# MAXIMIZE ASSET AVAILABILITY AND REDUCE MAINTENANCE COSTS – AN INTEGRATED APPROACH COMBINING CONDITION ASSESSMENT WITH DATA ANALYTICS

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## ABSTRACT

*The scenario in which industries and utilities operate has changed drastically in the recent years. In the past, investment and maintenance decisions were often determined more by avoiding technical risks than by budget restrictions. Nowadays, new business drivers have changed the perspective: investment (CAPEX) and maintenance cost (OPEX) on assets must be financially motivated and optimized, supporting also an increased demand of assets availability and reliability. Most of the operators are starting to apply, also to substations, modern asset management methods. Main pillars of an efficient methodology are the right maintenance strategy, the knowledge of assets failure modes and real understanding of asset life cycles.*

*The proposed tool- and technology-based approach combines asset assessment methods with data analytics. The paper describes also the application of the proposed tool in a plant, where the assessment criteria (inputs) and dedicated algorithms (data analytics) are used to estimate the fleet health condition, to analyse the risks and report mitigation actions (output).*

*The estimated risk map and the reported service messages and instructions give a clear prioritization of suggested mitigation actions, like for instance need of preventive maintenance or investments in new assets (retrofit or upgrade).*

## INTRODUCTION

Today's distribution utilities have to face the challenges of cost, aging infrastructure, reduced maintenance force, growing demand, environmental concerns, regulatory issues, customer satisfaction and reliability issues.

These challenges have given increased importance to the cost effective and efficient use of physical assets. Asset management needs decisions about installed assets allowing the business to maximize long-term profits, while achieving maximum customer satisfaction with acceptable and manageable risks [1]. The goals of asset management are to reduce spending, improve performance, effectively manage risk, and find an optimal balance among these. Asset management must consider issues such as aging infrastructure, asset utilization, maintenance planning, automation, reliability and risk management [2]. In particular, the maintenance approach influences heavily the asset management activity and optimization results: on technical aspects (ensure reliability and safety) and on financial aspects (CAPEX, direct and indirect savings).

Past maintenance practices were based on original equipment manufacturer manuals, industry standard guidelines and service experience. While some of these guidelines were based on the number of equipment operations and/or age, the majority resulted in a time-based or even run-to-failure maintenance program [3]. It was common for circuit breakers and transformers to be tested annually, every three or more years.

New maintenance approaches provide emphasis on equipment health condition. The goal is summarized by two requirements: "Tell me when I need to do maintenance and what maintenance to do"; and "Tell me that I have a problem now and what I should do about it". This approach is the condition-based maintenance (CBM), which is capable of reducing costs, increasing productivity and maintaining high equipment reliability and availability while ensuring a higher safety level. CBM let efficiently implement the well-known Reliability Centered Maintenance (RCM).

Since smart asset management means also risk management, the equipment condition is only a part of the story. It is also important to be aware of the consequence of failure, usually measured as a sum of direct and indirect costs of a fault or downtime. The estimation of these costs depends on equipment importance (criticality) within the substation or plant, and on its life cycle status. The first is mainly dependent on the electrification network and application, e.g. are there redundancies, is the main switchgear for the production plant, is a spare feeder, etc. The second refers to the equipment spare availability, equipment production or obsolescence, and the existence of retrofit solutions. This information comes typically from the equipment manufacturer, and helps to establish refurbishment or replacement requirements, also known as end-of-life (EOL) decision.

The paper presents an integrated assessment process and tools to implement the new smart asset management approach.

## INDICATORS TO DRIVE SMART ASSET MANAGEMENT

A smarter asset management approach, based on CBM and RCM methodologies, relies on regular assessments of equipment condition and, therefore does not apply rigid

maintenance schedules.
The condition assessment process is vital in order to detect in advance the most important failure causes, and therefore apply maintenance to restore an acceptable asset condition. There are several statistics on electrical distribution system failures, like [4] and [5]. Table 1 shows aggregated statistics for Medium Voltage (MV) distribution assets.

| **Top causes of electrical distribution failures** | |
|---|---|
| Loose connections / parts | 30% |
| Environmental conditions (humidity, dust, etc) | 20% |
| Incorrect work | 17% |
| Faulty insulation (dielectric problem) | 10% |
| Faulty equipment (mechanical, electrical, electronic) | 9% |

