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Dielectric Assessment of 11 kV Three-Core XLPE Power Cable during New Substation Commissioning

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Abstract

Assessing the condition of power cables is crucial to ensure they are ready for operation. Neglecting this can lead to significant losses, especially for large industrial users. A key indicator of potential issues is any discrepancy between the dielectric properties measured during commissioning and those specified by the manufacturer, which may suggest that the cables are not yet ready to be installed. To mitigate such risks, the dielectric performance of newly installed 3C 500MMP XLPE cables was evaluated both before and after jointing and termination, prior to commissioning the new main substation. The assessment included Insulation Resistance (IR) and Dielectric Absorption Ratio (DAR) tests, along with continuity and a 24-hour soaking test to verify electrical connectivity and overall performance. The IR and DAR tests yielded results within acceptable ranges, with insulation resistance values exceeding 0.1 GΩ and DAR values above 1.6. Continuity tests confirmed proper jointing and termination, as evidenced by resistance values below 5 Ω. Furthermore, the absence of tripping incidents during the 24-hour soaking period provided additional assurance of the cables' readiness for energization.

Keywords

Dielectric Absorption Ratio, Insulation Resistance, Soaking Test, XLPE Cable

1. Introduction

Cross-linked polyethylene (XLPE) cables are widely used in electrical networks due to their excellent insulating properties. Manufactured under tightly controlled factory conditions, XLPE cables can withstand voltages far exceeding their rated levels without failure. However, most failures in XLPE cables are attributed to moisture ingress at joints or terminations, as well as poor workmanship or substandard materials during jointing and termination processes.

Condition monitoring of power system components such as transformer cores and windings [1], on-load tap changers (OLTCs) [2] [3], and power cables [4] is a fundamental practice for maintaining system reliability and operational integrity. Commissioning tests of power cable insulation systems are critical for minimizing the probability of early failures, identifying manufacturing or installation defects, and mitigating the long-term degradation effects associated with insulation aging. Performing these diagnostic assessments immediately following installation is essential, as they establish baseline reference values for key insulation parameters, thereby defining the system's initial or "zero-state" condition.

Cable testing also plays a vital role in identifying defects that could lead to premature failure of the cable or its terminations under controlled conditions [5] [6]. These tests must adhere to defined specifications to ensure that all electrical equipment and systems (whether supplied by contractors or the owner) are functioning correctly and comply with relevant standards and the manufacturer's published tolerances. Additionally, testing verifies that equipment and systems have been installed in accordance with the design specifications (ANSI/NETA MTS-2007: *Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*, 2007).

In practice, it is essential to determine the dielectric characteristics of power cables during commissioning to confirm their readiness before energization. While these characteristics are typically provided in the manufacturer's datasheet, actual values may deviate due to various factors. Insulation failures can occur during transportation, installation, or during jointing and termination, even before the new substation is commissioned. Failure to verify the dielectric condition of cables can result in catastrophic system failures; events that are risky, costly, and time-consuming.

This paper aims to evaluate the dielectric characteristics of newly installed 3C 500 MMP XLPE cables both before and after jointing and termination, prior to the commissioning of a new substation. The analysis is conducted using Insulation Resistance (IR) and Dielectric Absorption Ratio (DAR) tests. Additionally, the continuity and operational performance of the cables before energization are assessed through continuity testing and a 24-hour soaking test.

2. Method

2.1. Test Method and Equipment

A total of six drums of three-core 500 mm^2 (3C 500 mm^2) XLPE power cables were utilized in this study, as shown in **Table 1**. Each cable segment was tested individually prior to the execution of jointing and termination works.

Table 1. Cable lengths used in this study.

Portion number/cable drum	Cable lengths (m)
1	490
2	480
3	460
4	490
5	460
6	480
7	470
8	480
9	490
10	450
11	440
12	470

To ensure the cables' readiness, compliance with the following criteria was mandatory: (1) IR test with a pass threshold of greater than 0.1 GΩ, (2) DAR test with a pass threshold of DAR greater than 1.6, and (3) Continuity test with a pass threshold of resistance less than 5 Ω [7] [8]. After proper jointing and termination of all cable segments, a 24-hour soaking test was conducted prior to energization. Cables were deemed ready for operation if no tripping occurred during this 24-hour period.

