On-line condition monitoring importance and evolution

N. L. Fantana
ABB Corporate Research, Germany

Abstract

In recent years there has been an increase in the availability of on-line condition monitoring devices and systems and of monitoring installations in utility networks. Their installation is judged considering a lot of factors including: general utility strategy, expected value from such an installation, asset and risk management, utility best practices, economic, environmental or regulatory pressures, and will vary from one utility to another. What is the present experience, the value from on-line condition monitoring and what are the opportunities and challenges in future grids and considering modern technologies? The paper intends also to position on-line condition monitoring in life strategies and point to evolution and international activities related to the topic.

1. Introduction

How to reduce equipment failure and minimize consequential costs? This is a key issue in utilities and for all power equipment users. Presently a set of factors come together contributing in various ways to make the situation in utilities especially challenging:

- Aging network equipment, average age is continuously growing, 30, 35, 40..
- Economic constraints in utilities
- Required high availability of power supply.
- Increased loading, go-to-the-limit situations
- Changes in power flows, especially due to distributed generation,
- The need to know - if possible instantly, in real time - the situation in the network and status of the equipment.

Increasing efforts have been done to respond to these challenges by advancing diagnosis and monitoring research, by using diagnosis and on-line condition monitoring (OLCM), by having internal utility strategies for asset management or for installing and using OLCM systems. Installation of OLCM systems has been done with new power equipment installations, but also for aged power equipment still in operation.

It is important to position the OLCM in an integrated life concept, to understand the failure mechanisms and evolution of failures and to highlight the value and importance of OLCM systems for an utility.

2. OLCM and degradation detection

Degradation occurs over power equipment lifetime under normal operation and in case of special events. A simplified, principle example is shown in Fig. 1. It is considering both the changes in the condition of equipment versus time, the blue condition curve, and the related costs to restore the equipment condition, the red cost curve. The degradation starts at point S and is detectable at point D in time. The detection in D should allow reacting before failure occurs. The reaction time available to act should be less than the time from degradation detection to failure t_DF. The longer this time the better additional actions such as additional diagnostics to get more details or better localize problem, perform maintenance or major repair can be planned and executed. The earlier the detection of degradation is the lower the cost to restore equipment condition and to limit the damage in the network. The degradation detection point is continuously evolving with technology and knowledge.

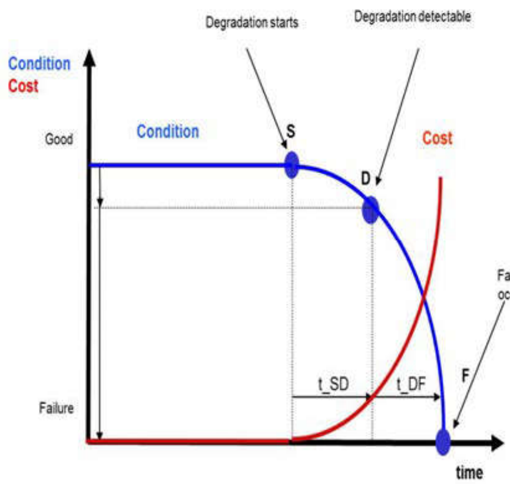

Fig. 1 Principle view of degradation and costs to restore equipment condition

Depending on the equipment or subsystem and the physical / chemical degradation mechanism, the materials used, construction details, etc., the time from detection of degradation to failure occurrence, can be very different. Cases exist where we talk about few hours from detection to failure but also cases exist where it can be considerably longer. Such rapid evolution times can only be handled by on-line condition monitoring.

The degradation evolution shown in Fig. 1 highlights the importance of detection of the condition degradation as early and as precise as possible, such that a meaningful action can be taken by operator or maintenance team to minimize damage to the electrical equipment and network. Early detection and precise detection are both challenging and contradictory. Efforts are needed to avoid false alarms. A continuous monitoring can be decided and put in operation after considering a set of factors such as: actual network and economic constraints, the equipment condition, the time constraints regarding replacement or spare provision, the importance of the unit and the length of the time from degradation inception to failure,

OLCM is a good mean supporting degradation detection and failure avoidance, however at best it should be integrated in a holistic context considering equipment and network. Such a strategy for asset supervision and management has to consider beside economic aspects i.e. the importance of the equipment in the network, the condition of the equipment. Such condition related information can be derived based on few major information pillars, such as: equipment history, e.g. operation and maintenance, information from diagnosis tests performed, information from OLCM systems, expert knowledge and manufacturer's expertise, Fig. 2.

