SORAL - SYSTEM FOR CONDITION MONITORING AND FAILURE RISK ASSESSMENT OF MV CABLE LINES BASED ON OFF LINE DIAGNOSTIC METHODS

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ABSTRACT

The article describes the current experience in applying the diagnostics of MV cable lines in the DSO and the ongoing SORAL project.
Diagnostic systems which measure partial discharges and tan delta in MV lines have been used in Poland since the turn of the century. Research work so far has focused on MV cables and on attempts to define key parameters which would indicate advanced ageing processes. The measurements and analyses conducted so far have not enabled the formulation of assessment criteria for failure risk. However, key parameters indicating the increase in the failure risk have been identified. The research up to now is a valuable contribution to the process of creating assessment criteria for failure risk, using the IT system which automates this process. This task is carried out now in the SORAL project. The project is implemented by DSO (ENERGA-OPERATOR) and IT Company (Globema) consortium and is financed from EU funds.

INTRODUCTION

MV power cable network is one of the most important parts of distribution power systems. The oldest parts of cable networks consist of belted paper insulation lead covered (PILC) cables and Polyethylene (PE) insulated cables. Since the 1970's, cross linked polyethylene (XLPE) insulated have supplanted cables the older designs. MV cable networks are increasingly complex systems of interconnected cables that are regularly modified. As a result, cable circuits often consist of a range of cable, joint and termination designs. Consequently, the active aging processes exhibited by individual cable sections and accessories may occur at different stages
Managing that part of the grid mainly has been based on failure rate analyses. This is not very effective as it involves extra costs of failure removal, additional power cuts, difficulties in planning investments and maintenance works resulting from the absence of knowledge about the aging processes of cable lines.
Many novel diagnostic methods have been proposed for MV cable systems over the last few decades. They are being used increasingly in MV cable network. Currently, two of the primary measurement techniques: diagnostic systems based on measurement of partial discharge (PD) and tan delta (TD) tests are used. The small diagnostic systems available enable making off-line measurements in operated cable lines. The information obtained from PD and TD measurements can provide knowledge supporting efficient management of this important network element. For diagnostic measurements, the following voltage waveforms are typically used: DAC and VLF. The problem lies not in correct execution of the measurements but in interpretation of their results and diagnosis of the technical condition of the cable lines on the basis of acquired set of information, taking into account other technical and operational data on the cable network. It is very important that the partial discharge measurements provide data on each part of the cable line.
On the basis of examinations carried out before the SORAL project it has been found that:

- Basic parameters indicating the risk of the failure are: reduced PD ignition voltage and the occurrence of increased PD intensity in a power cable. The study shows that, the lower the PD ignition voltage, the higher the percentage of cable sections of an increased PD intensity.
- No correlation between the increase of PD value and increasing probability of the failure occurrence has been found.

The knowledge acquired from the analysis of partial discharge measurements constitutes a vital element in managing this component of network assets. However, to build an effective management system of the network a wide knowledge gained by the users is necessary as well as a reasonable and correct knowledge management (technical information, failure analysis, line load). The Polish DSOs have not had tools that could offer the assessment of risk of failure of the MV cable network. Currently there is an offer of diagnostic measurement services, and DSOs perform diagnostic measurements. Assessment of measurement results is performed without unequivocal criteria. They are not measurably scalable. The results of diagnostic tests were assessed individually for each case. However, there are no standards to support the management of a MV power network.
DSOs have not had tools implemented to gather diagnostic data in the IT systems, and to link them to the technical and service data of the cables. Major distribution companies have the IT systems of GIS class with technical information on the grid. Potentially, there exists the possibility of expanding the GISs to include the database with data from diagnostic measurements.
EOP has over 13,000 km of SN cable lines. Diagnostic measurements in this network have been performed since