The recorded data encompassed details such as the cable system name, installation location, total installed cable length, and specifications of cables and accessories including joints and terminations, with their respective types, ratings, and installation dates. Additionally, the data included the cable system's operating voltage, testing methods, voltage levels (peak and RMS), test durations, and other parameters such as test frequency. Information on the test equipment, specifically type and serial number was also documented.

Test results had to specify whether the test passed, failed, or included any evaluation measurements based on the testing technique. In the case of a failed test, the data of the failed result had to include the test failure voltage level, the instantaneous voltage level at the precise time of failure (not the RMS or peak test voltage), the exact time into the test when the failure occurred, the failed cable system component (including identification and location), and the date, location, and name of the person who performed the test.

The insulation resistance tester, shown in **Figure 1**, could measure up to 10 TΩ and had a selectable test voltage range between 250 V and 5 kV. It was used to perform the IR test, DAR test, and Continuity test. **Figure 2** shows a discharge rod that was used to discharge cables or other electrical objects. The discharge rod was essential to ensure that the test subject did not retain any charge. It could withstand up to 40 kV DC, ensuring the tester's safety during testing.

Figure 1. Insulation resistance tester.

Figure 2. Discharge rod.

2.2. Insulation Resistance (IR) Test

The wiring diagram for the IR test is illustrated in **Figure 3**. An applied voltage of 5 kV was used, appropriate for the power cable's 11 kV rating. Testing was performed on all phase-to-phase connections (R-Y, Y-B, and B-R) as well as on each phase-to-earth connection (R-E, Y-E, and B-E). Each cable segment was tested individually before jointing to ensure the absence of faults. Any cable showing a fault was repaired prior to jointing with other sections. The test was deemed successful if the insulation resistance exceeded 0.1 GΩ.

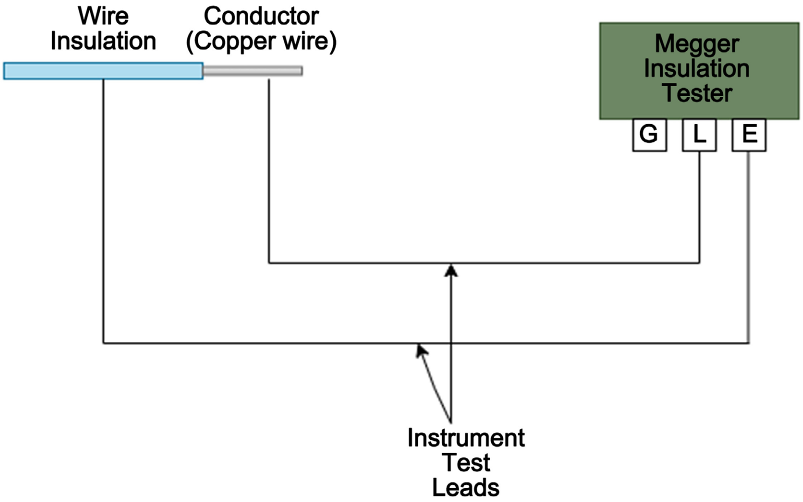

Figure 3. Wiring diagram for the IR test setup.

The cable was installed employing the Horizontal Directional Drilling (HDD) technique to ensure rapid soil coverage, thereby preventing extended exposure to rain or surface water. This approach mitigates initial moisture absorption and reduces the risk of damage to the cable insulation during installation.

2.3. Continuity Test

Figure 4 illustrates the wiring diagram for the continuity test. Although the power cable is rated at 11 kV, the insulation resistance tester was set to 5 kV for this test. Continuity was checked across all phase-to-phase connections (R-Y, Y-B, and B-R). The continuity test was conducted on each cable segment prior to jointing to identify any faults. Only cables passing this test were permitted to be jointed. The test was considered successful if the measured resistance was below 5 Ω.