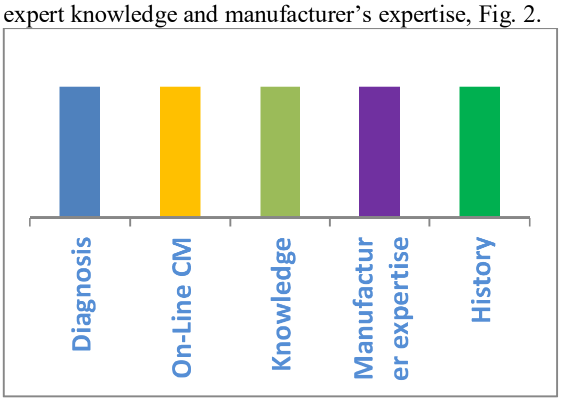

Fig. 2 Positioning of OLCM in an integrated life concept for asset management

Statistical information is also important to get feedback from installed equipment and to set priorities of deeper analysis or research and development of diagnosis and OLCM methods, devices and sensors for degradation detection and avoidance of failures. An excerpt from failure statistics for power transformers is shown in Table 1, [1],[2]. Failure statistics show themselves an evolution over time and have intrinsic uncertainties depending on the available data sources, still can give a good picture. The results of the recent, transformer failure survey from CIGRE, from about 1000 heavy transformer failures from 1996-2010, see column "CIGRE2012" in Table 1, show an increase of the winding failures compared to previous statistics, an approximately constant percentage of core failures from total, some increase in tap changer failures, and a varying evolution in bushing failure. They hint to the necessity to increase effort in diagnosis and monitoring to consider active part and insulation for diagnostics however continue efforts on monitoring and diagnosis of other major equipment parts like bushing or on-load tap changer are needed too.

Similar statistical data exist for other substation equipment and recent publication of CIGRE study committee A3 gives information for high voltage equipment such as circuit breakers and GIS [3]. OLCM is applied to such high voltage equipment too, however taking into account specific degradation mechanisms and monitoring requirements.

Table 1

	CIGRE 1968-78	Doble 1993-8	CIGRE 2012
Winding	19	43	49
Core	3	4	3.7
Bushings	12	19	13.6
OLTC	12	10	23

2. OLCM and Value

Importance of OLCM is given by the value obtained by applying it for the supervised equipment asset and for the whole electrical network.

The aspect of "Obtaining value from OLCM" was addressed in detail by the CIGRE working group B3-12 [4]. One important aspect which has been investigated was to identify the main drivers to install condition monitoring. The results found are shown in Fig. 3. Cost saving as the major driver was expected, however company image is noticeably the second highest motivation, and it is linked to supply quality, reduced outages and customer satisfaction.

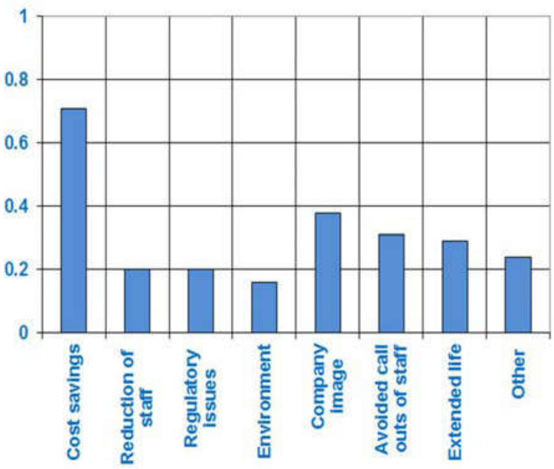

Fig. 3 Main drivers in utilities to install OLCM

Maintenance cost reductions and reduced call out of staff are also important especially in cases where distances to installed equipment are long and terrain is difficult. The extension of life although on rank 4 is often encountered in practice as a typical case of monitoring. A unit is often kept in operation, supervised by a monitoring system, e.g. until replacement unit or part becomes available. Finally, regulatory aspects can play an important role especially when they may require monitoring installations for important equipment for improved network operation.

Another important aspect regarding OLCM systems is related to the question where the value/benefit of such a monitoring installation comes from. How this aspect is perceived by utility experts, according to the mentioned survey, is shown in Fig. 4. The highest value is perceived from medium-term activities. One such situation could be for example change of maintenance practices, e.g. going away from the time based to a condition based or risk based maintenance.

