," says Craig Stiegemeier, business development and technology director for ABB's Transformer Remanufacturing and Engineering Services (TRES) North America division. The better approach is to proactively monitor the oil quality and schedule maintenance based on signs of contamination or degradation.

Another weakness of traditional preventive maintenance is that the environmental state is ignored. "A circuit breaker in a coal dust environment will require more routine maintenance than one in a controlled environment," explains Rick Gardner, sales and marketing manager for ABB's Low & Medium Voltage Service organization. "The buildup of contaminants will result in tracking, sluggish performance of the mechanisms, and in some cases increased heat, depending on how extreme and the length of time between maintenance intervals." Likewise, monitoring gas, temperature, and other variables in high voltage circuit breakers provides valuable clues into potential degradation so that maintenance can precede failure.

High-risk components are prime candidates for predictive rather than preventive maintenance. "A transformer's condition is unique to its design, how it has been used, and how it has aged in its environment," says Stiegemeier. "In effect, every large power transformer has a unique design DNA. Each one is optimized for a specific location in the network and therefore they are not interchangeable."

For transformers, the greatest risk lies with transmission lines and generating plants, where the impacts of unplanned outages are particularly painful. Sometimes, a spare cannot be capitalized until it is used. Other than for critical applications, utilities often don't buy spares because the cost would have to come out of shareholder value rather than be recovered as part of the rate base.

Assets with multiple condition variables benefit most from sophisticated maintenance models. They are well suited to online monitoring and diagnostics or periodic condition data acquisition, rather than traditional preventive practices. “For high voltage circuit breakers, the primary parameters to record are the number of operations on the breaker, the number of faults it has seen, and at what fault currents it was exposed,” recommends Robert Stoner, sales and marketing manager for ABB High Voltage Service. “For gas breakers, the gas level, pressure and density are additionally recorded.”

Proper breaker upkeep greatly reduces the incidence of unplanned outages. Time-based services are appropriate for certain low-risk breakers. “We recommend annual and five-year maintenance cycles, with key parameters assessed annually and overhauls performed every five years,” Stoner explains. “After five years, each breaker should be taken out of service and its hardware examined, including its lubrication, settings and timing, leaks, and other signs of wear. In addition, all breakers should be exercised periodically to ensure the mechanism continues to open and close properly.”

An additional maintenance weakness common in the industry is attrition of the experienced workforce. The lack of a proper talent pool places assets at risk of ill-timed or improper maintenance, whether preventive or predictive.

Gardner summarizes the four primary impacts on equipment as follows:

- Environmental influences: The conditions under which equipment operate have a direct impact on their maintenance requirements.
- Proper maintenance: Having a strong and well documented maintenance program reduces the likelihood of unplanned downtime.
- Age from degradation: Periodic equipment age calculations are essential to making proper maintenance decisions and ensuring maximum uptime.
- Workforce attrition: As employees with tribal knowledge of older equipment leave the workforce, the skills gap must be filled, whether from internal or external sources.

Clearly, traditional preventive maintenance is not dynamic enough to support the demands of today’s most critical equipment. Moving those assets from inflexible, interval-based maintenance practices to an intelligent, comprehensive, condition-based strategy offers greater agility and control over the many variables that affect reliability and uptime.