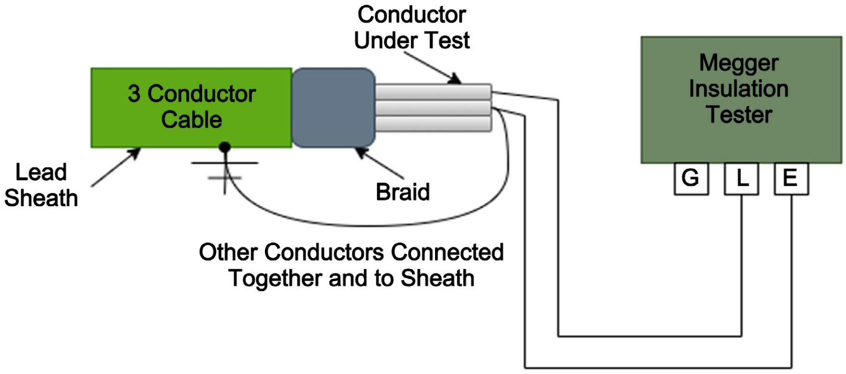

Figure 4. Wiring diagram for the continuity test setup.

2.4. Dielectric Absorption Ratio (DAR) Measurements

DAR is calculated by taking the ratio of the insulation resistance of 11 kV-rated power cable measured at 1 minute to that measured at 30 seconds following the application of a 5 kV.

DAR tests on 11 kV cables are usually performed at rated voltages, but studies show that 5 kV is sufficient to obtain reliable dielectric absorption results. This voltage strikes a balance between test accuracy and protecting the cable insulation by detecting moisture ingress and continuity faults without causing undue stress.

Measurements were taken for all phase-to-phase connections (R-Y, Y-B, and B-R) as well as phase-to-earth connections (R-E, Y-E, and B-E). The DAR results reflect the insulation resistance characteristics of the cable. The test is considered successful if the DAR value exceeds 1.6.

2.5. 24-Hours Soaking Test

After successfully completing all insulation tests, the system was energized under load to verify the power cable's condition. Over a 24-hour period, the system was monitored for rated voltage and live phasing. Voltage testing ensured the system operated within the rated 11 kV range, allowing for a tolerance of −5% to +5%. Live phasing tests confirmed the correct phasing of the system.

3. Results

3.1. Results of Insulation Resistance (IR) Test

Table 2 and **Table 3** present the IR test results for phase-to-earth and phase-to-phase measurements, respectively. It is evident that all power cables tested prior to jointing and termination exhibited IR values above 0.1 GΩ, thereby passing the test, despite some variability in the readings. Certain phase measurements showed lower values, while others were higher. Notably, the cable segment in portion 1 displayed greater inconsistency compared to the other portions.

Table 2. IR test results for phase-earth.

Portion number/ cable drum	Cable length (m)[a]	R-E (GΩ)	Y-E (GΩ)	B-E (GΩ)
1	490	5.97	3.46	4.61
2	480	6.13	4.06	5.18
3	460	5.43	5.81	5.46
4	490	6.13	4.67	5.38
5	460	6.28	4.58	6.17
6	480	5.45	5.13	5.92
7	470	7.16	8.22	6.43
8	480	8.82	7.69	7.33
9	490	5.29	7.77	6.17
10	450	5.42	6.18	7.19
11	440	9.12	8.71	9.41
12	470	8.83	6.38	8.46
Overall	5660	35.41	33.72	38.27

Table 3. IR test results for phase-phase.

Portion number/ cable drum	Cable length (m)[a]	R-Y (GΩ)	Y-B (GΩ)	B-R (GΩ)
1	490	16.91	19.26	15.81
2	480	16.98	18.15	17.97
3	460	20.13	21.05	15.55
4	490	17.71	19.82	18.55
5	460	17.78	14.31	16.9
6	480	5.45	5.13	5.92
7	470	22.31	18.33	19.21
8	480	18.21	21.61	21.42
9	490	17.33	16.43	15.21
10	450	24.37	18.26	17.54
11	440	30.62	29.11	25.72
12	470	21.58	18.92	22.26
Overall	5660	42.41	48.22	39.19

The inconsistencies in the test results were primarily attributed to the absence of a solid grounding connection to the power cable during testing. Additionally, the presence of mud or sand on the power cable conductor or copper strip (likely due to inadequate cleaning before connecting the insulation resistance tester probes) contributed to these variations. Since the cable was installed using the HDD method, which typically results in muddy site conditions, there was a high likelihood of mud and sand adhering to the exposed conductor cores when the cable caps were removed for testing [9].

