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CIGRE JWG A3.43 progress report "Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems"

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SUMMARY

In March 2019 the joint working group A3.43 "Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems" started its activities with the goal to provide inside three years a guide on how to use the data from monitoring activities of switchgear.
The working group counts presently 34 members, from 17 different countries met already five times and work is ongoing on the main Technical Brochure (TB) structure as follows:

1. Executive summary
2. Introduction
3. Literature Review
4. Condition indicators of T&D switchgear
5. Tools and Criteria for lifecycle management and Switchgear Health Index
6. Compliance with digital substation for data management
7. User's experiences of end-of-life of T&D switchgear: survey, case studies and interviews
8. Future needs and trends

A literature review offers a glimpse into state of the art tools and techniques for lifecycle management and the equipment used. A very steep increase of publications on this matter is observed in the last years with implications in other aspects beyond lifecycle management. Second, the condition indicators as determined in the TB737 are taken over and used in this work as proxies for the switchgear variables evaluation.
The main part of the work concentrates on the tools and techniques their framework established. The works from other WG's on substation level on B3 study committees are introduced as an organic part of the activities. A fundamental decision has been made to follow Health Index concepts as defined in B3.48 concentrating on providing valuable inputs specifically for switchgear. The main focus is on Tools and Criteria for lifecycle management for which the target is to propose models which can condense the specific and deep knowledge of the members to arrive to an advanced and reliable assessment. Some concrete examples are planned to act as guidelines on how to apply the theory to real life scenarios.
The digitization of substation equipment is an ongoing process, which is radically changing how assets will be controlled in the substation. IEC 61850 is today the followed standard on which this automation revolution is based for operation and protection. Four members from study committee B5 are part of the group specifically to identify the potential benefit of a technology which has not been driven by

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monitoring. User experiences are under evaluation. Preliminary results, not presented here, have shown mixed opinions between use and necessity. Finally, the future trends identified so far are discussed. The role of condition monitoring systems as enablers for future developments in the networks is discussed.

KEYWORDS

Monitoring, Assessment, Condition Indicators, Lifecycle Management, T&D

INTRODUCTION

The joint working group A3.43 "Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems" started its activities in March 2019 with the goal to provide inside three years a guide on how to use the data from monitoring activities of switchgear.
The working group counts presently 34 members, from which 24 are regular and 9 corresponding from 17 different countries. The main background working categories are well represented with 41% vendor , 38% manufacturer, 12% Accademia, 6% consultancy and 3% certified testing laboratories. The team has met four times in person and once virtually due to Covid-19 restrictions. The stage is reached where the main TB structure is defined, and the chapters are drafted.

LITERATURE REVIEW

In the past, three CIGRÉ working groups analysed issues related to condition assessment of high voltage (HV) equipment:
TB 167 (WG 13.09) gives a general overview on the philosophy and application of condition assessment to HV switchgear. It does not focus on the analysis of the monitoring methods.
The TB 462 (WG B3.12) treats the issues related to on-line condition assessment in HV substations. The main conclusion is that information obtained from condition assessment can provide the relevant value for asset life management; the economic effectiveness however is not straightforward but can be demonstrated based on probabilistic calculations.
The TB 737 (WG A3.32) includes also condition assessment in medium voltage (MV) equipment. It treats as its main point several non-intrusive condition assessment methods (NICAM). It classifies them both according to the parameter to be monitored and to the technology used.
The A3.43 will be tightly linked from the works conducted in the A3.32 and B3.48 “Asset health indices for substations equipment”. From a conceptual viewpoint it shall bridge the gap between the condition monitoring methods and information generated by these and the final estimation of a health indices on switchgear level.
IEC 61850 is taken as the link between the real world of the condition monitoring methods and the digital world and ultimate representation of health indices. As extensive the IEC 61850 standard is, it is not described in detail, but only the relevant components that directly affect the tools and criteria.

