Implementation of On-line Partial Discharge Measurements in Medium Voltage Cable Network

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Abstract

Condition based maintenance is usually used as part of cable network asset management. Due to the physical hidden structure of a cable network its condition can be monitored only by means of measurements. Cable joints and terminations have turned out to be the most fault prone components in a medium voltage cable network. Most degraded spots in cable system produce partial discharges which can be measured. Through these measurements, we are able to locate these spots before they lead to cable failure.

Commercial on-line partial discharge measurement systems for medium voltage cables are available for continuous and periodic measurements. The biggest advantage of on-line measurement is that no interruption in electricity distribution is needed. Since these measurement systems are relatively new there is lack of information about how to use them effectively. The statistical and random nature of partial discharge phenomena makes it impossible to give exact figures on acceptable discharge levels or time from discharge ignition to a final breakdown. Thus so called knowledge rules need to be created from real life measurements.

The purpose of this paper is to describe how an online partial discharge measurement system can be used effectively in a medium voltage extruded cable network. Effective use is based on both the theory behind partial discharges and the limitations that on-line partial discharge measurement system has.

1. Introduction

Cable failure probability usually follows the so called bathtub curve where the failure probability is high at the beginning and at the end of cable life. The bathtub curve is presented in Figure 1. The main reasons for failures on newly installed cables are: damage during manufacture, transportation or installation and bad workmanship. The rise of failure probability at the end of cable life is mainly caused by cable aging. This means that the most interesting times for cable diagnostics are right after cable installation and at the end of cable life.

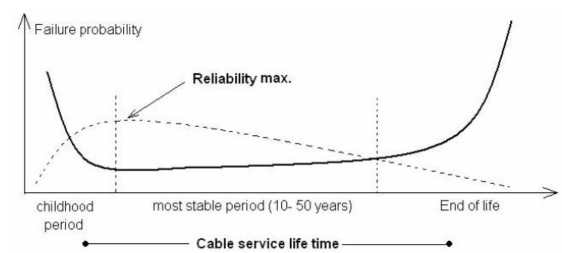

Fig. 1 – The failure probability and the reliability of a cable as function of time [1]

Detailed cable fault statistics are hard to find in literature. One reason for this is the fact that the failure rate in extruded medium voltage cables is very low and thus there seems to be no reason to collect detailed fault statistics. There is not enough reliable failure statistics available to be able to say what the most common cable failure causes in XLPE insulated cables are. From a few statistics found it seems to be that most of the technical faults happen in cable joints and terminations [2; 3; 4]. From these cable joints seem to be the most fault prone components. This is an interesting observation and further research should be done to confirm this. Cable failure causes in Macau are shown in Figure 2.

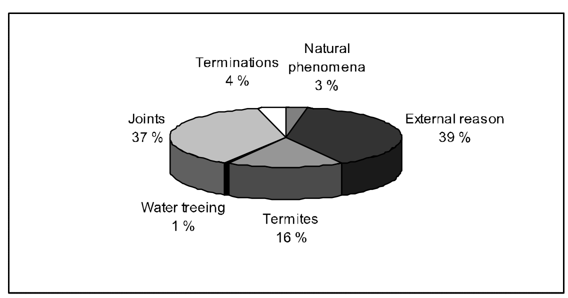

Fig. 2 – Cable failure causes in 11 kV XLPE insulated cable network in Macau between the years 2005-2010. [2]

At first partial discharges in general and their appearance in a medium voltage cable system are discussed in Chapter 2. Then in Chapter 3 limitations in on-line partial discharge measurements, the current state of measurement systems and areas where more research is needed are discussed. Finally at Chapter 4 possible applications for an on-line partial discharge test are proposed based on the theory and current measurement systems.

