EXPERIENCES AND NEW DEVELOPMENTS WITH CONDITION BASED MAINTENANCE IN THE NETHERLANDS

T.G.M. van Rijn
Ksandr / Nuon Tecno – The Netherlands
Theo.van.rijn@nuon.com

Jos H.M. Slangen
Ksandr – The Netherlands
Jos.slangen@ksandr.org

Frank S.W.de Vries
Ksandr / Nuon Tecno – The Netherlands
frank.de.vries@nuon.com

INTRODUCTION

Ksandr is an independent international organisation that supports Assetmanagement in making well considered decisions. For Utilities in the Netherlands we have increased the knowledge about asset behaviour by sharing experiences and sharpening the knowledge rules. Our participants collect and share measuring data on asset belonging. Our specific knowledge- and failure platforms gives the participants the opportunity to meet and exchange experience and practice knowledge. The three subject in this paper cover experiences with condition based maintenance:1) Optimization of maintenance of 10 kV infrastructure though condition based maintenance, 2) A methodology for determining critical spare parts of 50kV minimum-oil circuit breakers by cooperation of Dutch utilities and industry and 3) Evaluation of improved knowledge rules for determining partial discharges in medium voltage cables including statistical analysis is discussed.

1. OPTIMIZATION OF MAINTENANCE OF 10 KV INFRASTRUCTURE THOUGH CONDITION BASED MAINTENANCE

ABSTRACT

This paper describes experiences of implementing condition based maintenance developed by Ksandr with NUON and their customers in the Netherlands. An investigation for determining the most adequate maintenance program for different type of equipment in the 10 kV grid has been carried out based on Failure Mode and Effect Analysis, failure data analysis, experience of the end customer with respect to the equipment in use and best practices of other utilities and industries. A conditioned based maintenance program has been developed for the coming 20 years expecting a cost reduction of about 30-50 % in maintenance depending on the type and use of the equipment.

1.1 introduction

Due to ever increasing pressure to reduce costs, the utilities and industries look for ways to find an optimal way to perform maintenance on the assets without a decrease of the reliability. In principal there are two methods: corrective maintenance (restore after a failure) and preventive maintenance (maintain functionalities). The last method can be divided into time-based, user-based and condition based. The optimal maintenance program depends also on the type of the equipment, the experiences with respect to failures, the conduct of business, the accepted out of service time.

One of the most important aspect where service providers have to deal with, is the 100% availability of the manufacturing plant and short- or no possibility to take the equipment out of service in order to perform inspections and maintenance. Therefore implementing of on-line diagnostic methods in a maintenance program become very crucial.

1.2 Availability and customers

By optimizing the maintenance of the assets in most situations we have to deal with several aspects.
First the type of the components to be maintained. It is necessary to know the major and minor failure mechanisms. This can be achieved by sharing field data with different users, collecting historical and failure data and specific data of the customer and results of activities of specialised research centres. A second issue is the type of customer. In principal customers can be divided into different classes all with their own characteristics: 24h/7d production plants with stops every x number of years for overall maintenance activities, season-dependent industries such as groceries farms and fun fairs with stops out of the season period, 9h-17h customers with maintenance only after business hours and 9h-17h customers without any restrictions.

In the figure 1.2 the relations between assets, customer and type of maintenance is presented.

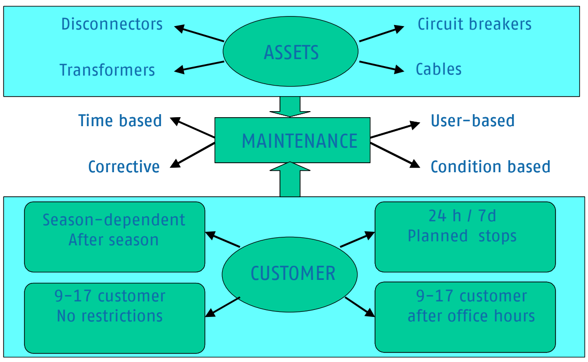


Figure 1.2 Relation between customer, assets and maintenance.