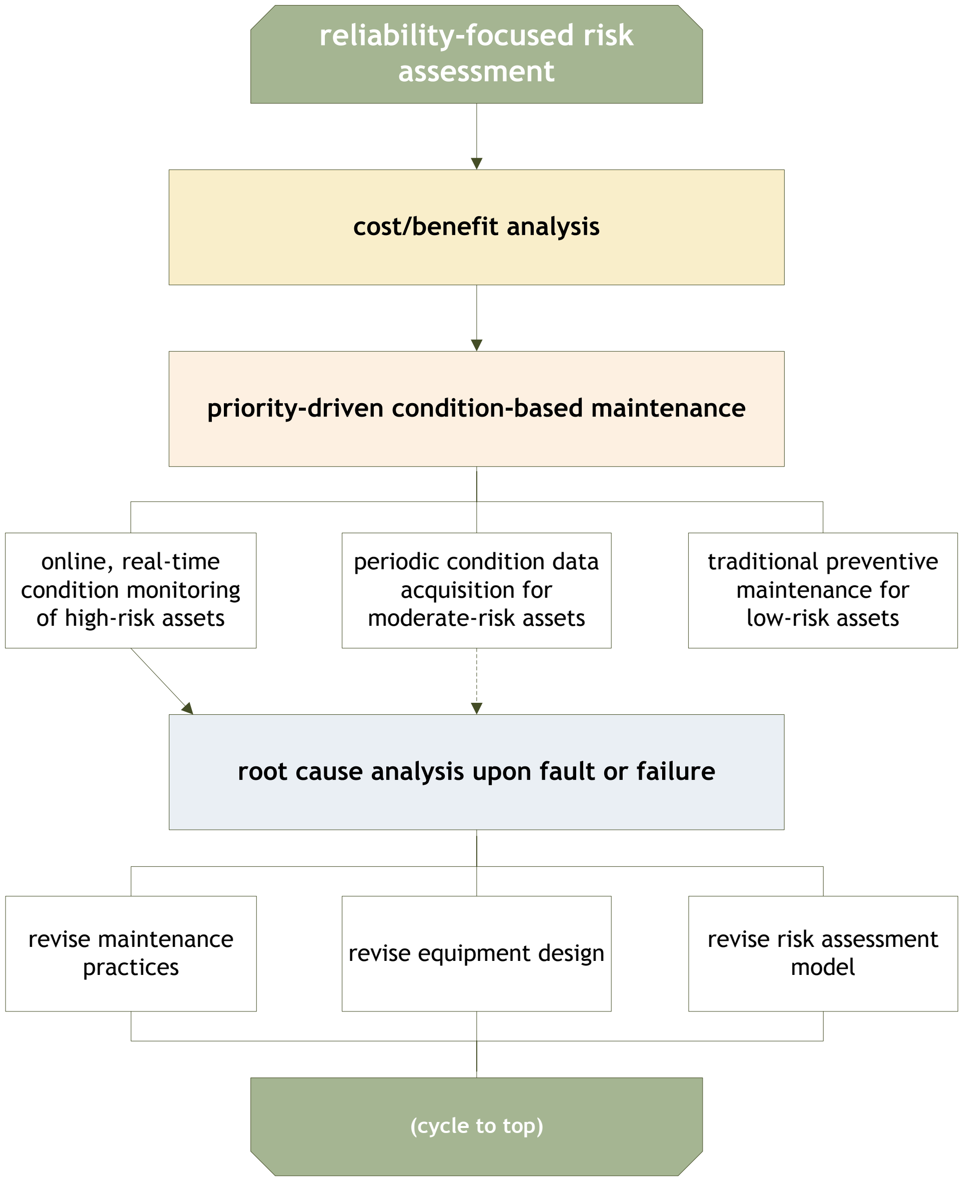


Figure 1: Four Keys to Assessing Risk and Prioritizing Maintenance

Key One—Reliability-centered Risk Assessment

The first step in a comprehensive, condition-based maintenance program is to ascertain and quantify the risk of failure of key assets, because each fault or failure presents risks to safety, reliability, performance, and the bottom line.

Risk assessments establish the foundation from which maintenance decisions are made. Assessment data is gathered from system diagrams, maintenance histories, fault and significant event histories, environment and condition observations, and other relevant sources. Based on the analysis of the system and data, risk reports with prioritized recommendations are developed.

Model-driven risk assessments consider all the possible risk conditions for a given piece of equipment. “Our transformer model weighs more than 60 different parameters in its risk of failure calculations,” says Stiegemeier. “The goal is to provide an estimated cost to reduce the risk of failure by a given percentage.” For instance, when unusual findings in oil chemistry or electrical measurement are discovered during a transformer’s annual health check, the condition is analyzed and the utility is given an estimated percentage risk of failure.

Assets with the least probability of failure in the next calendar year are designated in green. Those at moderate risk are indicated in yellow, and the worst behaving transformers are marked red. Once the risk of failure estimates are determined, steps are recommended to lower the risks, such as replacing a fan motor, bushing or pump.

For low and medium voltage switchgear and circuit breakers, a risk assessment may involve the full fleet, an individual power plant, or specific equipment. Risk assessments for these assets capture the age, last preventive maintenance date, maintenance frequency, and internal and external condition variables. In addition, the owner must decide how long they want the equipment to survive, whether safety upgrades should be made, and whether to extend the life of the gear.