*Table 1: top failures statistcs*

Asset condition assessment can detect most of the mentioned failure causes before they happen. As explained in [6] to implement CBM and RCM it is important to join condition assessment and the proper analytics to determine the equipment condition and improving actions, ensuring the overall reliability and economic operation of the power station.
These analytics, to be effective, shall produce Key Performance Indicators (KPI) in order to classify assets by risk and schedule and prioritize the actions. The risk of failure of an asset is the combination of its probability of failure (POF) and its consequence of failure (COF). Usually, directly relating a physical condition to a reliability index expressed as a mathematical probability is not an easy task. Therefore, the proposed analytics translate KPIs with comprehensible indicators, called: Health Index (HI), calibrated against POF, and Importance Level (IL) derived from COF. In the case of HI, the analytics can generate discrete levels like “good”, “fair”, “poor” and “very poor”. For IL, since COF is the sum of direct and indirect costs of a failure (money), the output can be, for instance, discrete levels, like “low/average”, “high”, “very high” and “critical”.

When considering asset condition assessment solutions it is important to understand the differences between faults management and regular maintenance versus long-term asset degradation and financial planning [7]. Defects or faults are strictly linked to the condition of the equipment and its components, degrading or failing according to known failure modes. These faults affects operation and reliability of the asset throughout its life. However, the end-of-life of the asset is not directly depending on a defective component (if detected and fixed). Long-term degradation that ultimately contributes to asset end-of-life needs to be estimated with specific inputs and analytics which considers technical and financial factors like equipment obsolescence, spare parts availability, maintenance costs as well as asset performance. This degradation is usually expressed as Remaining Useful Life (RUL), which is not affecting maintenance planning, but together with HI and IL, is key for financial planning of replacement or refurbishment. This paper covers the risk analysis part, explaining how to calculate and use HI and IL, for MV switchgears.

## PROCESSES AND TECHNOLOGIES FOR AN EFFICIENT CONDITION ASSESSMENT

The implemented condition assessment process is composed of several steps shown in Figure 1.

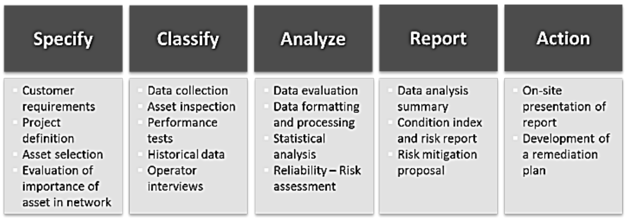


*Figure 1: Condition assessment process*

The first step, called “Specify”, is the definition of asset manager requirements for the assessment project. Main requirement is the asset selection (fleet). Moreover, at this stage the asset manager or plant manager provides inputs to determine the importance level for each asset (at least from a system point of view).

The second step, called “Classify”, let the assessor collect the required information to determine the asset conditions, like historical data, performance tests, inspections and operator personnel interviews.
For this second step, it is important to allow a reasonable level of flexibility and scalability because every application case might present different requirements. For instance, some cases require a full assessment with tests, meaning a switchgear shutdown; other cases require only observation and a lite inspection, without a shutdown. To cover most of the scenarios, the proposed solution offers three levels of assessment: off-site, on-site lite and on-site full.

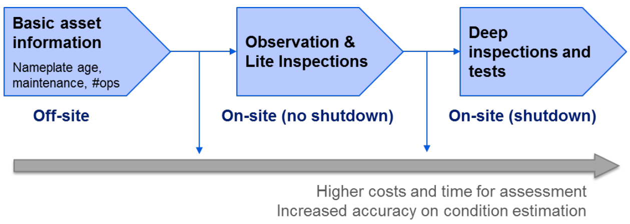


*Figure 2: Three-tier scalable assessment approach*

The sequence of actions of this second step, shown in Figure 2, lets the user choose when to stop according to the project requirements. Higher the level reached during the assessment, higher the costs and time spent, and higher accuracy on the estimated asset condition.
Every level contains a set of assessment questions or qualitative and quantitative inputs, called criteria. Quantitative criteria are for instance: last maintenance

date, age, number of operation, etc. Qualitative criteria lets collect information of the equipment on a certain aspect, which is linked to a potential failure mode, offering a set of simple answers, which makes the assessment as much as possible easy, fast and independent from the assessor, as shown in Table 2.