In principal the maintainability and the optimization of the maintenance is mainly determined by the availability of the assets and therefore determined by the type of customer.

1.3 On-line quick scan

On-line techniques become more and more crucial in the optimization of maintenance on technical equipment. In the last decade a great step forward has been achieved in the development and interpretation of the results of those techniques: 1) on line partial discharge measurements, 2) infrared inspections, 3) oil analysis and 4) visual inspections. Because the on-line inspections are cheap compared to a complete revision, in general these inspections (or a certain part of it, depending on the type of component) are performed each 2-3 years. It appears that about 85% of the failures in the MV grid have to deal with failures in dielectrics (such as oil, epoxy resin, paper) and failures in the primary system. The dielectrical failures are mostly attended with partial discharges. UHF and/or acoustical detection techniques are available for measuring the PD activity and interpretation based on the increased experiences, knowledge criteria becomes more and more available. Thermographic inspections are more and more used in the MV and HV systems and therefore the knowledge of the failure mechanisms of the MV and HV components has increased.
To decide what is the optimal way to maintain a certain type of component the experiences of different users is shared. in a Failure Mode Effect (and criticality) Analysis. To decide if the components have to be taken out of service for maintenance depends on the knowledge of the major and minor failure mechanisms and the possibility to determine the condition using on-line detection techniques.
After setting the specific knowledge rules for each failure mechanism which can be diagnose, condition codes can be generated as shown in figure 1.3.
a) code 9, the component is in an acceptable condition. For circuit breakers it is advised to perform a simple functional test. A new on-line inspection is scheduled.

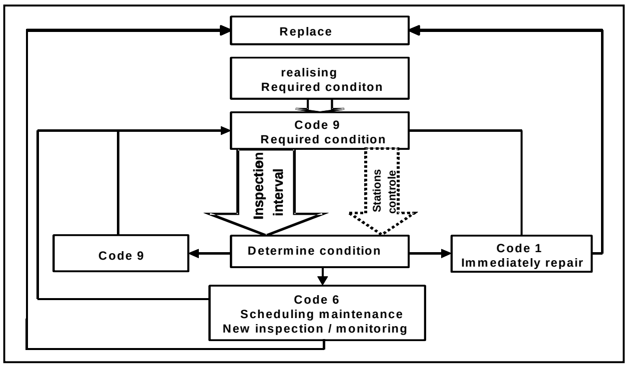


Figure 1.3 Process to generate condition

b) code 6, the condition of the component is suspicious.
c) code 1, the condition of the component bad. The chance of an outage in the near future is realistic. The component has to be taken out of service immediately and maintained. If the required condition can not be realised through maintenance or overhaul, the component has to be replaced.

1.4 Case: 10 kV grid of University of Nijmegen

The 10 kV grid of the University consists of 36 MV substations. In the following table an overview is presented of the different type of components that are used and the time intervals that are normally used in a time based maintenance program.

	# bays	interval [yr]	age
Circuit breakers			
Minimum Oil 1	7	3	1965-1970
Minimum Oil 2	7	3	1970-1975
Minimum Oil 3	1	5	1970-1975
Vacuum 1	6	10	1995
Vacuum 2	15	10	1995
Disconnectors			
Disconnector 1	16	5	1970-1985
Disconnector 2	11	10	1965-1970
Transformers			
Transformer oil	44	10	1965-1990

The history of the components is not available in detail. The experiences of the grid owner was that no major failures did occur in the past 5 years. The components are used equally with respects to e.g. the load and switching activities and the installations are equally critical with respects to the processes.
No maintenance was performed for more than 20 years and so it was unknown if there was a question of lack of maintenance. After a short investigation it became clear that the environment played a major role in optimizing the maintenance. Especially the contamination of dust and moisture and the way of ventilation had a big influence on the condition of the components, especially the disconnectors and minimum oil circuit breakers.
After the quick scan (PD, DGA, Infrared and visual inspection) every single component was labelled with a condition code 1, 6, 9 and unknown if the condition can not be measured. The components in the unknown-category were maintained in standard way and have to be maintained so in the future. The components in the categories 1, 6 and 9 were maintained as explained earlier in this document. To be sure that the approach is reliable, 10-15% of all the components in category 9 were maintained in a standard way. From these results it appeared that the components received the right condition code by the quick scan. For many components it was possible to extend the time interval for the following inspection by optimizing the environmental condition with respect to contamination, dust and heating.