2. Partial discharges in extruded medium voltage cable system

In this paper partial discharges are classified in four different types based on the discharge properties and place of occurrence. These types are internal discharges, surface discharges, corona and electrical treeing. Internal discharges take place inside the insulation in small gas filled cavities. Surface discharges take place along the surface of dielectric material or along the interface between two dielectric materials. The later is also called surface tracking. Corona discharges usually happen around sharp edges at the interface between metal and air. Electrical treeing forms a growing tree like structures inside the insulation and is caused by multiple micro scale internal discharges. [5] The harmfulness of partial discharges depends on the discharge type and location. Different discharge types can be recognized because they all have their own characteristics. The only place in a cable where corona discharges are likely to take place is at the metallic contacts at the cable end. This means that corona discharges are not harmful when cables are concerned. The harmfulness of surface discharges on the surface of terminations depends on the initial reason behind the discharges. Surface discharges caused by moisture and dirt are less harmful than discharges caused by insufficient distance between cables. Surface tracking is very harmful because it erodes the insulation surface which in time will lead to failure [6]. Internal discharges deteriorate insulation directly and are thus usually very harmful. Electrical treeing has the highest impact on insulation deterioration and it is often the final cause that leads to a breakdown.

In extruded medium voltage cables there are many places where partial discharges may ignite. Partial discharges might appear in voids or cavities within the insulation or at interfaces between insulation and semi-conductive shields, in broken neutral or in electrical trees initiated from protrusions, contaminants, voids or water trees. [7] Cavities, protrusions, contaminants, shield interruptions and de-laminations are all defects that may form during cable manufacture. De-lamination may also form due to external pressure which strangles the cable. Water trees are formed due to the ingress of moisture in cable insulation. Cracks might form when insulation is subjected to extreme temperature conditions. The neutral might break due to excessive fault currents or corrosion. Rough handling during installation may damage the outer protective layers, insulation or insulation screen and thus speed up the aging process. Today an acceptance test for medium voltage cables is conducted after manufacturing. When, cable manufacturing and testing are properly conducted new cables should not contain any harmful defects. Today it is common to install cables with fully watertight structure, which in theory should decrease the amount of problems related to water treeing. Faults related to manufacturing mistakes have been reduced due to improved manufacturing techniques and quality control. Cable plowing has become more and more common also at medium voltage level. It is important to control how this affects the amount of damages caused to the cables during installation.

Many defects in joints and terminations that cause partial discharges are there because of workmanship errors. With good training often the best results and reliability are obtained. Typical defects causing partial discharges in joints are cavities, surface tracking at the interface between the cable insulation and the joint insulation, cuts made in the cable insulation during preparation and irregular cut at the end of the insulation shield. Cavities are the most likely to occur due to the improper shrinkage of accessory components or poorly shrunk heat shrink or cold shrink layers. [7] Moisture penetration is a common factor that speeds up the deterioration of a joint.

The most problematic part in termination is the point where the insulation shield is cut and stopped. Without proper stress relief, the high electric field concentration in this point quickly ages the insulation and short circuits the termination. Every irregularity in this area will affect the concentration of the electric field and thus might ignite partial discharges. These kinds of irregularities in cable termination are voids left between the cable insulation and layers above it, rough insulation shield ends or cuts made in cable insulation while removing insulation shield. [8; 9] Other factors causing partial discharges in terminations are humidity, dirt, too short distance between other cables and bad cable lug contact. Sharp edges at the metallic connections lead to corona discharges and humidity, dirt and too short distance ignite external surface discharges. [6]

3. Partial discharge pulse detection and data analysis in on-line measurements

Partial discharge pulses attenuate, disperse and reflect while propagating in a cable system. The propagation constant depends on frequency which causes distortion in partial discharge pulse shape. Discharge pulses that are induced in cables are broadband signals with frequency content in a range of 10 kHz- 1 GHz [10]. A cable works as a low pass filter for the partial discharge signal which means that only lower frequencies (below 10 MHz) of the signal can be detected after some length (about 1 km) of traveling in the cable [11; 12]. Higher frequencies can only be detected close to the measurement site. Cable structure affects on the discharge pulse propagation and through that to the achievable sensitivity. For cable lengths between 0,3 – 5 km, the achievable sensitivity is about two times better in a single core XLPE cable than in a three-core XLPE cable [13].

