AMP 223 ELECTRICAL INSULATION FOR MEDIUM VOLTAGE SHIELDED CABLES AND CONNECTIONS NOT SUBJECT TO ENVIRONMENTAL QUALIFICATION REQUIREMENTS (VERSION 2020)

Programme Description

The purpose of the AMP described herein is to provide reasonable assurance that the intended functions of electrical insulation for medium voltage shielded cables and connections that are not subject to the environmental qualification requirements and are exposed to adverse localized environments caused by temperature, radiation, significant moisture, wear, and or chemical (e.g. such as leakage of solvents, hydraulic fluid and borates) or surface contamination and susceptible to age-related degradation are adequately age managed [1-6].

Adverse localized environments and adverse service conditions could lead to early failure of medium-voltage cable circuits and this programme is intended to manage significant ageing effects to preclude in-service failure. It is recognized that one cable programme can cover all cable types. However, because different degradation mechanisms and assessment activities apply to instrumentation and control low and medium-voltage power cables, this programme has been developed separately.

Medium-voltage shielded cables and accessories that are properly installed, supported, and kept cool and dry are expected to have a long life. However, cables or accessories that are subject to adverse conditions needs to be covered by an ageing management program. The following are recognized adverse conditions with respect to the longevity of medium-voltage shielded cable circuits [7-9].

Adverse localized high-temperature and/or high-radiation ambient environments under normal operating conditions; bulk area temperatures are not expected to significantly affect the ageing of medium-voltage cables. However, care is taken in environments that exceed 50°C (122°F) and for cables operating near their ampacity limit in ambient environments of 40°C (104°F) or more because any combination of ambient temperature and high motor winding temperatures or ohmic heating can cause higher rates of thermal ageing to the motor connecting cables . Also, localized hot spots such as next to or above steam generators, pressurizers, or hot process pipes, such as feedwater lines, main steam lines etc. are a key concern, especially if the cable is adjacent to hot process piping. With respect to high-radiation ambient environments, assuming a 60-year desired life for a medium voltage cable, no appreciable effect would be expected for average dose rates up to 0.1 Gy/hr (10 rd/hr) [8]. Although minimal effects are expected at 0.1 Gy/hr (10 rd/hr), the effects could be appreciable if the cables are simultaneously exposed to high temperature (for example, greater than 50°C (122°F) with conductor temperatures reaching ampacity limits).

High conductor temperature from ohmic heating; design practices or ohmic heating calculations are reviewed to confirm that elevated conductor temperatures (for example, >90°C [>194°F], a common cable thermal rating for ethylene propylene rubber and cross-linked polyethylene) does not occur, and the current balance on multiconductor-per-phase cables are equally distributed is verified. This verification could be performed through the use of infrared thermography if cables are accessible, through measurements of current on individual conductors or by software (if the installation and type of cables are known).

High-resistance connections at terminations or splices; identification of high resistance connections can be through the use of infrared thermography or periodic visual inspection for signs of discoloration or deterioration of the splice or termination. If the adequacy of the connection was confirmed at the time of splice or termination preparation through the use of a micro-ohmmeter or other recognized method, periodic evaluation may be unnecessary for most connections, but it may be desirable for aluminium connections until stability is confirmed.

Significant moisture (partial or full submergence); age related degradation of the electrical insulation may occur resulting in a decrease in the dielectric strength of the conductor insulation such as cables in buried or embedded raceway, cable trenches, cable troughs, duct banks, underground vaults, or directly buried in soil installations). The cables in the scope of the program subjected to long-term (years continually or periodically in wet conditions) wetting are identified and their susceptibility to significant moisture ageing is reviewed.

The presence or absence of these conditions can be determined, but is not limited to: (a) the review of available data of radiation levels, and temperatures, (b) recorded information from equipment or plant instrumentation, (c) utilization of infrared thermography to identify hot spots, (d) the as-built and field walk down data (e.g. cable routing data base), (e) plant modifications and maintenance practices, (f) review of relevant plant-specific and industry operating experience, (g) plant corrective actions [10], (h) inspection of buried or embedded raceway, cable trenches, cable troughs, duct banks, underground vaults. If there are no adverse conditions, a long life can be expected for the cable circuits. Accordingly, for verified benign environments and service conditions, monitoring and maintenance are not expected to be necessary. Further action would be required only if failures occur or degradation from very long service is recognized.

If one or more adverse conditions are observed, further assessment, testing, and/or corrective action will be necessary to ensure reliability, unless the cable and/or its accessories have been designed for the conditions.

The ageing effects detected in electrical insulation for medium voltage shielded cables are reduced insulation resistance (dielectric strength), loss of mechanical properties, material hardening or loss of strength (e.g. dielectric or material). These ageing effects are produced by degradation mechanisms such as thermal degradation of organic materials, radiation induced oxidation, moisture intrusion, chemical or surface contamination, radiolysis, volatilization of plasticizers, water/electrical trees, and wear.