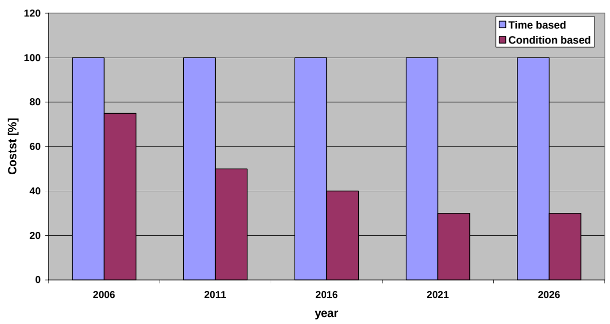
In the following table an impression is presented of the results of the condition codes, the maintenance needed and the optimal time interval for the next inspections.

Substation	Object	Remarks	visual inspection 04-2006	Infrared 04-2006	PCB	Uitgebreid onderzoek	DGA, physical	Function test	Conditioncode 07-2006	Maintenance	year
SKU nijmegen faculteit A											
BIBLIOTHEEK H0281	MS installation disconnector 1	clean, dry	9	9	9	9	9		9		
BIBLIOTHEEK H0281	10/0.4 kV Transformer	high temperature in tr-box	6	9	9	9	9		6	Monitoring	2007
BIBLIOTHEEK H0281	10/0.4 kV Transformer	DGA thermal fault (T 150-300 C)	9	9	9	9	6		6	new DGA sample 1/2 year	2006
GEBOUW 2 H0548	MS installation disconnector 2	pollution of surface, dry	6	9	9	9	9		6	complete overhaul disconnector	2007
GEBOUW 2 H0548	10/0.4 kV Transformer	polution of ventilationgrid	6	9	9	9	9		6	Cleaning ventilationgrid	2007
GEBOUW 2 H0548	10/0.4 kV Transformer	polution of ventilationgrid	6	9	9	9	9		6	Cleaning ventilationgrid	2007
GEBOUW 1 H0548	MS installation disconnector 2	incorrect position of disconnector	1	9	9	9	9		1	Replace disconnector	2006
GEBOUW 1 H0548	10/0.4 kV Transformer		9	9	9	9	9		9		
PSYCHISCH LAB H050	MS installation disconnector 1	clean, dry	9	9	9	9	9		9		
PSYCHISCH LAB H050	10/0.4 kV Transformer	pollution oil	6	9	9	9	9		6	Monitoring	2007
PSYCHISCH LAB H050	10/0.4 kV Transformer		9	9	9	9	9		9		
CURATOREN H021	MS installation disconnector 1	polution of surface	6	9	9	9	9		6	complete overhaul disconnector	2007
CURATOREN H021	10/0.4 kV Transformer		9	9	9	9	9		9		
CURATOREN H021	10/0.4 kV Transformer		9	9	9	9	9		9		
TALENGEBOUW H0511	MS installation vacuum CB 1	polution of surface; little discharge tracks visible	6	9	9	9	9	9	6	cleaning surface; optimization of environment	2007
TALENGEBOUW H0511	10/0.4 kV Transformer	polution of ventilationgrid	9	9	9	9	9		9	Cleaning ventilationgrid	2007
TALENGEBOUW H0511	10/0.4 kV Transformer	polution of ventilationgrid	9	9	9	9	9		9	Cleaning ventilationgrid	2007
TALENGEBOUW H0511	10/0.4 kV Transformer	polution of ventilationgrid	9	9	9	9	9		9	Cleaning ventilationgrid	2007
TALENGEBOUW H0511	10/0.4 kV Transformer	polution of ventilationgrid	9	9	9	9	9		9	Cleaning ventilationgrid	2007