At the conclusion of the assessment, the components of the equipment are prioritized based on the assessed condition. The highest focus will be on those colored in red, which represents equipment in distress, near failure, and needing urgent attention. “Typically basic preventive maintenance tasks that bring red conditions to a yellow state are performed immediately, where possible, rather than waiting for the assessment to conclude,” says Gardner. Risk assessment findings are documented in a risk reporting and mitigation plan.

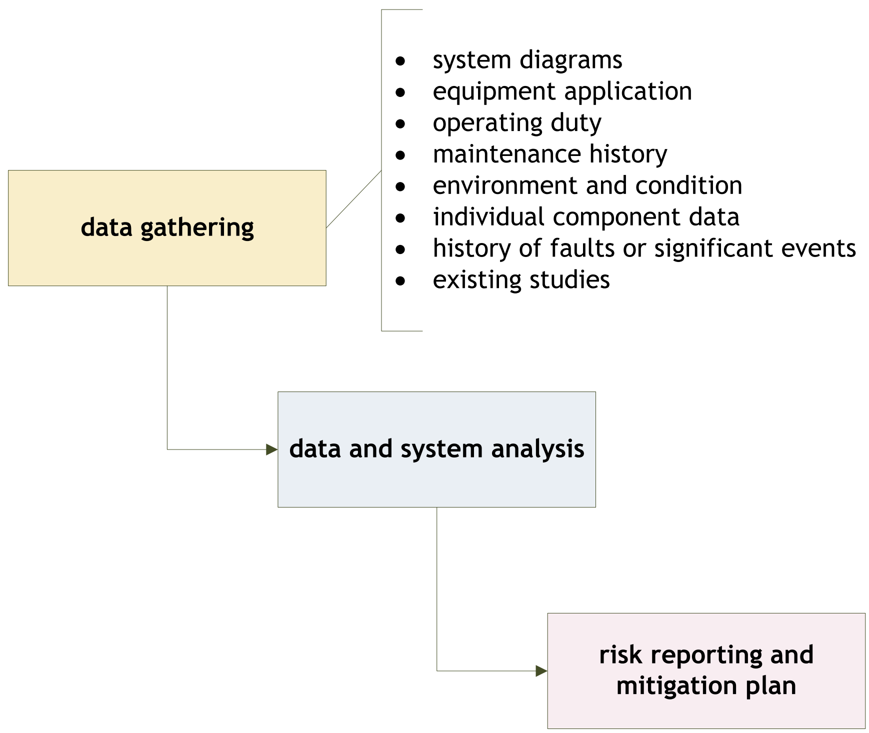


Figure 2: Three Phases of Asset Assessments

Key Two—Budget Considerations

Next, the risk of failure determinations must be balanced against the cost of applying the recommended mitigating actions. If the cost to lower the probability of risk is minimal, then the maintenance action is encouraged. However, when a transformer is nearing its end of life, an alternative, inexpensive solution may be in order. For example, if an aging transformer at a dam is at risk of rupture, rather than investing heavily in maintenance, the owner may choose to replace the mineral oil with vegetable oil in the transformer in order to lessen the environmental impact should a rupture occur.

Lifetime estimations weigh heavily in repair/replace decisions. “We recommend performing a life assessment on the organic material before judging whether the cost of maintenance is worthwhile,” says Stiegemeier. “If a nuclear transformer is at 40 to 60 percent of its remaining life, paying $3 million in maintenance to add 25 years to its life is more cost effective than replacing it with a new transformer for $10 million.” Since every company’s financial model is different, the economic value estimation of action is best left to the individual asset owner.

For low and medium voltage switchgear and circuit breakers, data from fleet and equipment condition assessments are captured in a life extension cost analysis tool, which reveals whether strategic maintenance or a wholesale change-out is more beneficial from a financial perspective. For example, new breakers have far fewer moving parts than their predecessors. Installing new breakers in existing switchgear will significantly reduce maintenance costs, while also avoiding the major outage associated with replacing an entire switchgear lineup. Gardner also recommends a cost/benefit analysis when deciding whether to stay current on available equipment updates.