The medium voltage shielded cable condition monitoring portion of the AMP does not utilize sampling for electrical insulation testing of electrical cables, as cable degradation is not necessarily equally distributed across a cable population. Since the main ageing effect is reduced dielectric strength of the insulation due to water / electrical trees (or other voltage related mechanisms, then sampling will not be effective in identifying the degraded cables. The specific type of test performed is determined prior to the initial test and is to be a proven test for detecting deterioration of the insulation system due to the adverse conditions it is enduring.

Electrical insulation of medium voltage shielded cables covered by this AMP are not subject to environmental qualification requirements, therefore this AMP is required to manage the ageing effects. This AMP provides reasonable assurance that the electrical insulation for medium voltage shielded cables and connections will perform its intended function.

Evaluation and Technical Basis

1. *Scope of the ageing management programme based on understanding ageing:*

This AMP applies to the electrical insulation of accessible and inaccessible medium voltage shielded cables subject to adverse localized environments caused by temperature, radiation, significant moisture, wear, chemical or surface contamination and subject to ageing management according to national regulatory requirements.

1. *Preventive actions to minimize and control ageing degradation:*

This is a condition monitoring programme; however, the following actions are taken to prevent or mitigate ageing effects for accessible medium voltage shielded cables.

For accessible cables, ensure that the thermal insulation of piping and equipment in the vicinity of the cables is maintained. If thermal insulation from piping and equipment adjacent to cable is removed in preparation for an outage, the effects on adjacent cable needs to be addressed. Procedures for restoration of thermal insulation in the vicinity of cable circuits is reviewed to ensure that the thermal insulation is inspected for acceptability and that adequate protection from thermal stresses is given to the cable.

For inaccessible cables, periodic actions are taken to prevent them from being exposed to significant moisture, such as identifying and inspecting in-scope accessible cable, cable splices, conduit ends, cable trenches, cable troughs, duct banks, underground vaults, or as applicable to embedded raceway or direct buried cable installations, conduit ends, penetrations, or other accessible access points for water accumulation, accessible cable conduit ends and cable manholes for water collection. The water is drained as needed to minimize age degradation effects on cable insulation properties.

Inspection frequencies are adjusted based on inspection results, (e.g. level indication, or direct visual) or plant specific operating experience. Inspections for water accumulation are also performed after event driven occurrences, such as heavy rain, rapid thawing of ice and snow, or flooding. Plant-specific parameters are established for the initiation of an event driven inspection. The periodic inspection includes documentation that either automatic, passive drainage systems, or manual pumping are effective in minimizing cable exposure to significant moisture. If there is monitoring of water level via automatic, or manual means such as a boroscopic inspection, this can be credited for a visual inspection. The periodic inspection is done at least annually, but the inspection frequency should be established to keep the cables from being exposed to significant moisture.

For situations where the draining of accumulated water by manual, passive or automatic means to minimize water accumulation in the raceway is not effective in minimizing cable exposure to significant moisture, additional justification is provided (e.g. additional testing, visual inspection, plant specific and/or industry operating experience, applicable cable research) that demonstrates that the cable subjected to continuous submergence (significant moisture) will continue to perform its intended function.

Medium voltage shielded cables are visually inspected (when possible) for direct indication that cables are not affected by temperature, radiation, significant moisture, wear, and or chemical (e.g. such as leakage of solvents, hydraulic fluid and borates) or surface contamination, cable-splice connections are intact, and for cable jacket surface anomalies such as embrittlement, discoloration, cracking, melting, swelling, or surface contamination due to degradation mechanisms. The cable insulation visual inspection portion of the AMP uses the cable jacket material as a first indicator of the ageing effects experienced by cable electrical insulation. However, the cable jacket can seem visually intact while the cable electrical insulation is aged.

1. *Detection of ageing effects:*

Medium-voltage cable assessment and testing is made by prioritizing cables subjected to the presence of adverse environmental and service conditions, such as the presence of water at the cable surface, high ambient temperature, high radiation, severe ohmic heating, and high-resistance connections. Cables subject to these conditions are assessed or tested using an appropriate test method. The appropriate test method is based on the nature of the adverse environment or condition, the cable design (i.e. extruded or laminated cable) and the expected failure mode [7, 11-13].

The effects of adverse dry environment conditions will be different from those caused by cables being energized in wet or submerged conditions because the failure mechanisms are not the same. Accordingly, different assessment methods apply.