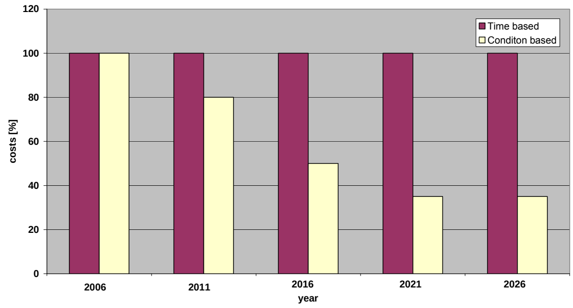
1.4.1 Cost reduction

The failure mechanisms of the disconnectors used by this customer are very well known and therefore it is possible to maintain these components fully condition based.

In the next graph the maintenance costs for the disconnectors are presented where the optimized condition based maintenance program is compared to the standard time based program. Because there had been back maintenance in 2006 and because the environment of several substations is optimized, it is expected that the maintenance costs will reduce in the near future



Also the failure mechanisms of the minimum oil circuit breakers are well known. The condition can not be measured without taking these breakers out of service. Therefore the cost reduction is in principal less compared to the disconnectors as explained earlier. However based on the experiences by other customers it is expected that the time interval between the inspections can be lengthened.



REFERENCES

[1] Wijnand R. Rutgers et al., 2001, "On-line PD Detection techniques for assessment of the dielectric condition of HV components", *Proceedings 2001 IEEE Int. Conference on Solid Dielectrics, Eindhoven, The Netherlands, pp 481-484*

2. METHODOLOGY FOR DETERMINING CRUCIAL SPARE PARTS AND KNOWLEDGE REQUIREMENTS TO EXTEND THE REMAINING LIFETIME OF 50KV MINIMUM-OIL CIRCUIT BREAKERS BY COOPERATION OF UTILITIES AND INDUSTRIES

Summary

Due to ever increasing pressure to reduce costs, the utilities and industries look for ways to find an optimal extension of the remaining lifetime of 50 kV minimum oil circuit breakers. The average age of this breaker type in the Netherlands is now 35 years and from reliability point of view there is no reason for replacement of this breakers. The failure rate is far below the normal expected rate and therefore the expected life time of such breakers is about 50 year. Industries and utilities want to have spare parts available much longer than the original equipment manufacturer can provide and they have difficulties in determining which spare parts – and knowledge resources are needed for a lifetime extension of 15 years from today.

A methodology for determining critical spare parts of the 50kV minimum-oil circuit breakers and knowledge requirements of maintenance and overhaul for the next 15 years has been developed by Ksandr and three utilities (NUON, Eneco and Delta N.V.) and one Steel industry (Corus IJmuiden) in the Netherlands. To realize this goal, it was necessary to know the most important threats for this period of time. Based on the experience by the users and the results from scientific investigations, spare parts are defined which will be critical during the intended remaining life time, and what actions will be necessary with respect to knowledge management.

With respect to the spare parts Ksandr has developed a database of all available spare part which can be shared.

2.1 Crucial Spare Parts

To determine the crucial spare parts (CSP) of the 50kV minimum-oil circuit breakers (50kV COQ)the following approach is used as shown in figure 2.1.

Step 1 Vision development of 50 kV CSP through risk management and lifecycle costing

Utilities and large industries determine their vision of replacement strategy through a risk assessment of the high voltage equipment with respect to the impact on their system. The overall system performance is dependent of the reliable condition of the equipment which can be determined through a technical assessments of the

equipment. The necessity of refurbishment or of a replacement depends on the expected system performance improvements, the respectively financial expenses and the outage costs due to the non-availability of the equipment [1]. In the case of the 50kV COQ in the Netherlands the maintenance costs do not exceed the probable outage costs and most of the types in service are in reliable condition. Insight and decision support has been improved by use of lifecycle costing of for various scenario's. In case of sufficient load capacity the participating utilities and industry in the Netherlands are going to keep the 50kV minimum oil breaker in service till 2021. With this vision in mind, the necessity to have all necessary spare part and knowledge available during this time span is the a common challenge. Therefore a joint effort to organise a 50kV minimum oil breaker (type COQ) crucial spare part platform till 2012 has been initiated in 2005.