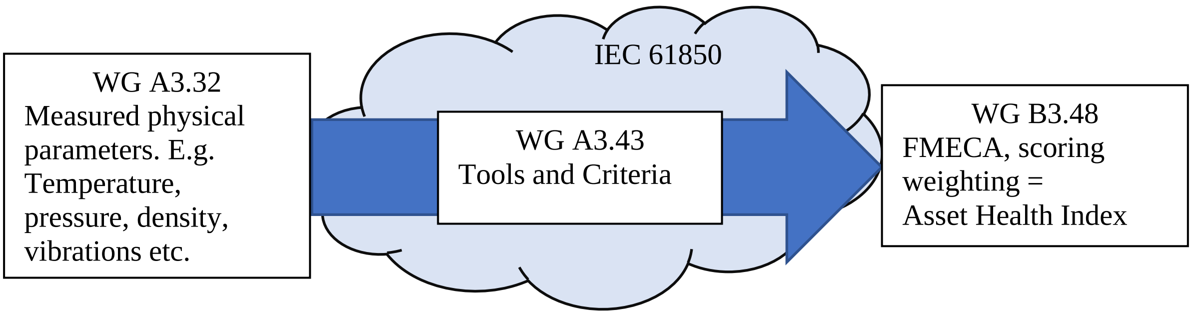

Figure 1. WG works and relationship among them

CONDITION INDICATORS OF T&D SWITCHGEAR

The CIGRE WG A3.32 presented a Circuit Breaker (CB) condition assessment process based on three stages starting by physical parameters measurements, followed by their transformations by specific diagnostic methods and the final interpretation within diverse decision support tools.

Figure 2. Threefold relationship between the switchgear, diagnostic methods and diagnoses [1]

The outcome of diagnostics methods is presented as condition indicators or symptoms, which are quantitative or qualitative parameters related to the condition of one part or one function of the switchgear. Even if some condition indicators use more or less specialized knowledge, sometimes complex, their interpretation are usually simple and straightforwardly comprehensible for switchgear technicians. These condition indicators are generally compared with acceptance values (thresholds) provided by international standards or by the CB manufacturer. If the thresholds are exceeded the condition indicator is to be considered as symptom [1], [2].

The ultimate condition assessment of switchgear would be obtained by an exhaustive internal inspection, requiring the dismantling of the switchgear. In this case one would gather complete and precise information about its real condition. However, this kind of intervention should be avoided, especially for SF_6 CBs due to high cost, environmental risks, and the possibility of errors during CB reassembling. Condition indicators provide indirect but essential information required for a proper CB lifecycle management. They include both measured values (obtained by maintenance process and monitoring) as well as observed values during periodic inspections and tests.

The purpose of this chapter is to review all known condition indicators, provide the definitions required to evaluate them from the raw measurements as well as the information to which function or part of switchgear they apply.

Switchgear aging modelling requires at least two kinds of parameter related to age (continuous wear) and to history of switching operations (discrete wear). Also, the condition indicators generally address these two ways of aging: the condition indicators related to age express the physical degradation: corrosion, mechanical strength and integrity, tightness, insulation, current carrying capacity, accessories, etc. and these related to switching operation history take into account the switchgear performance during the operation, dynamic electrical and mechanical integrity, contact wear, dielectric integrity of medium, etc.

The first group of condition indicators are mostly based on data acquired in continuous monitoring (e.g. trending or alarms on gas pressure or temperature, etc.) or periodic testing and inspections (e.g. visual observations, gauges reading, insulation integrity, PD, contact resistance, etc.). The second group of condition indicators are obtained during the switchgear operation. It could be done while the equipment remains in service or off duty. The basic indicator in this group is the history of operation i.e. the number and nature of switching operation (normal/fault condition) and derived cumulative I^2t for estimating the contacts wear. Several condition indicators are related to timing of operation, e.g. requirements for simultaneity of poles and series connected interrupter units [3], break times, make times, arcing times, pre-arcing times, etc. Other important condition indicators related to electrical performance of CB could be detected during normal operations such as restrike/re-ignition occurrence, multiple prestrikes occurrence in one interrupter, long delays between prestrikes within one pole, etc.

The CB operation follows a predetermined sequence of events of mechanical and electrical nature.

Condition indicators related to timing of operation are evaluated based on timing of these events and other related values.