| Examples of assessment criteria for switchgear | |
|---|---|
| Installation type | • Indoor in switchgear room<br>• Indoor plant floor<br>• Outdoor walk-in enclosure<br>• Outdoor aisle-less structure |
| Ambient temperature | • Indoor (environment controlled)<br>• Group A (tropical 30°C)<br>• Group B (semi-tropical 25°C)<br>• Group C (sub-tropical 20°C)<br>• Group D (continental 10°C)<br>• Group E (cold temperature 5°C) |
| Shutter operation | • Checked and good condition<br>• Checked and visible wear and degradation<br>• Checked and extreme wear or broken<br>• Not observed |
| Handling and tools | • Checked and operational<br>• Missing or damaged<br>• Not observed |

*Table 2: Example of qualitative assessment criteria for a medium voltage switchgear*

The presented assessment solution let the user leave a criteria not set or "not observed". The analytics will judge the missing data depending on the criticality of the criteria in the given scenario. For instance, a not observed shutter operation during an inspection is more important than the not observed "handling and tools"; or, a not set "last maintenance date" is less critical when a circuit breaker is 4 years old than at 12 years old.

The assessment data needs to be collected in an easy and fast way, in order to reduce time and costs, as well as input errors. Therefore, an effective assessment process needs the proper tools. The presented solution enhance the flexibility of the process with state-of-the-art technologies: the user can choose freely among desktop, laptop, tablet and smartphone and switch from one to the other smoothly. In particular, for the assessment off-site (in the office) a desktop or laptop can be enough, while on-site the handhelds option is very comfortable.
The assessors' team can share the project assessment data and continuously enhance it adding and updating the information, as shown in Figure 3.
Even the software running on these hardware tools needs to be scalable and friendly guaranteeing a satisfactory user experience. The proposed solution let the user choose among several software technologies: a classic spreadsheet (mostly for desktop and laptop users), a web portal (usable on every device), an App (for tablet and smartphone).

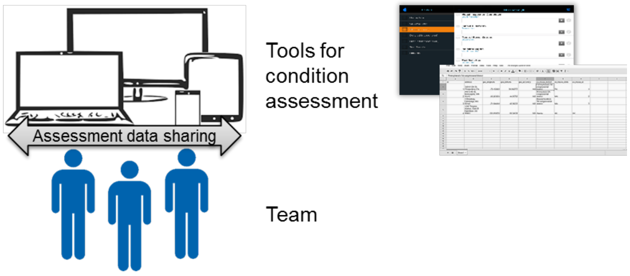


*Figure 3: Tools for condition assessment*

The proposed tools are equivalent from a functional point of view and the user can choose the preferred ones at every stage.

## DATA ANALYTICS AND REPORTING

Design knowledge, failure modes and causes experience are the base to create an efficient and effective data analytics for asset condition and risk analysis. Several books, like [8], and papers, like [9], suggest that assessment of power distribution system technical condition can be expressed, in general, in terms of dielectric, thermal, and mechanical aspects. This paper covers medium and low voltage distribution main equipment, like switchgears, breakers and relays. Therefore, the assessment and analysis considers also the following aspects: structural, instrumentation and protective functions, auxiliaries and accessories, safety and documentation.
Every aspects contains a set of input criteria collected during the assessment process. For instance, the "Close coil" condition refers to the auxiliaries/accessories aspect, the "Ambient temperature" impacts mainly on dielectric aspect, and so on. The proposed solution collects about 130 criteria, for each equipment class, mapped in the mentioned aspects.

The third step of the assessment "Analyze" checks and analyses the criteria towards aspects. For every aspect, the analytics calculate a health condition. Then the algorithm calculates the overall asset health index, weighing and summing up the aspects results, as shown in Figure 4.

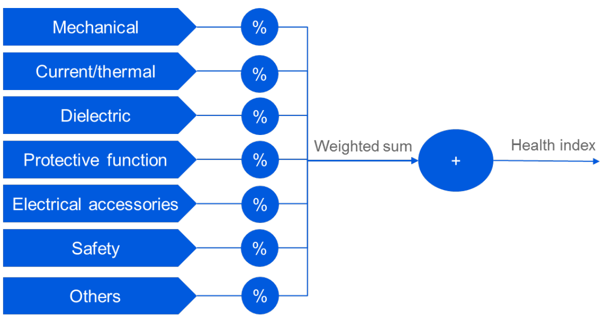


*Figure 4: Aspects evaluation for equipment HI calculation*

As said before, health index is an expression of POF therefore there are several ways to scale it. In this solution,

health index is a percentage value (0-100), where 0% means as-new or very good, while 100% means end-of-life or broken.
As an example, Figure 5 describes in detail how the analytics evaluate the mechanical aspects. For every belonging criteria, the algorithm analyses, scores and weights the input calculating a partial health indication. At the end, it sums up all these partial health indicators to calculate an overall aspect health value.