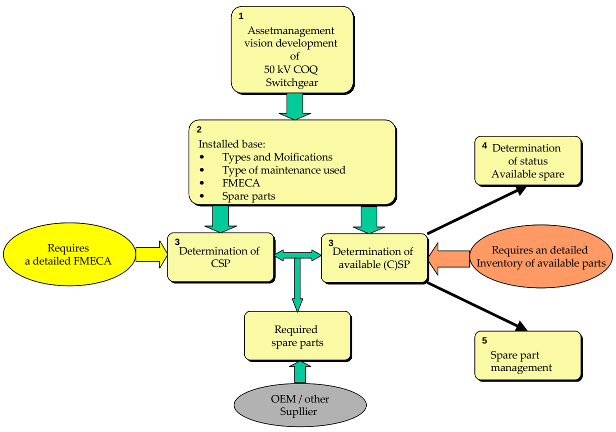


Figure 2.1 steps to determine crucial spare parts

Step 2 Stocktaking and investigation of Assets

The stocktaking process of the installed base involves the population size, spare parts and modification, and conditioning of parts. Also experiences, current maintenance program per switchgear, current outage time for maintenance, risk for maintenance induced failures, age and expected lifetime, and the current failure behavior and failure frequency and the effects on their system have been investigated per spare part platform participant.

Step 3 Determination of the crucial spare part

In the second step a global insight was generated of the experiences of each utility and industry operating the 50kV minimum-oil breakers. To determine in detail the parts involved in failures, the method of FMECA (**F**ailure **M**ode **E**ffect en **C**riticality **A**nalysis) was used and the participants experienced maintenance engineers have been interviewed. [2]. Also a further detailed stocktaking was necessary to determine which parts are available and which parts are not available today or in near future at each parties involved and of original equipment manufacturer (OEM) or other part suppliers. The crucial spare parts are determined through gap analysis between the needed parts and available parts. As a result of FMECA and weighting criteria of failure effects at each separate parties involved and it chance of occurrence through maintenance induced or other possible breakdown we estimating the need of necessary parts till 2021. The difference between the necessary parts till and available parts gives the crucial spare parts need which has to be organized to guarantee a reliable resources of parts in emergency case. Through this exercise the insight in the complexity of the switchgear and the technical impact of the preventive maintenance activities is deepened. In practice the preventive maintenance activities can be more directed to prevent the crucial components to fail because of restricted availability.

2.2 Knowledge and expertise

To determine the required knowledge and expertise till 2021 a similar approach has been used as for spare parts as shown in figure 2.2. Through gap analysis of necessary- and available knowledge and expertise we determined which joint actions are needed to recover and maintain knowledge and expertise.

Step 1 Vision development of 50 kV minimum oil breaker knowledge management

Utilities and large industries determine their vision of knowledge management approach to keep the equipment in service till 2021. They working on a joint approach to keep and recover the scared resources.

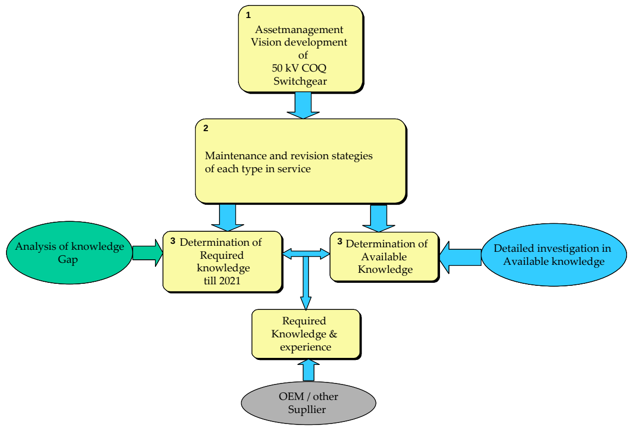
Step 2 Determine future maintenance-, overhaul- and replacement strategy

