BENEFITS OF MONITORING AND DIAGNOSTIC SOLUTIONS

Data center case study

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Introduction

Medium voltage switchgear is a vital component in data center power distribution systems. Nevertheless, its maintenance is often overlooked because of its long-life span and relatively low equipment failure rates.

This paper explores a case study that demonstrates that integrating a condition-based maintenance philosophy to existing preventive maintenance practices can decrease the overall total cost of ownership by up to 40% and increase maintenance intervals by up to 30%.

Condition based maintenance addresses the causes of failure in medium voltage (MV) systems, reducing failure rates drastically by detecting any errors that may arise in between two scheduled maintenance cycles. Repairing or replacing the switchgear can be expensive due to downtime and the urgency, increasing the price of labor.

This paper is based on a maintenance study completed for a data center in Europe. Its existing plan was based on three types of maintenance tasks:

- Activities to be carried out annually
- Activities to be carried out every three years
- Activities to be carried out every six years

The aim of the analysis was to prove the return on investment of condition-based maintenance using monitoring and diagnostic solutions by calculating the impact of the reduced number of maintenance activities requiring on-site work, increased maintenance intervals, and an optimized maintenance plan. Reduction in both cost and probability of failures were considered.

Due to customer confidentiality, the complete maintenance protocol is not released in this paper, but the outcomes are.

First, it is important to understand the major causes of MV switchgear failures and which causes can be monitored using a condition-based approach.

Causes of failure in medium voltage equipment

External conditions play a big role in the performance of a switchgear. Current leaks can cause equipment to heat up. The build-up of dust inside the switchgear can lead to partial discharges which can significantly damage the equipment.

IEEE 493-2007 [1] includes an end user survey on the causes of the medium voltage equipment failure with both insulated and non-insulated busbars. For insulated busbar, the survey shows that defective parts and inadequate maintenance are the most common causes of failure, resulting in up to 66% of all failures.

The data shows that installing a condition monitoring system with breaker diagnostics and temperature and partial discharge systems will reduce the number of failures.

The data from sensors is received in real time– unlike preventive maintenance where the data is only available in the next interval. Although not all machine related failures can be covered using a sensor (e.g. lack of lubricant), even if a conservative approach is taken, at least half the failures can be covered using sensors. Loose connections can be detected through thermal sensors, faulty insulation through partial discharge sensors or faulty mechanical parts in breakers through breaker diagnostics using opening and closing time. Therefore, the risk of failure is significantly decreased with a monitoring and diagnostic solution. It is worth noting that condition monitoring does not make the equipment maintenance free, rather maintenance "light" through an optimized approach, significantly decreasing maintenance and failure costs.

Economic loss in case of failure

The economic impact of a complete shutdown due to a switchgear failure is immense. A study done by the Ponemon Institute [3] in 2016 spanning more than 60 data centers found that on average a data center stood to lose around $740,300 during an outage.

A similar study was carried out by the Uptime Institute [4] in 2018, reaching a similar outcome. It showed that a data center loses on average $849,696 during an outage.

This can also add to the long-term costs of following a corrective maintenance approach. In addition to the costs associated with repairs, a bigger price tag comes from the halt in operation. Reliability of the system is vital for any data center, making a complete shutdown for repair works the worst-case scenario.

IEEE surveys [2] estimate that the industry average for downtime is 261 hours per switchgear failure. This will vary as the downtime is dependent on the type of failure, the administrative process, the type of industry and the related consequences.

SWAPs maintenance program: See, Watch, Act, Perform, Secure

The NFPA 70B [5] and ABB user manuals clearly outline the practices that should be adhered to for the maximum effectiveness of a preventive maintenance program. To meet this guideline, ABB applied SWAPs, an abbreviation that stands for See, Watch, Act, Perform, Secure. This maintenance program aims to maximize productivity, protect assets, and optimize investments. The program defines the right timing and actions to take when performing maintenance on ABB electrical equipment.

The SWAPs program is based on IEC[1], IEEE, GB standards, NFPA [5] and ISO [6].

SWAPs is always tailored to the customer's specific installation and recommends the list of activities to be carried out at each level. In the SWAPs program, the recommendations for maintenance activities are based on the age of the electrical equipment, the environmental and operational conditions in which the equipment is installed, the previous maintenance performed, and the presence of monitoring and diagnostic solutions.

The program supports customers from start to finish, throughout the products' entire lifetime, including prompting customers when it is time to retrofit protection relays and circuit breakers.