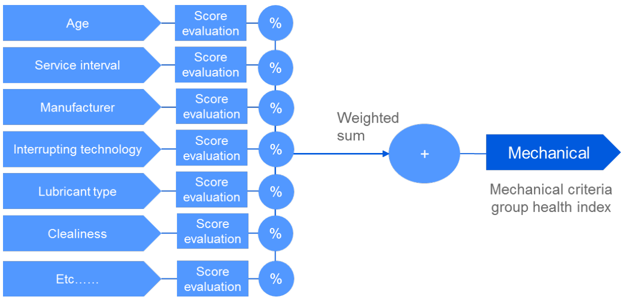


*Figure 5: Mechanical group of criteria*

The score evaluation for each criteria works as shown in Figure 6: an example of the cleanliness observation for the switchgear room. Every score might vary depending on other criteria, where there is a clear correlation among criteria and linked failure modes. For instance, the presence of dirt and dust in a humid environment will look different compared to an environmental controlled room.

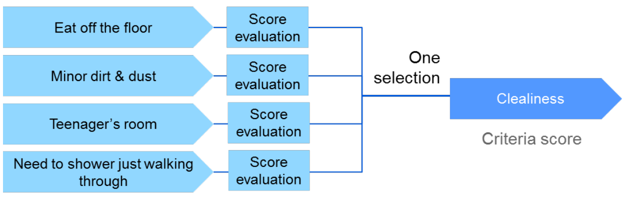


*Figure 6: Clealiness evaluation during inspection*

Once the asset health condition is calculated, the analytics have to match it with the corresponding IL, a representation of COF. In this solution, IL is a percentage value (0-100), where 0% means average or low importance, while 100% means critical asset. Figure 7 shows the algorithm schema to calculate IL, for each asset.

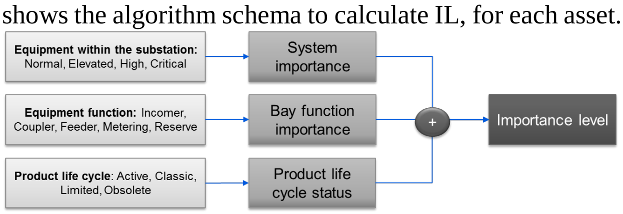


*Figure 7: Importance level calculation*

The three main pillars to calculate IL are the following: system importance of the asset within the substation or plant, the bay/equipment function, and the product life cycle. This last topic can be very critical because it represents the spare availability, repairing, and retrofitting possibility. Possible values are the following: "Obsolete" when the product is no longer manufactured and spare availability is not guaranteed; "Limited" if the spare and life extensions solutions are granted; "Classic" when the product and spare are still available, and "Active" if the product design and production are continuously enhanced. The algorithm scores and weights the three criteria, before summing up to calculate the overall asset IL.

The fourth step of the condition assessment process "Report" summarizes the risk status of the assessed equipment, suggesting mitigation actions to lower the risks. To tailor the report to the asset manager needs it is important to discuss the acceptable risk levels.
Figure 8 shows the main part of the report: a graphical chart about the assets risk, combining the estimated HI with IL. The colored areas gives immediately and indication of the asset risk level.

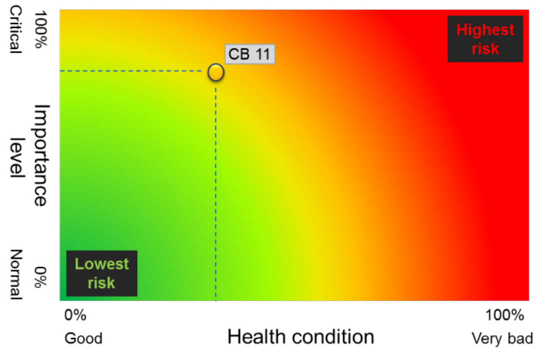


*Figure 8: Asset risk map*

The accepted level of risks (colored areas) and the risk map format is part of the project requirements. For instance, it would be also possible to use a risk map by levels, as shown in Figure 9. Every risk region has a color and the quantity of belonging assets.