Therefore, the condition of the cable insulation can be assessed with reasonable confidence using the following techniques based on the nature of the adverse environment or condition:

* Visual inspection. For cable jacket and connection insulation in adverse localized environments in search for surface anomalies, such as embrittlement, discoloration, cracking, crazing, swelling, and chemical or surface contamination. Also useful for detecting high conductor temperature from ohmic heating, although by then, the insulation may already be severely degraded.
* Infrared thermography; thermographic inspections are performed on accessible connections terminators and splices in operation conditions (energized and carrying normal current). When infrared thermography indicates that connections are overheating, the degree of damage is to be assessed, and the connection repaired or replaced as appropriate (same as for high conductor temperature from ohmic heating). Infrared thermography is also useful for detecting hot spots and high conductor temperature from ohmic heating.
* Tan δ testing; is likely to detect the dielectric performance deterioration of the cable. The deterioration can be due to severe thermal degradation in adverse localized environments, whether caused by unbalanced magnetic circuits in multi-conductor per phase circuits or by high continuous currents. However, a very localized effect may be difficult to detect with tan δ. The dielectric performance deterioration can also be due to water trees formation (moisture ingress). However, if a cable insulation system has only a single but significant flaw; tan δ may not necessarily detect it. Also note that it does not provide specific location information for identified degradation [7].
* Voltage withstand testing; can be applied to all types of cables and is used as either a simple withstand test (gives a go/no-go information) or monitored withstand test to get additional diagnostic parameters [22]. The test can be carried out with very low frequency (VLF) voltage, damped AC (DAC) voltage or high-voltage DC (HVDC). The simple withstand test detects localized, significant degradations, but provides no information concerning widespread, low-level water degradation [7]. As such this test is used to ensure that a large single defect is not the cause of high mean tan delta. It does however provide assurance for return to service for some period of time. This test provides no information regarding the amount of cable degradation [20].
* Partial discharge (PD); may be most useful in detecting termination and splice problems. Useful also to detect the effects of severe thermal degradation in adverse localized environments. However, water related degradation, such as water treeing, does not produce partial discharge signals. In addition, in the case of helical metal tape shields, oxidation or corrosion of the tapes from long term wetting is likely to severely attenuate partial discharge signals and impede their detection [7]. Frequency Domain Reflectometry (FDR) and Time Domain Reflectometry measurement (TDR); the results allow comparison with a base reflectogram of the cable to facilitate the monitoring of degradation. Useful for detecting the presence of water and its location along the cable as well as cable damage or connection problems (TDR only). However, this is to be used as a secondary test to localize degradation rather than a primary test to determine a degraded cable insulation.
* Insulation resistance and polarization index test. The value of performing this test is that it might eliminate the need for a more sophisticated test if it indicates that the insulation resistance is low. For example, for a medium-voltage cable, insulation resistances that are less than 30.5 MΩ-km (100 MΩ-1000 ft) can be considered inadequate. However, an insulation resistance test is not sufficient solely to be relied on for determining serviceability even if the cable has greater resistance. A thin layer of good insulation in series with a near-through-wall degradation or defect will mask the problem and result in a high insulation resistance. [11]. It is to be noted that a high insulation resistance result is not a sufficiently reliable indicator of the cable's condition, all by itself, and could cause a false impression of the state of the cable.
* Shield continuity and resistance test; useful to detect the condition of the screens and to be able to give credit to tests such as:
* Insulation Resistance (AR); Values in the order of tens of megohms can occur in a failed phase because the failures often blow the shield, leaving a high surface resistance between the conductor and the rest of the shield.
* Dielectric losses (PDE); because the current return to the measurement equipment is through the shield, if the shield is in bad condition the test results will be unreliable.
* Partial Discharge (PD); damage to the shield will cause noise interference which will invalidate the test.
* Reflectometry (FDR and TDR); damage to the shield will cause signal attenuation which may invalidate the test.
* Compressive Modulus (Indenter). Most effective at detecting thermally induced embrittlement and radiation-induced embrittlement. Suitable for assessing short segments of the insulation. Has been proven effective at evaluating and profiling cable damage resulting from localized heat and radiation sources (i.e. hot spots).
* If the set of tests show a degradation of the cable, then additional physical and chemical tests, as elongation at break or micro-sampling could be interesting to define the condition of the cable.
* Other testing that is state-of-the-art at the time the tests are performed.

The first tests are completed early on to create a baseline. If the cable has been in service for a period of time it is recommended that they be tested prior to first failure or prior to 15-20 years in service. Thereafter, a test is to be performed every 6-10 years. 10 years being the longest time between tests admitted (no 25% grace is allowed). All cables in scope of the ageing management program are tested at least once prior to the period of extended operation with subsequent tests performed at least every 6-10 years thereafter. Cables are tested with the same frequency if they continue to test “good.” Cables with results in the “further study required” range (cables showing signs of deterioration but which have not exceeded the acceptance criteria) are subjected to more frequent testing (for example, every two years or once per refuelling cycle) to determine whether the condition is stable or worsening.