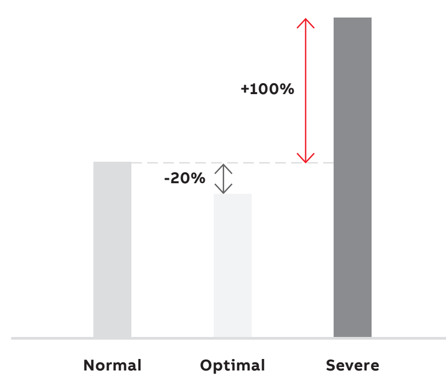
Environmental and operational conditions have a strong impact on SWAPs:

- Environmental conditions include temperature; humidity; rate of change of temperature; condensation; heat radiation; presence of flora and fauna; chemicals; presence of dust and sand; vibration and shock as well as altitude.
- Operational conditions include the age of the equipment; number of operations; load; short circuit current interruptions; and frequency of operations.

According to its value, each parameter can correspond to a different class of conditions:

- Normal condition is defined by international Standards (IEEE, IEC, and GB Standards)
- Optimal condition is the favorable range within the normal condition, based on historical equipment performance data and ABB experience. This favorable condition allows maintenance intervals to be increased
- Severe condition is outside the normal condition in operational and/or environmental condition which can cause premature aging and wearing and therefore higher safety risks and probability of failure

The condition of the equipment has a strong impact on maintenance costs and downtime. When compared to normal conditions, equipment operating in optimal conditions can save 20% in maintenance costs and hours, whereas equipment operating in severe conditions see maintenance costs double.



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— 01 Maintenance costs and downtime comparison in different conditions

[1] Including IEC, Classification of environmental conditions – Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weather protected locations, IEC Standard 60721-3-3, Part 3-3, 10/2002.

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02 SWAPs maintenance levels

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03 Maintenance plan with condition monitoring

SWAPs is based on four levels of maintenance activity–See, Watch, Act, Perform, and a fifth activity for critical situations, Secure.

Using the right experts
The levels See, Watch and Act can be carried out by data center operators' appropriately trained personnel, while Perform and Secure require ABB field engineers for additional expertise and product knowledge.

Trained personnel
Dedicated ABB trainings

ABB certified technician

See	Watch	Act	Perform	Secure
Overall visual inspection	**In-depth inspection** De-energized panel	**Basic maintenance** Cleaning, lubrication and functional testing of the equiptment	**Advanced maintenance** In-depth analysis of the asset and immediate corrective actions	**Special maintenance for critical situations** (Not included in the maintenance plan.)

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Starting from these levels, we provide a maintenance plan and related activities for circuit breakers, switchgear and relays, where maintenance cycles are diversified for different equipment conditions. For example, for severe conditions we need to reduce maintenance intervals by 50%, while we can increase them by 30% for optimal ones.

The presence of monitoring and diagnostic solutions also positively affect the SWAPs program.

With condition monitoring, the situation can be compared to an optimal condition as the data is available in real time from the sensors, rather than waiting for the next maintenance interval to check the condition manually. Therefore, we can increase maintenance intervals by 30%. In cases where switchgear maintenance is dependent on the maintenance of transformers or other equipment it is highly recommended to have condition monitoring of the whole electrification system to enhance the complete maintenance cycle.

Standard conditions

Device/year	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14
Circuit breaker						A				P						A				P						A		
Switchgear				S		W		S		A				S		W		S		P				S		W		
Relay				W		A		W		W		W		W		A		W		P				W		A		

Intervals can be increased by 30% (independently of the equiptment's conditions)

Standard conditions with M&D

Device/year	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5
Circuit breaker						A					P									A						P	
Switchgear						W				S	A						S			W						P	
Relay				W		A		W		W	A		W		W		W			P				W		A	

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Optimized maintenance using condition monitoring

Condition monitoring does not mean that the system becomes maintenance free, rather that it optimizes the complete process of maintenance. Focusing on the data center case in Europe, the maintenance plan is divided into three intervals with different grades of tasks being carried out: annual maintenance, three-year maintenance and the six-year complete shutdown tasks.

Annual maintenance
The annual maintenance tasks are predominantly based on See activities and a few Watch ones, thus keeping the switchgear mostly energized. Therefore, the main tasks include a partial discharge survey, exterior observation of ground contacts and checking of labels.

Many data centers have indoor medium voltage switchgear with access controls for technicians to enter the facility; for this reason, chances of vandalism and unauthorized access are limited. Therefore, some tasks like label checking can be shifted to a three- or six-year cycle, rather than doing them annually. Partial discharge online monitoring eliminates the need to inspect the equipment with a handheld device. Tasks like grounding inspection are still recommended.

Three-year maintenance
This is the most crucial activity in the complete maintenance cycle, as it is vital to justify the next six-year maintenance interval. Most of the tasks are based on See and Watch with only a few tasks in the Act category of SWAPs. In most scenarios, even a partial shutdown is not possible so certain tasks cannot be carried out completely. Condition monitoring on the other hand provides data irrespective of operation topography allowing data-driven maintenance decisions.