2003. Measurements from such a long period constitute a valuable source of data.

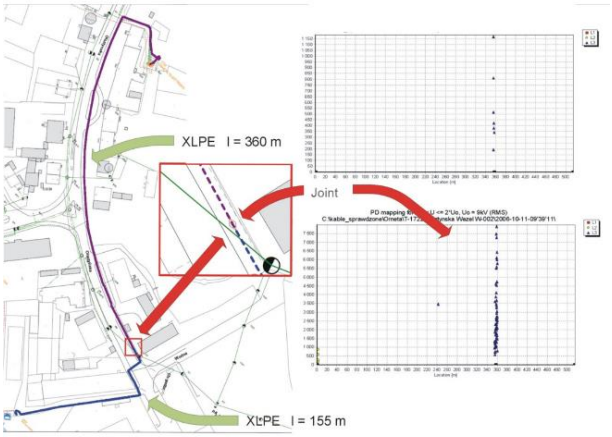

FIGURE 1: PD detection allowed to find the joint on XLPE power cable MV line in bad condition

SORAL PROJECT

Diagnostics especially aims at testing the after laying (quality control) and assessment of existing cable circuits condition. Information obtained from diagnostic tests gives a great opportunity for changing the current Corrective Maintenance and create new more efficient Condition-Based Maintenance. The challenge for ENERGA-OPERATOR, but also for distribution companies around the world, is to build such cable network management systems that will track the aging process of cable insulation and assess the risk of failure. Such systems will allow preventive actions and limit the number of failures in this network. An important step in the implementation of this new strategy is the SORAL project - System for condition monitoring and failure risk assessment of MV cable lines based of off line diagnostic methods.

funds. It is carried out by a consortium of two companies: ENERGA-OPERATOR (DSO) and Globema (ITC systems supplier). Implementation of the project has been planned for the period 2018-2021.

The project involves preparation of a tool for assessing the condition of insulation and the risk of failure of MV cable lines. Integrated knowledge obtained from diagnostic measurements, technical information and operational data will be used in the project. All over the world, research and development work is being carried out to define assessment criteria based on diagnostics and no standards have been developed to date. Therefore, this project is an innovative undertaking. The SORAL project encompasses industrial research and development work

Industrial research results will be the criteria for assessment of technical conditions of MV power line segments, based on technical and operational data and on diagnostic data obtained from measurements of partial discharges and tan delta. On the basis of decades-long experience in conducting diagnostic tests, and on the basis of technical and operational information gathered in GIS, the health index for specific elements of cable lines will be determined. The health index will enable the assessment of the risk of failure related to insulation deterioration. The use of partial discharge measurements is crucial here, since only these measurements provide information on the phenomena occurring along the cable. The partial discharge measurement alone makes it possible to assess individual sections of a cable line. In remaining attempts and measurements, data refer to the whole power cable line and not its sections. The health index will be determined using statistical methods, and based on available knowledge and experience. The health index of an asset is a figure which reflects its condition. This is a tool for asset management which makes it possible to define in unbiased way a policy for maintenance, refurbishing or replacement.