If the CB operates off duty the electrical events do not occur. The sequence is predetermined by the mechanical events and, to a lesser extent, by electrical network condition (mainly voltage and current waveforms). For example, the prestrike will occur when the contacts are close enough and instantaneous voltage exceed the withstand voltage across them. The deviation (e.g. delay) of one mechanical event will eventually affect the remaining events. Modelling the course of the sequence based on known timing parameters and comparing it to the measurements (e.g. current making) would allow to find eventual discrepancies. Any incoherence in this sequence could be interpreted as potentially problematic condition of CB.

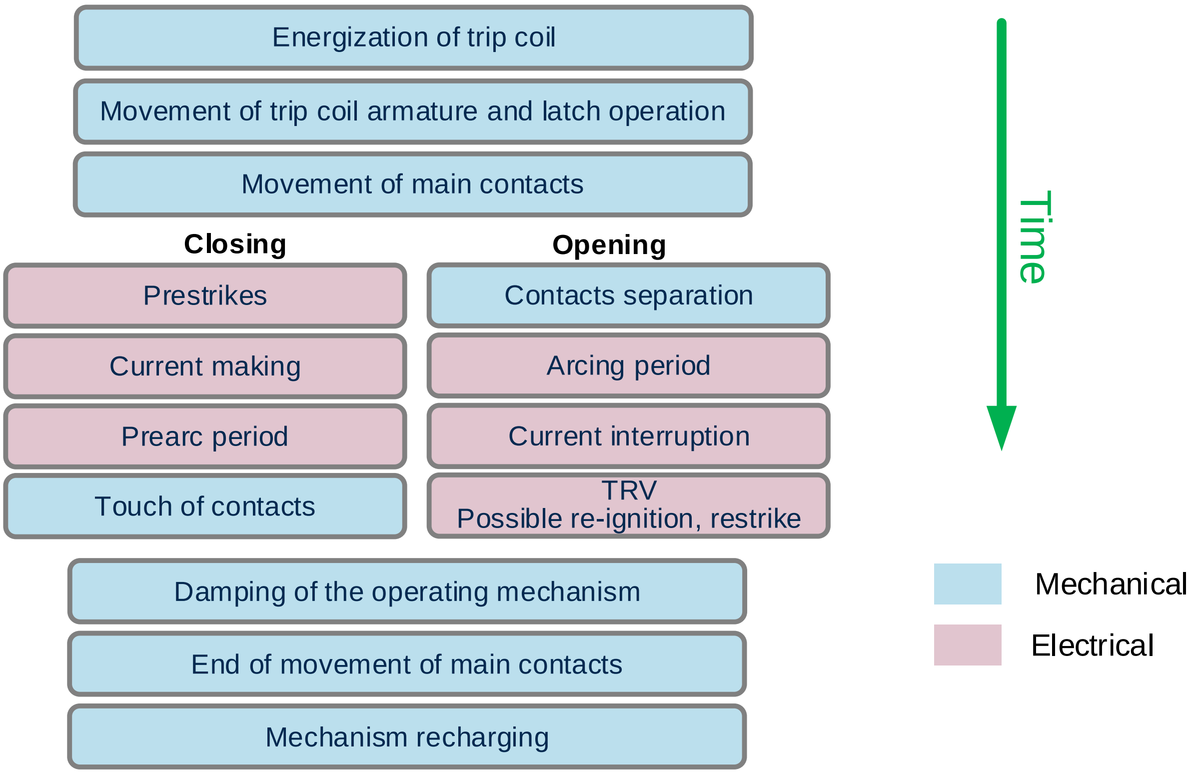

Figure 3. CB Operating sequence of events

TOOLS AND CRITERIA FOR LIFECYCLE MANAGEMENT

An asset lifecycle is the series of stages involved in the management of an asset. It starts with the planning stages when the need for an asset is identified and continues all the way through its useful life and eventual disposal.
The asset lifecycle can be tracked in different ways and is generally monitored in some way at every company, even if it is not always a formalized process. The importance of any given asset lifecycle is determined by a number of factors, including how costly is the asset to replace, how crucial it is to the business or company, and the overall reliability of the asset in question.
Also, the tools for lifecycle management should support the decision making process for investments into the primary assets at the right time into the asset lifecycle.
The basic premise of asset lifecycle management is to extend your assets' usability as far as you can, while maintaining its safe operation and without losing any functionality. Proper planning and management are essential to this process.
Great asset lifecycle management rests on four steppingstones. These include:

- initial and ongoing assessments
- data collection
- proposed plan creation
- integration across all assets.