Since the main degradation effect is reduced dielectric strength of the insulation due to water/electrical trees (or other voltage related mechanisms) , degradation is not necessarily equally distributed across a cable population. Sampling will not be effective in identifying the degraded cables. Inspections are performed to all medium voltage shielded cables exposed to adverse localized environments that may compromise their intended function.

1. *Monitoring and trending of ageing effects:*

Trending actions are included as part of this AMP, although the ability to trend results is dependent on the specific type of test(s) or inspection chosen. Results that are trendable may be used to provide additional information on the rate of cable insulation degradation.

1. *Mitigating ageing effects:*

This is a condition monitoring programme. However, preventive actions, where practicable, are taken to prevent or mitigate cables from being exposed to process heat damage or significant moisture. This programme has no specific operations, maintenance, repair or replacement mitigation aspects.

1. *Acceptance criteria:*

Any indication or relevant conditions of degradation may be evaluated for acceptance in accordance with the pertinent governing requirements or guidance documents. Examination results and flaws that exceed the acceptance criteria in the pertinent governing requirements or guidance documents may require repair or replacement activities, or further evaluation to demonstrate that the component will continue to perform its intended function through the period of long term operation. An unacceptable indication is defined as a noted condition or situation that, if left unmanaged, could lead to a loss of the intended function.

Acceptance criteria for condition monitoring techniques: The acceptance criteria for each test are defined by the specific type of test performed and the specific cable tested and will depend on the condition monitoring techniques used (e.g. applicability of the condition monitoring technique to the cable and connection electrical insulation material composition and physical construction characteristics).

Acceptance Criteria for Inspection: Cable visual indications for cable jacket are free from unacceptable surface anomalies such as embrittlement, discoloration, cracking, crazing, swelling, or surface contamination due to the degradation mechanism and effects of high-temperature and/or high-radiation ambient, wear, chemical or surface contamination or significant moisture. If the above indications are present, additional testing may be warranted to verify that the cable electric insulation is adequately managed.

1. *Corrective actions:*

An engineering evaluation is performed, and corrective actions are taken when the test or inspection acceptance criteria are not met. Such an evaluation considers the significance of the test or inspection results, the operability of the component, the reportability of the event, the extent of the concern, the potential root causes for not meeting the test or inspection acceptance criteria, the corrective actions required, and the likelihood of recurrence. When an unacceptable condition or situation is identified, a determination is made as to whether the same condition or situation is applicable to other inaccessible, in-scope cables. Corrective actions may include, but are not limited to:

Accessible medium voltage shielded cables; the source of the thermal damage is mitigated, or rerouting of the cable is considered.

Inaccessible medium voltage shielded cables; installation of permanent drainage systems, installation of sump pumps and alarms, more frequent cable testing or inspections, or replacement of the affected cable/section.

1. *Operating experience feedback and feedback of research and development results:*

This AMP addresses the industry-wide generic experience. Relevant plant-specific operating experience is considered in the development of the plant AMP to ensure the AMP is adequate for the plant. The plant implements a feedback process to periodically evaluate plant and industry-wide operating experience and research and development (R&D) results, and, as necessary, either modifies the plant AMP or takes additional actions (e.g. develop a new plant-specific AMP) to ensure the continued effectiveness of ageing management.

Operating experience has identified electrical cable and connection electrical insulation ageing effects due to adverse localized environments caused by temperature, radiation, moisture, wear, and chemical or surface contamination. For example, cable and connections insulation located near steam generators, pressurizers, or hot process piping may be subjected to an adverse localized environment [14-16]. Also, cables in terminal boxes and motor leads has shown up thermal ageing in operating experiences. These degradations are visually observable, in the form of colour changes or surface abnormalities. These visual indications along with cable condition monitoring can be used as indicators of cable and connection insulation degradation.

Operating experience has also shown that many polymer cable insulations rated 2 kV or greater are susceptible to water tree formation. The formation and growth of water trees is dependent on the level of dielectric stress caused by the operating voltage. Ageing effects of reduced insulation resistance due to other ageing mechanisms may also result in a decrease in the dielectric strength of the conductor insulation. Minimizing exposure to moisture mitigates the potential for the development of reduced insulation resistance. Industry operating experience indicates that the onset of XLPE expected water degradation occurred after 10-12 years of service, while failures have been observed in nuclear industry starting at 24 years of service [7]. For the other types of insulation commonly used in nuclear power plants [9], indicates that the earliest expected onset of significant water-related degradation occurs in approximately 20–25 years of wet service.

Guidance has been developed on the use of condition monitoring to identify the presence and extent of ageing effects for cable ageing assessment [17-19]. Related to this AMP, the Electric Power Research Institute among others have on-going programmes [20] to align R&D results with industry guidance and to identify potential gaps in current or planned research projects.

The plant monitors R&D activities and assesses the applicability to this AMP.

1. *Quality management*:

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements, e.g. [21].

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