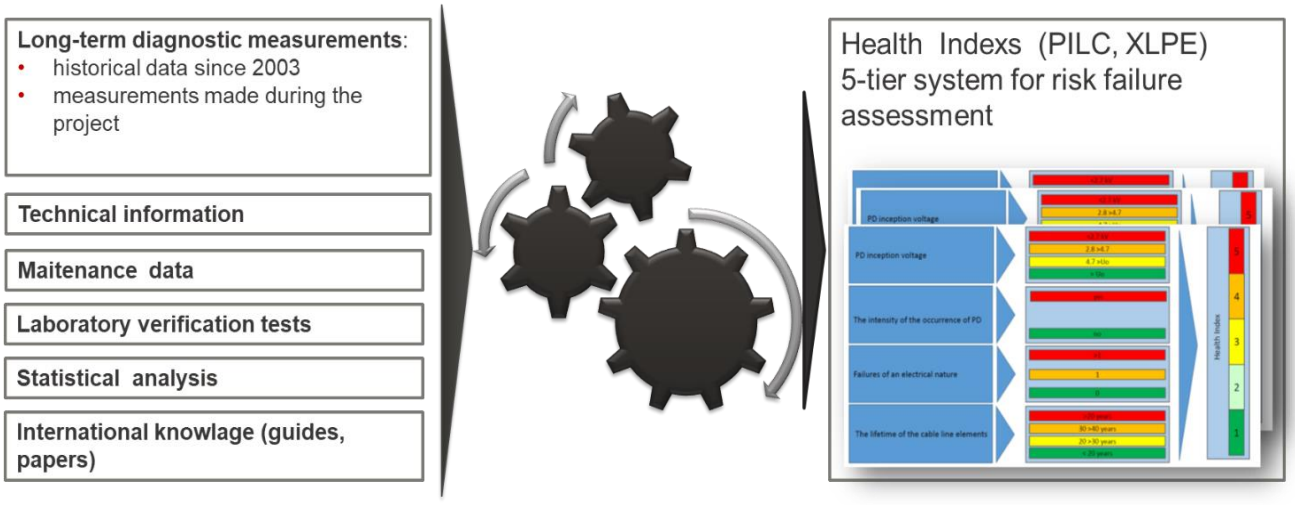

FIGURE 2: The process of defining health indexes

This project is implemented with co-financing from EU

The design of a health index requires three steps: finding the factors which affect links performance, grading the link characteristics for each factor and estimating the relative importance of the factors. The developed model will be calibrated to set at least 5-tier system for risk failure assessment. Analysis of the failure risk of individual cable line elements will be conducted for a selected part of the pilot area. The verification and potential calibration of the system will be based on laboratory tests of selected samples of cable lines.

As part of the development efforts, on the basis of the Health Index, a prototype IT system will be prepared to assess the risk of failure in cable lines. It will be verified and calibrated during the tests carried out in the pilot area. The major deliverable of the project will be a prototype of SORAL, a software tool for assessing the condition of cable lines and managing them based on predictive maintenance.

Project deliverables in the form of SORAL, a prototype software solution, will be implemented and applied for the first time for business purposes in ENERGA-OPERATOR SA (EOP). A favourable verification of these deliverables will allow us to offer this solution on a commercial basis to other distribution system operators.

DEMONSTRATION EREA

The pilot area has been selected in such a way that the new solution can be applied at the end of the project for the entire MV cable network. The pilot area covers nearly 700 km of MV cable lines (the city of Elblag, Poland). It ensures access to the cable lines of all types used currently in the ENERGA-OPERATOR SA's network (PILC, XLPE), with different ages and working in different technical conditions. Partial discharge measurement have been carried out in demonstration area with different intensity since 2003. First diagnostic measurements in the cable network in Poland were carried out in this area.

An important research element of the project is the performance of supplementary diagnostic measurements. These measurements are planned for 12 months. Measurements started in January 2019. The plan of diagnostic measurements in the MV cable network in the pilot have been prepared. Minimum number of cable lines subjected to measurements is 250. The plan covered measurements of various types of cables. Following tentative analysis of historic measurement data, information on failures and technical information, the lines with high probability of deterioration of condition of insulation due to aging process were selected.

At the end of 2018 new diagnostic system was purchased for the measurement of partial discharges and tan delta. FLV and DAC are used as measurement voltages.

FIGURE 3: Diagnostic system with FLV and DAC voltage test

The diagnostic tests supplement the knowledge from earlier diagnostic measurements carried out in the period from 2003. Together with historical data, they will provide a data set covering a very long line maintenance period, i.e. from 2003 to 2019.

To prepare employees for making measurements and data analyses, they were trained to operate the new measuring equipment and the IT system supporting the operation of the equipment and analysing results of measurements. Measurements are performed in turn using two test voltages (VLF and DAC). To verify that the assessment is correct (both with automatic and possibly manual processing), measurements are made from both sides of a cable line.