The need of maintenance- and overhaul- knowledge is mapped to gain insight in the necessary resources

Step 3 Mapping knowledge and expertise resources

Each utility, industry and OEM involved has completed a knowledge and expertise questionnaire which has resulted in a matrix showing the existing and availability resources till 2021. The gap analysis of required and available resources has resulted in a further investigation in joint maintenance and overhaul activities with utilities, industries and OEM.

Figure 2.2 Steps to determine need of crucial knowledge



2.3 Database of crucial spare parts.

A web based database is made available for the participants to manage and track the usage of critical spare parts and to make sure that the parts needed are easily accessible when needed most like during a breakdown. The user that brought in a spare part can decide the availability of it like permanent or during a certain period of time.

REFERENCES

[1] G.Balzer e.a. ,2006, “Selection of an optimal maintenance and replacement strategy of H.V. equipment by a risk assessment process”, Cigré B3-103

[2] E.R.S. Groot e.a. ,2003, “Successful implemented condition based maintenance concept for switchgear” Cired session 1.

3. EVALUATION OF IMPROVED PD KNOWLEDGERULES FOR MV CABLES

In the Netherlands, the utility Nuon is using OWTS partial discharge measurements as an after laying test for new XLPE medium voltage cables and also for condition assessments on (old) PIL cables. In the last five years, more than 1000 medium voltage cables were tested in the field. PD knowledge rules, for different types of cable insulation and accessories, are very important to determine the condition of the medium voltage cable network. So far, the PDmagnitude at Uo and inception voltage of occurring PD’s were known to be the most important quantities. However, different types of partial discharges can occur on different locations in a cable section, each with it’s own criticality and PD quantities. Statistic analysis, experiences and investigations in the high voltage lab and on (failed) components can further improve the knowledge rules for PD measurements on cables.

3.1 Improvement of knowledge rules

In cooperation with TU Delft new knowledge rules were developed based on statistical and practical analyses.

3.1.1 Statistical boundary values

The available datasets of cable components were matched with a particular statistical failure distribution. In this study, the statistical analyses was also combined with knowledge about component aging in order to generate more appropriate boundaries. The results suggested that calculation of boundary values should be done at 40% (lower boundary) and 80% (upper boundary) points. This resulted in new boundary values for a number of cable components.

3.1.2 PD parameters in relation to aging

Several partial discharge parameters can be important indicators regarding insulation degradation. Examples of indicators for aging processes are the inception voltage (PDIV), PD magnitude and PD intensity. In the HV lab at TU Delft, measurements on components in several aging stages, were conducted. Also aged components in the field were tested.

To verify aging behaviour for cable system components, a cable termination with an interfacial problem was tested in the HV lab. The cable termination was tested in four different aging stages until breakdown. The partial discharges where related to the tracking mechanism. The slope of the trend lines increases with aging.

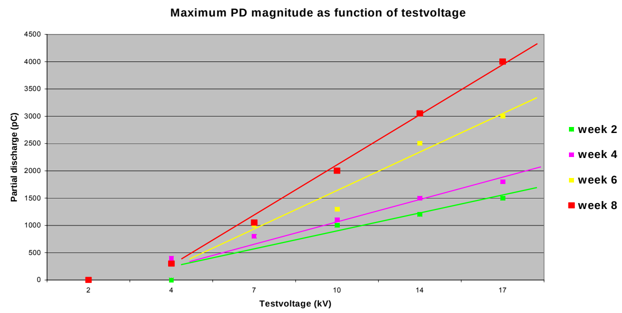


figure 3.2: PD magnitude vs test voltage for different aging stages in the HV lab.

3.2 Verification in the field

In order to verify the results of the lab measurements, several measurements and visual inspections, on specific components in the Nuon grid, were analysed. A few examples of different deviated stages of components are shown below.

