Condition Monitoring Program of HV Cable Systems

Mrs. Heena Sharma¹, Mr. M.T. Deshpande² and Mr. Rahul Pandey³

¹M.E (Power System) student, Department of Electrical and Electronics Engineering, SSTC Junwani, Bhilai, CSVTU, Chhattisgarh, India
²Departments of Electrical SSTC Junwani, Bhilai, CSVTU, Chhattisgarh, India
³Department of Electrical and Electronics Engineering, SSTC Junwani, Bhilai, CSVTU, Chhattisgarh, India

ABSTRACT
The electric cable industry is definitely in the mature product stage and while there are many incremental developments and improvements, the history and experience gathered enables us to approach issues of cable failure and cable life maintenance with ever improving tools.

The task ahead of us is to implement well established techniques of design and installation of electric cables that almost guarantee the proper and continuous function of this essential infrastructure asset.

A summary is provided of the causes of failure (damage, ageing, and electrical deterioration) and reduced cable life with the developing tools to predict and analyse such failures as part of a continuous process of monitoring the condition of the asset.

Preventative measures are well known and should be utilised at every instance. Some advances in the use of temperature monitoring and partial discharge detection, in combination with the preventative activities and training would provide for the achievement of the full cable life.

This paper discusses currently available technology, the shortcomings, and the trends for future development.

Keywords: XLPE cables, Partial Discharge (PD), Condition Monitoring (CM).

1. Introduction
The higher demands by the Electricity Industry have created an increased focus on the need to limit installation and service costs and obtain higher performance, reliability, and asset life. The traditional and more conservative approach to circuit loadings and emergency ratings has given way to the demands for the maximum use and efficiency of a cable asset without any deterioration or reduction in the long term performance. Such expectations can only be achieved with continuous monitoring and analysis of the condition of the cable so that the owner and operator have full confidence when taking decisions concerning the available capacity of the cable. Conditions that cause the degradation of the cable include the mechanical damage that may occur prior to the energizing of the circuit, the overheating of the cable with resultant ageing and deterioration, and the electrical deterioration of the insulating components.

2. Cable and System Design
The subject of cable design and cable system design considers three elements within the cable and ‘the environment in which the cable is installed’ is the external factor to be considered.

The cable elements include the conductor for electric current, the insulation suitable for the voltage level, and a means of protection from external elements during installation and in service. This is shown in fig.1.

---

Figure 1. Cross Linked Polyethylene (XLPE)
The real situation is that there are a large number of applications and range of service conditions, so that a number of different cable products with a wide variety of features can be generated. Apart from the varying electric current demands at a range of voltage levels, one must also consider the chemical compatibility of each of the materials selected combined with an understanding of the installation methods and the environment in which the cable will be installed.

An additional dimension which increasingly needs to be considered these days is the environmental assessment of the materials themselves, their effect on operating performance, and the impact of their ultimate disposal at the end of the cable’s useful working life.

Thus the whole subject of cable and system design is in fact quite complex, but always targeted to improve performance and cable life.

3. Why Do Cables Fail?

Power cables can fail for a number of reasons, the most common causes being external interference or damage, overheating, moisture ingress, poor accessory installation, cable or accessory defects, all of which will result in electrical failure or breakdown of the primary insulation. Identifying the real cause of a failure can be a difficult task as one form of damage may lead to another, and the root cause may not be plainly evident.

3.1 Mechanical Damage

Mechanical damage is usually attributed to activities during or after installation, when the cable is most exposed to the possible damage, however experience shows that damage during manufacture, transport, and handling is also possible. Testing of each cable length by the manufacturer of cable and care during manufacture results in a product without defect that can be expected to perform for the entire design cable life. Such confidence can only be assured by close adherence to proven design concepts, quality procedures during manufacture, and strict criteria during the testing phase.

Analysis of cable failures due to mechanical damage shows that damage that occurred during installation is often the direct cause of failure in service.

Severe mechanical damage (such as dig-ins) during service will result in immediate failure of the insulation and disruption of the supply of electricity. However, if the damage is not so severe as to cause such an instant reaction, it may go unnoticed and eventually lead to failure by one of the other main causes. For example, a civil contractor installing water pipes near a cable circuit slightly damages the cable sheath, and does not repair the damage. In time, moisture from the surrounding soil eventually corrodes the metallic sheath, permeates into the insulating layers and eventually causes electrical breakdown. Unfortunately, the energy released at the time of eventual failure will often burn away the evidence of the real cause.

There are also a number of other opportunities for mechanical damage to occur over the life of the cable, including insect and rodent attack, vibration, soil erosion, and corrosion.

Therefore having a cable with the best possible protection and good installation procedures is some of the best assurance for a reliable cable asset in service. Continued cable life is assisted by the monitoring and period checking of the cable and accessories.

3.2 Ageing and Overheating

Ageing and overheating is a direct result of incorrect system design, inappropriate installation, or abuse of the cable by overloading.