The measurements provide data which, at the next task, allow for, among others: observing changes to parameters of partial discharges resulting from aging processes of insulation of cable lines, verifying the criteria for assessing the condition of insulation with the use of tan delta measurement, verifying the possibilities of comparing results of measurement of partial discharges received using two different test voltages (VLF, DAC).

As there will be a great amount of technical, maintenance and in particular measurement data, the data will be collected in an IT system. The data collected in such a way will make it possible to conduct analyses and statistical research.

In the next step supplementary laboratory tests of cable insulation samples will be performed to assess the scale of aging processes. The works will be performed by a scientific institute as a subcontractor.

The scope of collected diagnostic data, together with technical and maintenance data of cable lines, is to make it possible to define the criteria for assessing the technical condition of specific MV cable lines (Health Indexes). The models will be developed for key cable line elements. Of key importance will be to define such models for PILC and XLPE-insulated cable sections. For these two cable types, aging processes operate differently and have different values of parameters measured during diagnostic tests.

SORAL - IT SYSTEM

The main product of the project will be the SOLAR IT system responsible for:

• preparation of input data based on GIS and SCADA systems
• storage of measurements and network model
• operation of calculation models
• analysis of measurement, technical and operational data
• geographical visualization of results

Based on GIS and SCADA systems data will be exchanged in the CIM standard, while dedicated interface will be prepared for automatic data exchange between the SORAL system and diagnostic equipment.

Network model

In addition to storing and presenting current data, SORAL will enable mapping of changes made on the network. Changes are both modifications to the location of the network run as well as the replacement of cable sections. Thanks to this, it will be possible to store historical data about the network, as well as measurement data and calculations made at various time points correlated with the corresponding network status.

Initially, historical measurement data and current data about the network will be introduced to SORAL. Ultimately, the system will collect further measurement data and information about changes on the network. This will allow you to create a history of measurements correlated with the corresponding network layout. These data will be the basis for analysis and systematic improvement of the network status assessment and the threat of failures.

Another feature of the system will be the ability to remember the changes taking place on the network, both those related to its technical parameters, as to its course or reconfiguration. Thanks to this, apart from its current state, it will be possible to present the network at any chosen moment in the past. It gives the possibility of a detailed analysis not only of historical and current, but also forecasting trends and predicting future events.

Network status - Health Index

An important component of the SORAL system will be computational models, which based on measurements (partial discharges and delta tangent), recorded events on the network, as well as prepared physical models and nominal and operational data, will enable the assessment of the technical condition of the entire network and its individual sections. It is anticipated, that in the future, in addition to the data mentioned above, environmental conditions will also be taken into account, represented by such parameters as, for example, the type of soil or soil pH. The set of this data will allow the implementation of the mechanism of the standardized Health Index for individual elements of cable lines, allowing to determine the risk of failure due to the state of insulation. This will give you the option of switching from the Corrective Maintenance model to the Condition Based Management (a strategy based on preventive activities dependent on the technical condition of MV cable lines). Presentation of the results on the background of the map and the actual course of the cable network will facilitate planning of operational works and modernization of the power grid.