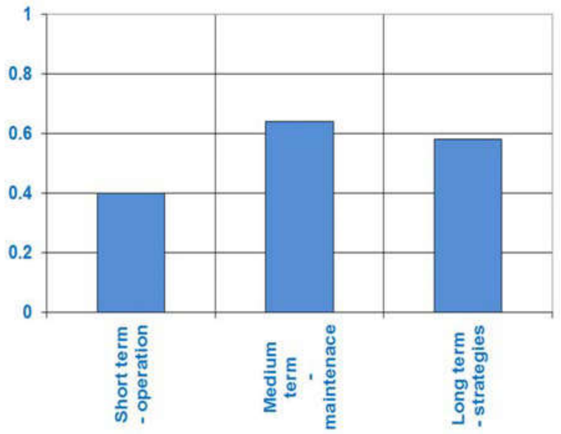

Fig. 4 Value from application of OLCM

Second highest value from OLCM was perceived in the long term aspects related to replacement of units, long term strategies and planning, as well as in accumulating internal knowledge related to equipment long term behavior and failure. Also, value from OLCM has been found in support for operation, especially by supporting immediately operational decisions and using better actual equipment capabilities. Some utilities are considering OLCM similar to having supervision by a (virtual) person on site 7 days a week x 24 hours a day, and see the benefit of OLCM systems in the fact that they can detect and inform timely, do not need humans on site and get info from distributed locations across the electrical network. In most cases the data from monitoring system is used as an early warning. The warning can then triggering diagnosis or more detailed assessment of the equipment condition based on all life data and knowledge and expertise available. The OLCM system is best positioned as an integrated part of the utility strategy for life long asset management, maintenance and operation support. There are few concerns related to OLCM too. One concern is related to the much shorter life of a monitoring system versus the life of primary equipment such as transformer or circuit breakers. This has to be considered in relation to the life and maintenance of such a system and sensors to keep its required functionality for decades.
Secondly, there is the problem of the considerable amounts of data which can be accumulated over long periods of time. This problem is requiring ways of systematical data storage, and methods for the analysis of collected data of processing and extraction of relevant information. The access to on-line data or historical data is leading to another problem related to access do data during operation, on the necessary rights and mechanisms needed in the organization and the information technology (IT) infrastructure. The access data and the access rights have become critical especial after year 2000. These are linked to the cyber security and are intensively discussed and considered in utilities and on country level. Access and use of data from monitoring, together with data from operation is technically meaningful, however not easy to achieve. Important is especially to have secure network operation, secure operation of the protection and control systems, without being disturbed in any way, even accidentally by the OLCM users. All these are guided by utility IT security policies and restrictions.
The OLCM system is perceived as bringing value but still as an valuable “add on” in most cases. However the trend is toward considering OLCM system as a sort of basis system a s sort of “insurance”, giving an early warning and helping to avoid unplanned outages and major failures.
It is difficult to estimate a priori the value of and OLCM installation. In [4] a set of methods are indicated , which can help estimate this for an OLCM project.

3. Evolution of OLCM

The OLCM systems are evolving and evolution is driven mainly by

- The evolution of the grids and requirements
- Evolution of user expectations and constraints
- The evolution of microelectronics, information, communication technology (ICT), sensing and other enabling technologies.
- Evolution of the equipment and degradation knowledge and data analysis.

Evolution related to the future grids with their increased complexity, changed operating conditions e.g. in terms of unpredictable and strongly fluctuating power flows, more use of power electronics, are expected to require more real time supervision. Additional processing, storage and communication functionality and also sensing capabilities are expected to be required e.g.in terms of processing the collected information local on the monitoring device.
Expectations of the user are also continuously evolving. In a recent CIGRE survey [3] user expect in few years a significant move from the present situation where a substation equipment expert is analyzing the data, towards more automatically processing data and involving a specialized condition monitoring expert more strongly in the process.
Evolution in OLCM will come also from technology advances like microelectronics and microsensing or communication and IT. Such advances will have a considerable impact allowing new and more precise sensors, additional processing and storage capabilities, better communication and integration in the substation environment, sharing data with the substation SCADA system or with the utility central system. The

monitoring systems will allow continuous access to information from power devices and inform the network operator, maintenance team or other utility group specified, as well as feeding central utility data stores with desired data. How a group of experts see the role and position of OLCM in future network is shown in Fig. 4, based on a survey [5].