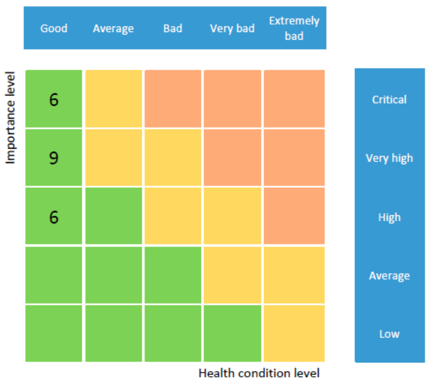


*Figure 9: Another example of risk map by discrete levels*

## APPLICATION CASE

For the sake of clarity, this paper considers only two examples explaining how risk is calculated and what might happen once a specific action mitigates the reported risk (step four and five of the risk assessment process).

The first example, shown in Figure 10 (left side), refers to two bays of the first medium voltage switchgear (bay 11 and bay 12) where three classes of equipment are assessed: circuit breaker (CB), protection relay (REL), and the metal-clad panel (SWG). Bay 12 is a main incomer, therefore with a higher IL compared to bay 11, which is a spare feeder. The condition of both panels (SWG11 and SWG12) is bad because both presented visible but correctable problems on the shutters.
The second example, shown in Figure 10 (right side), refers to two bays of the second medium voltage switchgear (bay 21 and bay 22). Both bays are normal feeders, so at a similar IL. However, both protection relays (REL21, REL22) have a much higher IL because they are obsolete (not anymore produced and with no guarantee about spares). A failure on one of the relay would cost a lot, since their repair or retrofit would take a lot of time (new relay selection, engineering, installation, wiring, commissioning, etc). Moreover, Bay 22 presents in general a worse health condition due to reported safety issues on interlocks and signalling lamps, which impacts on all the bay components.

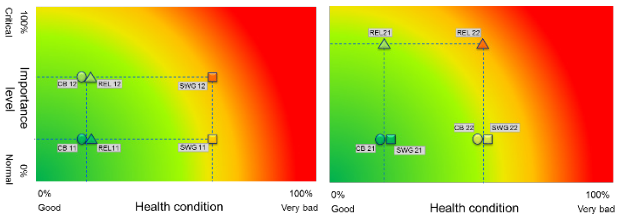


*Figure 10: application cases risk maps*

The report contains the risk evaluation as well as motivations, which drive the list of suggested mitigation actions, ordered by equipment risk. Figure 11 shows four mitigation actions: the first two actions (left) are about shutters repair, and let SWG11 and SWG12 health condition go to green level (like other bay equipment), the third and the fourth actions (right) is about protection relay retrofit with new ones.

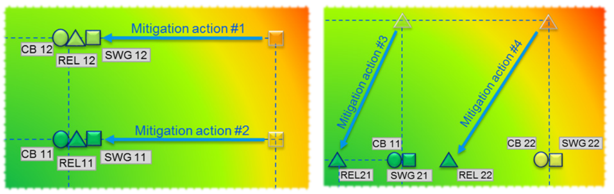


*Figure 11: mitigation actions on the risk maps (zoomed areas)*

Both REL21 and REL22 improve their health condition as well as their importance level. For brevity, the paper does not address the other mitigation actions of the report.

## CONCLUSION

State-of-the-art Information Technologies (IT) allows new efficient and smart way to address key aspects of asset management: asset condition assessment, risk analysis, maintenance planning and retrofit prioritization.
The proposed solution allows an easy assessment process with different data-entry tools: personal computer, tablet and smartphone; moreover, the user has a variety of software tools during the assessment: spreadsheet, web portal, and App. The data entry process is as much as possible objective and driven step-by-step.
The solution provides data analytics to elaborate the inputs, estimates the risk map and the mitigation actions, which can drive the asset manager to plan maintenance or new investments in new assets (retrofit or upgrade).
Moreover, the report helps the asset manager to change, if required, the maintenance approach, like the predictive-based, where a continuous monitoring of the health condition (e.g. with specific monitoring device and sensors) allows continuous risk control, guaranteeing high availability, reliability of the fleet, and safety.

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