With good maintenance, high voltage circuit breakers have several decades of total life. “Extending the life of a breaker through a rebuild is approximately half as expensive as replacing the breaker with a new one,” says Stoner. “Our customers are given the opportunity to rebuild breakers that are as many as 20 to 30 years old.” Whether a rebuild is needed, and its cost, depends on how long the breaker has been in service and its type of wear. The task may involve rebuilding internal mechanisms and select components, as well as implementing design improvements. Breaker rebuilds are particularly beneficial when a replacement will not fit without costly modifications.

Key Three—Priority-driven Condition-based Maintenance

Once the risk mitigation plan is cost justified, condition-based maintenance is initiated. Candidates for online, real-time condition monitoring and diagnostics include that equipment deemed most critical to the success of the operation. Condition monitoring through periodic data acquisition is appropriate for equipment of moderate risk, and traditional preventive maintenance practices are suitable for low-risk assets.

"The 90/10 or 80/20 rule says that most assets will age well and predictably. Condition monitoring helps to isolate the other 10 or 20 percent that are behaving abnormally," Stiegemeier explains. Modeling transformers for weather conditions and ambient temperatures helps to determine whether they are currently in a normal range or out of tolerance. The red, yellow or green designation is updated to reflect the most recent data.

Condition assessments allow companies to prioritize their maintenance focus. "We recommend identifying the most important low and medium voltage assets based on critical load, number of faults occurred, how well they were maintained, and other factors," says Gardner. Alterations to the maintenance routine are made based on condition assessments. "We've had incidences where companies let equipment go for extended periods and calibration was urgently required." Other maintenance actions may include upgrading protection and control equipment, performing arc flash mitigation, replacing old circuit breakers with magnetic actuator breakers, or other technology or safety upgrades.

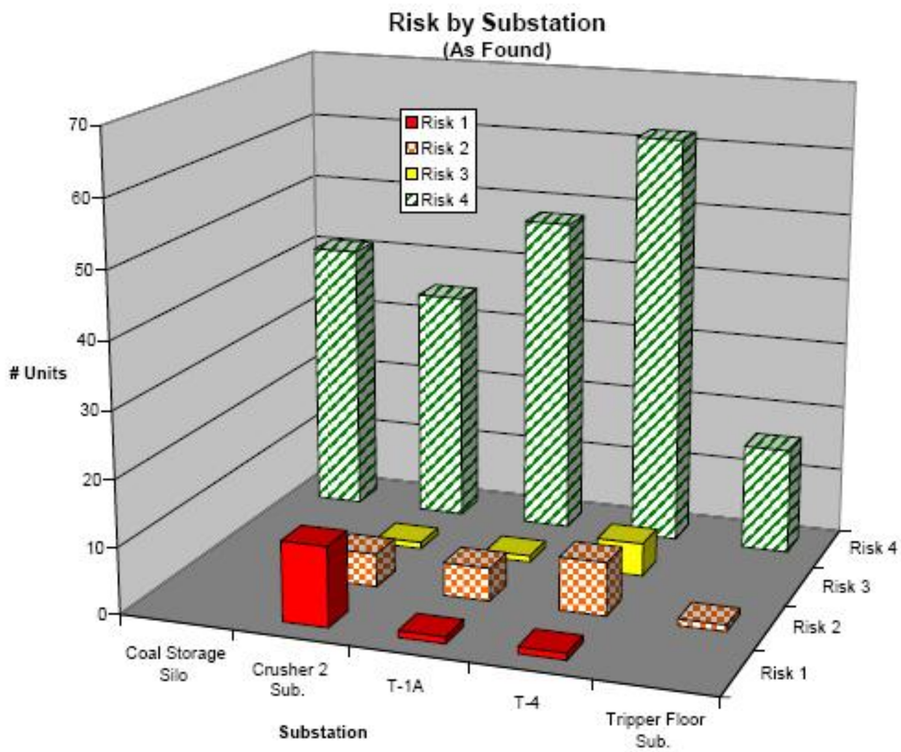
Assessing the condition of high voltage circuit breakers involves weighing the number of operations, the magnitude of faults to which it was exposed, and its estimated life. With this information, it can be determined which breakers are currently most prone to failure. A breaker's priority also factors whether it is a critical part of the transmission network, as opposed to one serving a less critical function.

"For the highest priority, highest voltage circuit breakers, we encourage online, real time condition monitoring, with set points for key parameters and alarms when out of range," says Stoner. Companies can monitor their own breakers online using a web-based tool, or outsource the monitoring to a third party. "We use ABB's internal proprietary algorithms to monitor high voltage circuit breaker condition and wear, as well as gas leakage."