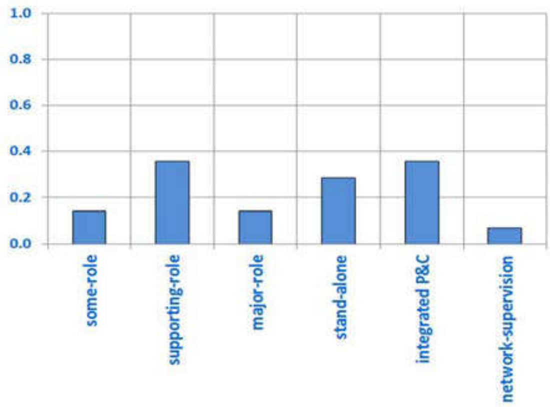

Fig. 5 Role and position of OLCM in future network

An essential evolution factor in OLCM will come from the increasing knowledge on degradation phenomena and materials. Also advanced data analysis algorithms will contribute to make good use of collected data.
Other possible changes could stem from the integration of some basic monitoring functionality in the protection devices or on substation and network level. Such a so-called network monitoring has been described in [4] allowing an integrated look at a network wide phenomena by using all available installed network supervision or recording devices, however it requires a considerable effort in collecting, storing and processing of data from the whole network devices.
In the view of the WG B3-12 [4] OLCM is expected to play an important and central role in future grids.
However there is also a downside of growing condition monitoring and supervision, and there are some challenges and aspects to be considered:

- lack of skilled personnel to deal immediately with a large number of such systems
- organizations difficulties to deal with the huge amount of data which can easily be collected,
- security regarding accessing and using the monitoring data, cyber-security aspects,
- dealing with lifetime aspects and integration.

The evolution and status and best practices regarding on-line condition monitoring systems are subject of investigations and work in various international organizations. Such activities in committees or working groups are fully dedicated to on-line condition monitoring or contain parts related to OLCM. Some activities in CIGRE and IEEE dealing with on-line condition monitoring are mentioned below including their status, as examples of activities related to OLCM and without claiming completeness:

- CIGRE WG B3.12 “Obtaining value from substation on-line condition monitoring”, finalized, [4], TB 462, 2011;
- CIGRE WG B3.26, Guidelines for the Design and Construction of AC offshore substations for Wind Power Plants, finalized, TB 483, 2011, considers monitoring aspect for this special situation;
- CIGRE WG A2.44, Transformer intelligent condition monitoring, work ongoing, expected technical brochure 2014;
- IEEE PC57.143, IEEE standard, Application of Monitoring of Liquid-Immersed Transformers and Components, finalized, published 2013
- CIGRE WG B2.36, Guide for Application of Direct Real-Time Monitoring Systems, finalized, TB 498, 2012, considers real time monitoring of overhead lines, mainly the “ampacity” aspects.
- CIGRE WG B5-05, Modern Techniques for Protecting, controlling and monitoring power transformers, finalized, TB 463, 2011

Interestingly the number of CIGRE working groups dealing with monitoring grew from 2, before 2000, to 11 after year 2000, showing a considerable increase in the interest towards monitoring of power equipment.

4. Conclusion

On-line condition monitoring systems are an important element in present networks and will play an important role in future grids in avoiding failures, reducing costs and allowing a reliable operation. Monitoring and diagnosis are both essential parts utility asset management and life strategies. The value of OLCM is in most cases seen as a support for decision making. In case of medium and long term strategies decision support comes from combining for decision support information on the network and from operation and events, use OLCM information, performed diagnoses and maintenance over time. The more experience will be accumulated by the world-wide engineering community the and the more major failures will be avoided, the more the question of importance and value from on-line condition monitoring will get an positive answer.

5. References

[1] S.Tenbohlen et.al. Trends of the Diagnosis of High Voltage Equipment, ETG 2012, Fulda, 15-16 11.2012, ISBN 978-3-8007-3465-8

[2] A. Wilson, personal communication

[3] C. Sölver, M. Runde et.al, “Final report on 2004-2007 International Enquiry of High Voltage Equipment”, CIGRE TB 509, 2012

[4] A.Mackrell, N.Fantana, et.al. , “Obtaining value from on-line substation condition monitoring”, CIGRE TB 462, 2011

[5] N.Fantana, et.al. , Expert round table IEEE-CIGRE on OLCM, IEEE PES Substation meeting, Raleigh, 2012