Using our example data center protocol, there are approximately 39 tasks that need to be completed. Condition monitoring can reduce that number to 13 tasks, providing a 66% reduction in activities, which saves time and money. This can be attributed to the sensors ability to provide the required information remotely.

Table 1 - Example of three-year maintenance activities replaced by sensors

Maintenance activity	Sensors replacing the activity
Inspect each cubicle for evidence of water intrusion or other physical damage	Thermal and partial discharge sensors
Perform a thermographic inspection on all cable termination points which are exposed	Thermal and partial discharge sensors

Some of these tasks can be shifted to a six-year full shutdown plan.

As an example, verifying the operation of the safety shutters is not required every three years, as they do not move during normal operations (breaker is racked in) and in the case of damage requires a more urgent approach demanding full de-energization of the busbars. It's a case where the inspection activity itself could lead to damaging the part.

In general, each maintenance activity should be evaluated based both on the failure mode and impact to critical operations. Therefore, it follows that the need for a breaker to trip due to a fault, or close to mitigate an unplanned outage are high priority operational needs. This warrants the inconvenience and risk of downtime to verify operational reliability. In contrast, interlocks and shutters are important for personnel safety but only come into play during maintenance activity, lowering their critical priority.

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Table 2 - Example of three-year maintenance activities to be shifted

Maintenance activity	Comment
Verify operation of barrier and shutters installed	Move to a six-year plan

Many operational tasks like switching the breaker are already carried out using SCADA systems and do not require on-site personnel. The advantage of condition monitoring is that switching of the breaker does not only guarantee that there is no jamming, but also provides breaker diagnostics; for instance, opening and closing time, spring charging time, and other parameters are evaluated within some predefined thresholds. Clearly not all of them can be postponed and some must remain within three years.

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Table 3- Example of three-year maintenance activities that cannot be shifted.

Maintenance activity	Comment
Verify primary and secondary moveable connections and grounding	To be completed in the same interval
Relay password to be verified	To be completed in the same interval

Reduction of the tasks at site directly reduces the cost of maintenance.

Six-year full shutdown maintenance
The full shutdown activities can continue as scheduled today, although the intervals could be increased gradually up to 30% as online monitoring gives the critical information in real time.

In the future some full shutdown tasks might be shifted to higher cycle (e.g. 12 years), but this should be done gradually to develop enough historical data to confirm the cycle. If sensors are working properly and giving stable data, it is not necessary to open that compartment to re-confirm after every full shutdown interval.

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Activities which have the potential to be shifted to a 12-year plan.

Maintenance activity	Comment
Inspect all the instrument transformers for physical damages, broken leads. If possible, check the tightness of the connections, defective wiring, etc.	With experience this can be shifted to 12-year plan rather than six-year plan
Check evidence of physical damage like overheating, and corona damage	With experience this can be shifted to 12-year plan rather than six-year plan


ABB
Environment Temperature
SAMSUNG
ABB
HyFlex
Ansell
ABB
Ready
Start
Trip
Clear

Conclusions

In conclusion, the installation of a condition monitoring system is an effective way to reduce operational costs in both cases with an observed failure and without. The monitoring system reduces the amount of time required for the routine maintenance, increases the time interval of maintenance by 30% and optimizes the maintenance activities. As a result, the total cost of ownership could be reduced by up to 40%.

Reaping the full benefits of condition monitoring requires a shift in data center power distribution strategies. There must be a significant percentage of switchgear in the installed base leveraging condition monitoring to realize these savings. Adding transformers and other critical equipment to the program continues to increase the impact.

The European data center case study illustrates the significant maintenance cost savings through condition monitoring by reducing three-year maintenance tasks from 43 to 13 (a reduction of 66%). Not only does this save costs (e.g. labor and parts), but it also reduces the risk of damage during unnecessary inspections. Secondly, the maintenance cycle can be increased by 30%, optimizing the complete maintenance program.

The decrease in operational cost and probability of failures increases the uptime. In the case of data centers, uptime is critical in meeting operational requirements and eliminating costly downtime. There is no doubt that using effective condition monitoring can have a positive impact on reducing costs and ensuring the smooth running of data center for many years to come.

References

[1] IEEE 493-2007 - IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems (Gold Book)
[2] IEEE Standard 493-2007 Appendix A (B)
[3] “Cost of Data Center Outages.” Ponemon Institute LLC, Jan. 2016.
[4] https://www.smart-energy.com/industry-sectors/energy-grid-management/new-report-finds-50-increase-cost-data-center-outages/, December 13th 2018
[5] NFPA, Recommended practices for electrical equipment maintenance, NFPA Standard 70B, 2019 (U.S. National Standard)
[6] ISO, Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment, ISO Standard 142224, 10/2016

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