As the topic of our working group is focused on switchgear, from here on in when we talk about assets, we are actually referring to high and medium voltage circuit breakers.

The purpose of this chapter is to build up on the notions defined in previous chapters, mainly on the condition indicators, and define a set of tools that, in combination with other economical and safety descriptors, can be used to analyse the asset lifecycle for making better informed decisions.
We have to acknowledge that different utilities and companies may be at different stages of implementation of an integrated asset management system as described by ISO 55000 and ISO 55001, or may not even contemplate any implementation in this direction. For this reason and to ensure the output of our working group covers all these cases, we will analyse the possibility of defining a minimum set of condition indicators that will still allow a basic lifecycle management implementation and also will discuss the optimal set of condition indicators for a comprehensive approach towards lifecycle management.
Following the identification of these sets of condition indicators for lifecycle management, we will focus on the data needed in this process.
We have identified the main categories of data that will be relevant for the process as follows:

- Data provided by equipment manufacturer(s)
- Measured values – data yielded by maintenance process and/or online monitoring systems
- Observed values – data gathered during periodic visual inspections, operational tests, etc.
- Reference data – values found in international standards (IEC, IEEE, etc.), best international practice recommendations (CIGRE, etc.), local knowledge (expert engineers), etc.
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Having now defined the data needed, the next phase is to identify how to use the data linked with the condition indicators to assess different functions of the switchgear.
As the amount of data collected is significant, we will also analyse the use of digital asset management platforms and their requirements for performing meaningful lifecycle management functions.
Following to above steps and to ensure the proposed approach is realistic and implementable, we will present workflows and relevant examples of how the system should be implemented and used.
In conclusion
From the arrival of a replacement or new asset, asset lifecycles affect every part of the business. When properly maintained throughout their lives, assets can bring an even greater return on investment than they do otherwise. When poorly maintained, they can negatively impact company resources and employees.
In addition, if companies are truly interested in implementing an overarching maintenance solution, an understanding of asset lifecycles is going to be an integral part of a preventive maintenance strategy.
Finally, asset lifecycles, when properly managed, can be a wonderful tool to increase the operational safety, return on investment, total productivity, worker satisfaction, and more.

COMPLIANCE WITH DIGITAL SUBSTATION FOR DATA MANAGEMENT

The digitalization represents the main electrotechnical revolution of the present years which is changing the way electrical assets are going to be designed and managed. Although the monitoring of switchgear is primarily a retrofitting activity, it is crucial to have a system which is ready to comply with the coming digital substations. This is the reason why we invited some members of the study committee B5 to join and support the working group A3.43.

The target of this chapter is providing an introduction into Digital Infrastructure in a substation and how a switchgear monitoring system should be best integrated in it.

The chapter will start with an overview of what kind of equipment is included in a digital substation (Fault recorder, IED, Point of Wave Switching), comparing distributed vs. centralized architecture.

Test Equipment Interface, Value update: Periodic measurement vs. Continuous measurement values, Hardware / SW (logical nodes) will part of the explained concepts.

A short description about legacy equipment and how to deal with them from protocol viewpoint.

Center point is here the IEC61850 standard, which from its introduction about 15 years ago became rapidly the “reference” to interpret the substation automation challenge.

A subchapter will be dedicated to this topic with the aim to introduce IEC 61850. targeting switchgear experts who have not heard anything about this standard before.

After reading this chapter they should know about the structure and design principles of IEC 61850 and the differences to other digital infrastructure implementations.
Attention will be focus on elements in IEC 61850 which relate to condition assessment on switchgear, bringing clarity to concepts like Logical nodes for switchgear (XCBR, XSWI) and Logical nodes for supervision and monitoring (SCBR, SSWI).

The topic Additional features/nodes outside the switchgear will be also threated.

Taking as reference the condition indicators described in Chapter 4 needed for condition assessment on T&D switchgear, an analysis will try to identify and describe any deltas between what is already defined in the standardized interface and what is still missing.