"Receiving condition data within hours, online, is significantly more meaningful than interval-based data, which might date back years," adds Stiegemeier. For online monitoring, a box mounted onto the side of the transformer tracks condition variables such as temperature, load, and basic oil chemistry.

Some switchgear is capable of being monitored remotely to alarm operators of events such as heat rise, current and voltage variance, open circuits, and other faults and abnormal conditions, according to Gardner.

For less critical high voltage breakers, interval-based maintenance is sufficient. At minimum, Stoner recommends yearly visual inspections of all high voltage circuit breakers.



Priority 1 (red)	Immediate Action is required. Equipment condition poses immediate risk to either personnel or reliable operations if not corrected immediately.
Priority 2 (orange)	Action within one (1) year is required. Equipment condition could pose a risk to either personnel or reliable operations if not corrected within a year.
Priority 3 (yellow)	Action within three (3) years is required. Equipment condition could pose a risk to either personnel or reliable operations if not corrected within 3 years.
Priority 4 (green)	No Action Required.

Key Four—Root Cause Analysis & Continuous Improvement

Despite implementing best practice maintenance strategies, companies will inevitably experience unplanned outages. Each time such an event occurs, a decision must be made as to whether to isolate the root cause of failure. When root causes are pursued, the findings can be leveraged as refinements to the maintenance program or improvements to equipment design, as well as reflected in the assessment model.

Root cause analyses ask why a fault occurred, what should be done to avoid it in the future, what needs to be fixed, and how quickly the equipment can get back online. While root cause analysis decisions are made on a case-by-case basis, utilities in general tend to be more proactive about analyzing failures than other industries.

If it is likely a storm or lightning strike failed a high voltage circuit breaker, a formal causal determination would not be necessary. On the other hand, when there is not an obvious explanation for why a fault occurred, a replacement breaker will be installed while the failed breaker is brought to the shop, taken apart, and investigated for the failure source.

Determining the root cause of a failure is essential to preventing similar occurrences in the future. Based on the findings, the recommended maintenance practice may be altered and improved, or there may be design changes made to improve the breakers themselves. “We make all new design features available to our customers in an upgrade kit,” says Stoner.

With transformers, age is often a primary consideration for whether a root cause analysis is performed. “If a failed transformer is at or near its end of life, then the analysis is probably not cost effective,” says Stiegemeier. “However, if a fault occurs when a transformer is five or ten years old, having an expert search the collateral damage for the root cause is a worthwhile investment. The challenge is finding the actual initiator of the event, rather than the innocent victims.”

The first step is analyzing the transformer’s design program. Although few transformers have online monitors at present, when they do, the black box is also reviewed. “Our transformer model searches for trends in recent oil samples and assesses other relevant parameters subject to a high risk of failure in order to isolate the root cause of failure,” he adds. “The knowledge gained during the analysis process is used to improve transformer design and maintenance practices. Our assessment model is likewise refined and continuously improved.”

“We want an answer every time, but we won’t always get one,” says Gardner. When a fault or failure occurs in low and medium voltage switchgear or circuit breakers, decisions are made rapidly. “Because of the potential revenue loss, there is a vested interest in getting the assets back online quickly. However, if the ‘crime scene’ is contaminated in the process, evidence is lost.” This is more of a concern in nuclear power plants, where finding the root cause is a higher priority than limiting the cost of downtime.

Conclusion

It is no longer practically or economically feasible to maintain strategic, high-risk equipment using fixed time- or cycle-based preventive methods. Instead, to ensure high asset availability, power companies must identify and prioritize their most critical equipment and manage them using a comprehensive, condition-based maintenance program.

Although traditional maintenance practices based on pre-determined intervals are deceptively easy and appear inexpensive, the true cost is evident with each unplanned outage. Unless a maintenance program factors the equipment’s unique physical environment, operating conditions, performance, maintenance and fault history, the work is unlikely to be sufficiently timely, accurate or cost effective.

Rather, best practices dictate that power companies that ascertain failure risks, weigh the cost factors, establish condition-based maintenance strategies by priority, and analyze and remediate the root cause of failures will be in a better position to continually improve asset availability.

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