3.2.1 Lubrication problems in a termination

The condition of the cable termination is influenced by the way it is assembled. Under normal condition this type of termination show no PD's at voltages up to 2xUo. In this case, lack of lubrication between semi conductive and insulation layers is causing the PD activities. 2 different deviated stages show 2 different PD vs test voltage patterns.

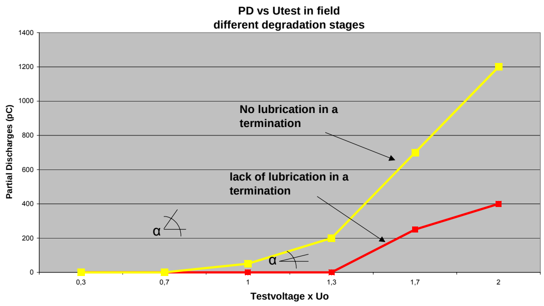


figure 3.3: PD magnitude vs test voltage for different deviated stages in a termination with lubrication problems.

3.2.2 Deviations in oil joints

Several oil joints showed PD activities during condition assessments. After visual inspections, the differences in measurement results, for different deviations in the joints, are shown in figure 3.4.

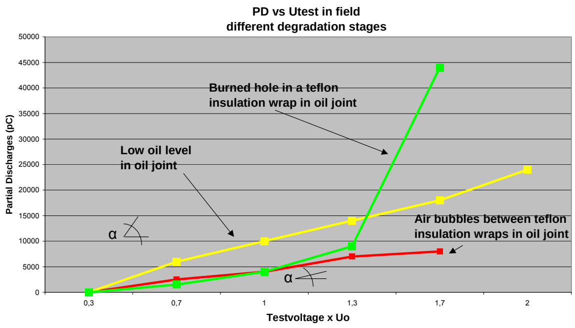


figure 3.4: PD magnitude vs test voltage for different deviated stages in oil joints.

3.2.3 Breakdown after condition assessment

In a few cases, condition data of the cable system was collected a few months / years before the cable spontaneously broke down. This data provided important information and the boundary values for these specific cable components were adjusted.

3.2.4 Partial Discharges in PILC insulation

Temporary effects have to be taken into account when determining the condition status of the cable insulation. In some cases very high PD magnitudes (above the boundary values) were detected in PILC insulation while a second measurement (after a few months) showed no PD activities on the same spot. Both measurements were conducted at a stable (cold) conductor temperature condition. The discharges were caused by temporary cavities in the main cable insulation and not by critical defects. In the future, when discharges above the boundary values are detected in the cable insulation, it is recommended first to repeat the measurement in stead of replacing a cable part.

3.3 Implementation of the knowledge rule model

The final important step in the condition assessment on medium voltage cables is to combine the different outcomes of PD parameters resulting in an overall condition index. A condition code generator is developed by TUDelft to generate an objective overall condition index based on the following parameters for each cable component: PD magnitude at Uo, PD magnitude at 2xUo (new statistical boundary values) PD vs test voltage and the PD inception voltage.

Each (sub)condition code represents a percentage of the total condition status. The condition index gives information about the technical condition of each cable part, joint or termination in the cable section. The reliability of the total cable system is depended on the weakest component. However, the recommended maintenance/replacement action is depended on the importance of the cable section.

The model is successfully tested at Nuon on a large number of measurement data and reports from previous condition assessments.

3.4 Conclusion

It can be concluded that the improved knowledge rules for PD measurements on MV cables are applicable for a reliable determination of the cable condition. This conclusion is based on verifications with field measurements and visual inspections on cable components .

REFERENCES

[1] O.M. Piepers, 2006, "*Analysis of condition data of high voltage components*", TUDelft , The Netherlands

[2] F.J. Wester, 2004, "*Condition assessment of power cables using partial discharge diagnosis at damped AC voltages*", Publishing Optima Grafische Communicatie, Rotterdam, The Netherlands.