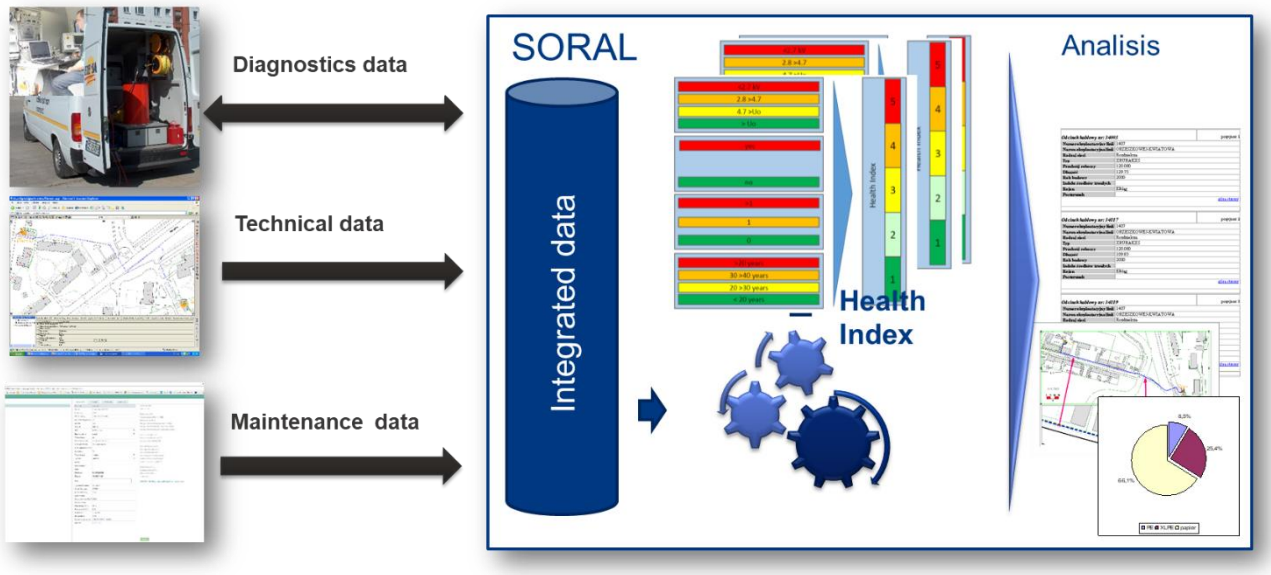

FIGURE 3: Block diagram of the SORAL system for evaluation of the technical condition of individual elements of cable line and the risk of failure

Analytical environment

The SORAL system will enable analysis based on all of the data mentioned above. In particular, it is possible to answer the questions:

1. What is the Health Index of individual lines?
2. What is the Health Index of individual cable sections?
3. What is the topology and topography of the network?
4. What changes have occurred over time?
5. How will the Health Index change after modernization of the cable section?
6. Which segments should be replaced to raise Health Index to the set value?
7. What is the spatial Health Index distribution and are any correlations revealed?

A big challenge will be the ability to maintain a history of measurements correlated with network changes. In order to limit the huge amount of data and to facilitate the interpretation of results, it is planned to convert the measurement data cloud into the functions of probability distribution of the occurrence of anomalies in the cable (failure occurrence). As a result, the system will be able to indicate on the map the endangered places and their surroundings together with information on the probability of a failure.

CONCLUSIONS

The health index is a powerful tool for representing the overall health of an asset. Taking advantage of existing outcome of experience and diagnostic techniques, it provides a way for capturing operating observations and field inspections or testing into a figure which shows asset condition. This makes it possible to optimise maintenance procedures and replacement policies. The SORAL system will be an expert tool to enable a change in strategy in the MV power network management. The existing strategy, Corrective Maintenance (reaction to a failure) will be replaced with a new strategy, Condition Based Maintenance (preventive measures undertaken depending on the technical condition of MV power lines). The system will enable undertaking preventive measures reducing the number of failures. The elements of power lines with the highest failure risk will be replaced. The analysis of failure risk will be used to plan the replacement of power lines, before the failure actually occurs. Replacement will be planned for fragments which are in poor technical conditions and not for the whole line. The knowledge about the cable line will be used to predict its lifespan. In urban areas, it will be possible to correlate maintenance work with construction work, e.g. road repairs or laying underground cables, to reduce costs in case the replacement of the cable might be necessary in the foreseeable future.

To fulfill the needs of ENERGA-OPERATOR SA, the research part of the project will define criteria for assessment of the technical condition of insulation of the cable line elements. In the development part of the project, a prototype management system for a cable network will be developed, based on technical condition and failure risk assessment.

The main objectives of implementation of the new, more efficient asset management are the following:

- reduction of operating costs,
- reduction of investment costs,
- improving reliability and quality of electricity supply, reduction of the average outage duration for each customer (SAIDI) and average number of interruptions (SAIFI).

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