AMP 201 ELECTRICAL INSULATION FOR ELECTRICAL CABLES AND CONNECTIONS NOT SUBJECT TO ENVIRONMENTAL QUALIFICATION REQUIREMENTS (VERSION 2021)

Programme Description

The purpose of the AMP described herein is to provide reasonable assurance that the intended functions of electrical insulation for electrical cables (e.g., power, control and instrumentation) and connections that are not subject to the environmental qualification requirements and are exposed to adverse localized environments caused by temperature, radiation, moisture, wear, and or chemical (e.g., such as leakage of solvents, hydraulic fluid and borates) or surface contamination are adequately age managed [1-4, 8-11].

In most areas within a nuclear power plant, the actual operating environments (e.g., temperature, radiation, moisture, wear, chemical or surface contamination) are less severe than the plant design environment. However, in a limited number of localized areas, the actual environments may be more severe than the anticipated plant design environment. These localized areas are characterized as “adverse localized environments” that represent a limited plant area where the operating environment is significantly more severe than the plant design environment. For example, next to or above steam generators, pressurizers, or hot process pipes, such as feedwater lines, main steam lines etc. Adverse localized environments are a plant-specific condition; therefore, the operating plant clearly defines how adverse localized environments are determined. The operating plant identifies and inspects the adverse localized conditions for each of the most limiting conditions (e.g., temperature, radiation, moisture) for the accessible cables and connections within scope according to national regulatory requirements. Adverse localized environments are identified through the use of an integrated approach. This approach may include, but is not limited to: (a) the review of EQ programme radiation levels, and temperatures, (b) recorded information from equipment or plant instrumentation, (c) utilization of infrared thermography to identify hot spots on a real-time basis, (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 [5].

Electrical insulation used in electrical cables and connections may degrade more rapidly than expected when exposed to an adverse localized environment. Cable or connection electrical insulation subjected to an adverse localized environment may increase the rate of ageing of a component or have an adverse effect on operability. An adverse localized environment exists based on the most limiting actual operating environment (e.g., temperature, radiation, moisture, wear, and chemical or surface contamination such as leakage of solvents, hydraulic fluid and borates) for the insulation material of cables or connections.

These adverse localized environments have been found to cause degradation of the insulating materials on electrical cables and connections that are visually observable, such as color changes or surface cracking. These visual indications can be used as indicators of degradation. Additionally, operating experience in some member states has shown degradation of cable insulation [6] due to changes in overall environmental conditions following a modification in the plant and resulting in degradation of the heat sink.

The ageing effects detected in electrical insulation for electrical cables and connections are reduced insulation resistance and material hardening or loss of strength (e.g., dielectric or material). These ageing effects are produced by ageing related 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 programme described herein was written specifically to address electrical insulation for electrical cables and connections at plants whose configuration is such that most (if not all) electrical cables and connections installed in adverse localized environments are accessible. Accessible cables and connections are visually inspected and represent, with reasonable assurance, all cable and connection ageing effects in the adverse localized environment. If an unacceptable condition or situation is identified for an accessible cable or connection, a determination is made, consistent with a member state’s acceptance criteria and corrective action program, as to whether additional visual inspections or testing is required and if the same condition or situation is applicable to inaccessible cables or connections electrical insulation. As such, this programme does not apply to plants in which most cables are inaccessible.

In this programme, the accessible in-scope cable and connection visual inspection is performed from the floor, with the use of scaffolding as available, without the opening of junction boxes, pull boxes, or terminal boxes. The purpose of the visual inspection is to identify adverse localized environments (employing diagnostic tools such as thermography as applicable). These potential adverse localized environments are then evaluated which may require more detailed visual inspection or testing as applicable to assess electrical cable and connection electrical insulation ageing effects and degradation mechanisms.

The cable condition monitoring portion of the AMP utilizes sampling for electrical insulation testing of electrical cable and connections, if applicable. The component sampling methodology utilizes a representative sample that considers operational experience of electrical cable and connection insulation types as permitted by national regulatory requirements [7, 18].

Electrical insulation for electrical cables and connections 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 electrical 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 electrical insulation of accessible cables and connections (cable system) subject to adverse localized environments caused by temperature, radiation, 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 of electrical insulation for electrical cables (e.g., power, control and instrumentation) and connections that are not subject to the environmental qualification requirements and are exposed to adverse localized environments caused by temperature, radiation, moisture, wear, and/or chemical or surface contamination.

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.

Cables are visually inspected (when possible) for direct indication that they 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:*

Insulation ageing degradation may cause cable jacket and connection insulation surface anomalies. The inspection of cable jacket and connection insulation surface is used to infer the adequacy of the cables and connections. If unacceptable visual indications of surface anomalies exist, then cable insulation assessment and testing are needed. Cable assessment and testing is made by prioritizing cables subjected to the presence of adverse environmental and service conditions, such as 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 [12-15]. The inspection frequency of the cable system is determined based on engineering evaluation [16-18].

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. If visual inspections identify age degradation consistent with this AMP, then testing may be performed as applicable. For a large number of cables and connections, a sample population may be tested. The following factors are considered in the development of the electrical cable and connection electrical insulation test sample: environment including identified adverse localized environments (high temperature, moisture, wear, etc.), voltage level, circuit loading, connection type, and insulation material. The component sampling methodology utilizes a representative sample that considers operational experience of electrical cable and connection electrical insulation types as permitted by national regulatory requirements.
* 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. 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 [13].
* Voltage withstand testing; can be applied to all types of cables (although normally performed on medium and high-voltage class 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 [19]. The test can be carried out with very low frequency (VLF) voltage, damped AC (DAC) voltage or high-voltage DC (HVDC)[[1]](#footnote-2). The simple withstand test detects localized, significant degradations, but provides no information concerning widespread, degradation [13]. 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 for medium voltage cables.
* 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. These tests are useful in identifying insulation degradations along the cable as well as cable damage or connection problems (TDR only). However, these tests can only 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. [14]. 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 (typically used only on shielded medium voltage cables); 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 (medium voltage cables only).
  + 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). When performed in situ, this test measures the compressive modulus for the outer surface of an electric cable’s polymer jacket material. The condition of underlying cable insulation is to be inferred from the indenter compressive modulus measurements made on the outer jacket material
* 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 that is usually admitted (no 25% grace is possible). 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 refueling cycle) to determine whether the condition is stable or worsening.

In order to optimize the programme with reasonable assurance, a representative sample (based on international guidelines), combined with criticality analysis results of a reliability programme could be defined, if permitted, by the national regulatory requirements [21-23].

More explanations and considerations related to testing methods to be used and the respective acceptance criteria can be found in Appendix 1 of AMP210.

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 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 unacceptable conditions are found. The evaluation is to consider the age and operating environment of the component as well as the severity of the anomaly and whether such an anomaly has previously been correlated to degradation of electrical insulation for electrical cables or connections. Corrective actions may include, but are not limited to, testing, shielding, or otherwise changing the environment or relocation or replacement of the affected cables or connections.

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 [6, 24, 25]. These environments have been found to cause degradation of electrical cable and connection electrical insulation that are visually observable, such as color changes or surface abnormalities. These visual indications along with cable condition monitoring can be used as indicators of cable and connection insulation degradation.

At the time when this AMP was produced, no relevant R&D was identified.

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., [26].

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1. HVDC is not recommended on service-aged extruded dielectric cable insulations. [↑](#footnote-ref-2)