Measuring partial discharges from medium voltage cable ends is difficult because the measurable frequency range of discharge pulses is at the same range as most of the background noise [14]. Background noise sets the limit for the sensitivity of on-line partial discharge measurement and modern signal processing is needed to extract the partial discharge pulses from the measured data. [15] This requires a lot of computing power.

Ultra-high frequencies can be used when measuring only a single accessory at a time. When lower frequencies including most of the noise are filtered out the sensitivity is increased. However measurements made with this way can not be directly calibrated to match with broadband measurements. Also in many cases there is no access to cable joints which means that only cable terminations can be measured. [8]

Sensors are important part of an on-line partial discharge measurement system. Both capacitive and inductive sensors can be used. Capacitive sensors are more sensitive but their risk of failure is higher. That is why inductive sensors are preferred. [6] There are many places where sensors can be installed. The best place for a sensor depends on the frequency band that is being measured. [16; 17] Development of an optimal sensor requires the knowledge of the wanted frequency band and information about the installation site. The price of sensors that can be used in on-line partial discharge measurements is still high because of small manufacturing volumes and markets. Currently there are no guidelines for the installation of sensors. With current safety regulations in Finland, the installation of on-line partial discharge measurement systems without an interruption is not allowed even though in some cases it would be theoretically possible.

Partial discharge data needs to be analyzed before any recommendations can be given. When, cable systems are being measured the most important information is the discharge source location. In continuous on-line partial discharge measurements the remaining life time of the discharge site is estimated by following up the discharge trends: magnitude, charge density and occurrence rate over time. The research of discharge trends is still in progress but the results so far look promising [18; 19]. In case of periodic on-line partial discharge measurements remaining life time estimations are based on partial discharge pattern analysis and knowledge rules. The amount of on-line partial discharge measurements conducted in real extruded cable systems so far is quite small. Thus more research needs to be done to be able to form reliable knowledge rules. [3] The inability to control the voltage during on-line measurements makes life time estimation harder than what it is with off-line measurements.

To increase the effectiveness analyzing should be as much automated as possible. There is a need for a learning system that has automated analysis in it to be developed. The results achieved so far with automated analysis look promising [20].

4. Possible applications for present on-line partial discharge measurement systems

Partial discharges are ignited by deteriorated spots in joints, terminations, metallic shield and cable insulation. The theory related to partial discharges, measurement sensitivity and time to fault estimation accuracy all set limitations for the use of on-line partial discharge measurements. On-line partial discharge measurements are most suitable for detecting problems in the cable terminations, joints or metallic shield. In these cases harmful levels of partial discharges can be detected well before a breakdown. With continuous measurements, reliable estimations about the remaining life time can be made. In case of cable insulation, electrical treeing is usually the reason for partial discharges [21]. In most cases defects related to electrical treeing can be detected only a few hours before a breakdown with current measurement sensitivity. Thus an on-line partial discharge test can not be used to estimate the overall condition of cable insulation.

Possible applications for on-line partial discharge measurements are:

- The quality assurance of installed cables
- Continuous cable monitoring
- Location of problematic joints and terminations
- Cable replacement prioritizing

In case of quality assurance of installed cables, an off-line partial discharge test should be preferred because of its better sensitivity and the possibility to use higher test voltage. That makes it possible to also check the condition of the cable insulation. Continuous cable monitoring can be used to decrease the amount of unplanned outages caused by cable failures in important cable sections or in old cable sections waiting for replacement. The replacement of certain joint or termination types noticed to suffer from premature failures can be prioritized with on-line partial discharge measurements. Some sort of cable replacement prioritizing could be made based on the amount of deteriorated spots found during periodic on-line measurements. It should be noted that more research needs to be done before one can tell how beneficial periodic measurements really are.

5. Conclusion

More work needs to be done to find out the full potential of on-line partial discharge measurements in a medium voltage cable network. At the moment, continuous on-line measurements seem to be most promising and already offer reliable results. Nowadays the big question is: “Is it economical?”

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