Overheating of cables accelerates the ageing process and can lead to cable or core movement (due to thermal expansion) that was never designed or catered for in the system arrangement. If such movement is concentrated at one point (as is often the case, for example, at the accessory) damage and/or failure at that point (the accessory) will certainly result. As paper insulated cables age due to overheating, they become quite fragile, and mechanical impact, or an attempted movement, may be sufficient to crack the increasingly delicate paper insulation layers and cause failure.

The newer XLPE insulated cables also suffer problems when overheated, initially seen as deformation of the insulation layer, but eventually resulting in a breakdown of the polymer chains, baking and carbonizing of the insulation. With the insulation at any one of these stages of deterioration, any additional stresses imposed by voltage peaks, impulses, and spikes will initiate the breakdown of the entire thickness of insulation.

3.3 Electrical Deterioration

Partial discharge is, as the name suggests, a “partial” discharge (or breakdown) within the insulation medium. It is generally initiated from a small defect or contaminant within the insulation or a void. These defects increase the electrical stress at that point to a level where discharge is possible even within solid materials.

The XLPE insulated cables are not tolerant of continual partial discharges and rapidly deteriorate and fail. This phenomenon also occurs in paper insulated cables but is generally less destructive to them as they exhibit a unique “self-healing” property due to the mobile impregnating compound or pressurized oil.

Manufacturers of XLPE cables take great care during manufacture to ensure no sites for partial discharge activity exist, and during routine testing, all cables are energized well beyond their working voltage whilst PD levels are monitored. It is therefore unlikely for new cables to exhibit such problems for many years of service.
3.4 Causes of Electrical Deterioration
A perfectly manufactured insulation would tolerate expected operating conditions indefinitely, provided external factors did not affect that insulation adversely. Partial discharges at accessory interfaces will degrade the insulation of the power cable. As mentioned earlier in this document, the paper insulated cable has the capability to accept some discharge, whereas the XLPE insulation suffers from such discharges so that break down may occur quite rapidly. Water treeing, the phenomenon of water penetration into the XLPE under voltage stress, resembling a growing tree, tends to develop into a site for an electrical tree and eventual partial discharge, and hence eventually leads to electrical failure of the insulation.

4. ESSENTIAL ELEMENTS OF A CABLE CONDITION MONITORING PROGRAM
In this section, nine essential elements that constitute an effective cable condition monitoring (CM) program are presented. This is shown in Figure 2.

These elements are as follows:
1. Selection of cables to be monitored.
2. Development of database for monitored cables.
3. Characterize and monitor service environments.
4. Identify stressors and expected aging mechanisms
5. Select CM techniques suitable to monitored cables.
6. Establish baseline condition of monitored cables.
7. Perform test & inspection activities for periodic CM of cables.
8. Periodic review & incorporation of plant & industry experience.
9. Periodic review & assessment of monitored cables condition

4.1 Selection of Cables to be monitored
The purpose of the first element of the program is to identify and select electric cables that are candidates for inclusion in the cable condition monitoring program. Power, instrumentation, and control cables that have high safety significance, high plant risk significance, or are important to continued safe operation of the plant would form the core group of cables to be included in the program. Generally, these cables have either a direct safety-related function, are required to achieve and maintain safe shutdown, or are required to mitigate the consequences of design basis accidents. These would also include, computer and digital I&C cables that have a safety-related function or are required for mitigation of the consequences of an accident.

4.2 Database of Monitored Cables
The second element of the cable CM program is the database for the electric cables that are to be monitored under the program. The purpose of the cable CM program database is to provide a single centralized source of information for the cables in the program so that the cable monitoring program engineer can access, analyze, and evaluate the documentation and data necessary to make cable condition assessments and to guide the direction of program decisions and activities.
4.3 Characterize and Monitor Environments
The third element of the cable CM program is the characterization and monitoring of the service environments in which the cables in the CM program will be operating. By characterizing the conditions in a cable’s normal operating environment and identifying any sections of a cable run that could be exposed to potentially more severe adverse conditions, the cable engineer can determine the global and local stressors that could cause a significant increase in the rate of aging degradation or other damage to a cable. The cable engineer will also use the environmental information to determine, and document in the database, the frequency for the performance of periodic cable inspections and condition monitoring testing, the frequency for periodic monitoring and verification of global environmental conditions, and the frequency for monitoring the status of any adverse local environmental “hot spots” (local adverse stressors) that have previously been identified. Identifying the locations of environmental “hot spots” will also help the cable engineer to specify more frequent or more detailed CM inspection and testing for those cable circuits, or sections of the cable circuits, that are exposed to the identified local adverse stressors.

4.4 Identification of Cable Stressors and Aging Mechanisms
The fourth element of the cable CM program is the identification of stressors affecting cable systems and their associated aging/failure mechanisms. By identifying these stressors, and quantifying their severity, the cable engineer can determine the primary aging and failure mechanisms that will affect each cable circuit. These are the processes that the cable CM program inspection and testing activities must be able to detect and monitor, since they can cause degradation or other damage that may, over time, lead to the ultimate failure of a cable system. This information may then be used by the cable engineer, in cable CM program element 5, to select the most effective CM inspection and testing techniques for detecting and monitoring the anticipated aging/failure mechanisms.