AN outlook will be also given to Future developments related to T&D switchgear assessment in the area of digital substation data management like wireless technologies, 5G, IoT, already integrated sensors coming from the manufacturers.

Some example of the state of the art of digital substations which are in operation using digital data management systems for condition assessment on T&D switchgear will provide the reader with some input about "lessons learned" in these projects.

USER’S EXPERIENCES OF END-OF-LIFE OF T&D SWITCHGEAR: SURVEY / CASE STUDIES / INTERVIEWS

In order to know from firsthand, which type of tools for lifecycle management for T&D switchgears based on data from condition monitoring systems, a series of interviews were carried out on several utilities and TSO from different parts of the globe. During the interviews, the bullet points below were discussed.

- Monitoring systems (on-line and/or off-line)
- Maintenance strategy
- End-of-life decision
- Asset performance process
- Future trends

The following lines describe a brief summary of the topics discussed.
Monitoring systems is not a new subject for all the interviewees, in fact all of them have had some experience using them. Nevertheless, is fair to mention that, most of interviewees said that they have installed on-line monitoring systems only on critical assets and high-value assets with strategic importance. A common statement mentioned is that the asset lifetime, exceeds at least by factor of 2, the monitoring system lifetime. It provokes that the monitoring systems components get obsolete and generate false alarms, therefore it has to be either disabled or disconnected. Interesting enough, most of on-line monitoring systems are installed on power transformers and very few of them on GIS.
In contrast, off-line monitoring is regularly done. In fact, it is closely linked to the maintenance strategy. The maintenance strategy is designed according to each company philosophy. However, at the end, it relies on time-based maintenance or condition-based maintenance.
Mainly, the end-of-life decision is driven by the asset age. Obviously, there are cases where this decision is driven by the asset condition. But generally, the lifetime for an asset is estimated on average for 40 years, or even 60 years for GIS. Regarding the secondary equipment, it is replaced after 20-25 years of

service. The asset performance process is different from every company, each one has its own rules, parameters, and calculations. It is very dynamic because continuously is improved due to new learnings, new experiences and so on. It is valid to mention that it is a complicated topic with difficult answers.

FUTURE NEEDS AND TRENDS

The future needs and trends of six months ago were very much different than the ones today in a world hit by a global pandemic. The fundamental approach in this chapter is the discussion in the field of tools and techniques for lifecycle management of the ongoing and future trends and the identified future needs which are not necessarily the same. A technology or methodology that is trendy today might not be in several years. A necessity identified today might become a requirement in the future.

The chapter has a top-down approach starting from the electrical network, going through the tools used in lifecycle management and ending in the experts.

On the electrical network level, the trend of maximizing asset usage, increasing the risk and narrowing margins is discussed under the light of condition monitoring and life management. The impact of variable renewable energy sources (VRES) on the power system stability and the role of automation in the reaction times assessed. The asymmetry in the digitization of operation centres down to substations and ultimately to single assets is reviewed.

Tools-wise, an exponential growth of works in the field of Artificial Intelligence (AI), Machine Learning (ML), augmented reality, evolutionary computing, digital twins, etc. is observed since 2000 with almost half of the works dedicated to the energy industry. The integration of these tools in all the different levels from the asset until the final user is reviewed.

Finally, the ultimate actionable decisions on the assets will be taken by the experts. But who or what will be the experts in 10, 20, 50 years? Today a decline in interest in the study of Power Systems across Universities is observed. More trendy topics such as renewables, electro-mobility and others are adsorbing the students and future experts. At the same time, the AI revolution is gaining speed and training advances computing systems to take decisions before relegated for humans might be the only path that it will be naturally followed.

The chapter closes with the identified gaps during the WG works. Gaps that are not addressed in the WG, yet relevant for future studies.

CONCLUSION

Thanks to the active contribution provided by different members, the working group is proceeding further with the aim to provide a practical support for asset managers how to best use the monitoring and diagnostic data collected with either continuous monitoring as well as periodic diagnostics. Proceeding with this pace there is a good chance to respect the deadline to offer a Technical Brochure by the end of 2021.

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