4.5 Selection of CM Techniques
The fifth element of the cable CM program is the selection of condition monitoring inspection and testing techniques that can be used to detect, quantify, and monitor the status of the aging mechanisms that are causing the degradation of cable systems. By selecting CM techniques that are best suited to the detection and monitoring of the anticipated stressors and associated aging and degradation mechanisms identified, the cable engineer can more accurately monitor the condition of critical plant cables, assess their operating condition, and implement corrective actions to manage aging and degradation in those cables that are found to be experiencing stressors and aging/degradation rates beyond specified design conditions. Realistic and timely assessment of cable condition is the best means for managing cable degradation and avoiding unexpected early cable failures.

4.6 Establish Baseline Cable Condition
The performance of baseline cable CM inspection and testing is the sixth element of the cable CM program. This activity establishes benchmark values for measured cable parameters, physical condition, and appearance at the time of installation (or the beginning of a cable monitoring program). The cable CM inspection and testing techniques that are used to establish baseline cable condition were selected in cable CM program element 5 where it was determined that they were the methods best suited to identify, quantify, and monitor the status of the aging mechanisms that are causing the degradation of a particular cable system.

4.7 Perform Cable CM Inspection and Testing
The performance of periodic cable CM inspection and testing is the seventh element of the cable CM program. The implementation of this program element involves the routine performance of inspection and testing procedures to provide a periodic assessment of the physical condition and appearance of a cable system, the status of the cable circuit’s operating environments (including locally adverse environments), and the quantitative measurement of the properties, operating parameters, and performance parameters that indicate the condition of the cable systems included in the plant’s cable CM program. The data and results obtained from the periodic testing and inspections are documented in the cable CM program database.

4.8 Operating Experience
The eighth element of the cable CM program is the review of cable-related operating experience and incorporation of applicable information into the program. By actively reviewing industry-wide operating experience regarding cables, a plant can be alerted to deficiencies or defects in specific cable types or configurations, inadequate or damaging installation practices, testing techniques that can potentially damage cables, useful new testing techniques, manufacturing defects, or misapplications of cable types. Regular review and analysis of cable failures or cable-related problems in one’s own plant can sometimes reveal adverse performance trends or otherwise point to emerging problem areas that can be monitored more closely and/or corrected in a timely fashion before the occurrence of an early cable failure.

4.9 Periodic Review and Assessment of Cable Condition
The periodic review and assessment of the condition of cables that are being monitored under the cable CM program is the ninth element. The purpose of this element is to perform a formal periodic review that brings under consideration all of the inspection and CM testing results, inspection and testing data trends, surveillance and PM test results, applicable operating experience, and operating environment conditions and trends in order to establish an assessment of the present condition for each cable in the program.
5. CONCLUSIONS AND RECOMMENDATIONS

In-service testing of safety-related systems and components can demonstrate the integrity and function of associated electric cables under test conditions. However, in-service tests do not provide assurance that cables will continue to perform successfully when they are called upon to operate fully loaded for extended periods as they would under normal service operating conditions or under design basis conditions. In-service testing of systems and components does not provide specific information on the status of cable aging degradation processes and the physical integrity and dielectric strength of its insulation and jacket materials.

Condition monitoring inspections and tests provide the means for evaluating the level of aging degradation of electric cables. Portions of a cable circuit that pass through areas experiencing more harsh environmental conditions or local adverse environmental stressors can cause excessive aging and degradation in the exposed sections of a cable that could significantly shorten its qualified life and cause unexpected early failures. Periodic cable condition monitoring inspection and testing can provide cable condition status information and measurements of cable insulation properties, physical integrity, and dielectric strength. Severely damaged or degraded cable insulation can then be identified and repaired or replaced to prevent unexpected early failures while in service.

The review of cable-related operating experience can play an important role in the assessment and management of electric cable aging and degradation. Industry-wide operating experience can alert licensees to cable manufacturing defects, inadequate installation practices, misapplication of cable types, and other environmental and operation factors. Regular review and analysis of in-plant cable failures or cable-related problems can sometimes reveal adverse performance trends or otherwise point to emerging problem areas that can be monitored more closely and/or corrected in a timely fashion before the occurrence of an early cable failure.

References


AUTHOR

Heena Sharma presently pursuing his M.E in power system engineering from Shri Shankaracharya Technical Campus, Bhilai.

M.T Deshpande presently working as Head of Department (Electrical) in Shri Shankaracharya Technical Campus,He is M.Tech in Power System, having 31 years of experience in steel industry and 10 years in teaching.

Rahul Pandey presently working as Assistant Professor in Shri Shankaracharya Technical Campus, IEEE member.He is ME in Power System, having 06 years of experience in teaching.