3.2. Results of Dielectric Absorption Ratio (DAR) Measurements

Table 4 and Table 5 present the DAR results for phase-to-earth and phase-to-phase measurements, respectively. The readings were generally consistent but did not meet the minimum passing criterion of DAR > 1.6. This indicates that exposed insulation without proper termination can lead to lower DAR values [10]. Low DAR in individual portions might results from their short length rather than from insulation failure. However, after all cable portions were properly jointed and terminated, the DAR test results met the required standard. Jointing improves overall insulation condition by creating longer and stable insulation system, which increases DAR above 1.6.

Each cable segment was tested individually prior to jointing and termination. When the insulation was not properly terminated, its dielectric absorption capacity was reduced. Once the insulation was correctly terminated, the DAR measurements improved, as reflected in the overall test results of the completed cable sections. The readings were consistent across most portions except for portion 3. Although portion 3 did not show significant inconsistency, the DAR value still failed to meet the minimum requirement. This may be attributed to the possibility that the cable conductor was in contact with the ground [10] [11].

Table 4. DAR test results for phase-earth.

Portion number/ cable drum	Cable length (m)[a]	R-E (GΩ)	Y-E (GΩ)	B-E (GΩ)
1	490	1.02	1.26	1.04
2	480	1.10	1.27	1.13
3	460	1.75	1.05	1.10
4	490	1.05	1.09	1.27
5	460	1.19	1.25	0.83
6	480	1.23	1.21	1.13
7	470	1.23	1.16	1.19
8	480	1.17	1.02	1.27
9	490	1.31	1.22	1.41
10	450	1.27	1.31	1.16
11	440	1.27	1.18	1.31
12	470	1.31	1.22	1.24
Overall	5660	1.77	1.81	1.83

Table 5. DAR test results for phase-phase.

Portion number/ cable drum	Cable length (m)[a]	R-Y (GΩ)	Y-B (GΩ)	B-R (GΩ)
1	490	1.03	0.82	1.10
2	480	1.18	1.08	1.16
3	460	1.20	1.08	1.04
4	490	0.82	1.03	1.11
5	460	1.21	1.91	1.21
6	480	1.06	1.14	1.25
7	470	1.41	1.31	1.37
8	480	1.35	1.22	1.19
9	490	1.27	1.31	1.26
10	450	1.41	1.27	1.39
11	440	1.22	1.37	1.18
12	470	1.16	1.08	1.14
Overall	5660	1.71	1.69	1.76

3.3. Results of Continuity Test

The continuity test passed on all portions of the power cable, as shown in **Table 6** This successful result was maintained after the entire cable system was completed. If the continuity test fails on one or more sections, fault location must be performed. A failed continuity test indicates leakage within the cable, allowing current to pass between phases [12]. Cable portions that fail the continuity test cannot be jointed or terminated until the issue is resolved [13].

Table 6. Continuity test results.

Portion number/ cable drum	Cable length (m)[a]	R-Y (GΩ)	Y-B (GΩ)	B-R (GΩ)
1	490	0	0	0
2	480	0	0	0
3	460	0	0	0
4	490	0	0	0
5	460	0	0	0
6	480	0	0	0
7	470	0	0	0
8	480	0	0	0
9	490	0	0	0
10	450	0	0	0
11	440	0	0	0
12	470	0	0	0
Overall	5660	0	0	0

3.4. Results of 24-Hours Soaking Test

The performance of the new Type 3C 500 MMP XLPE cables was evaluated through a 24-hour soaking test conducted prior to energization. During this period, the cables were energized without load continuously for 24 hours. The system showed no tripping events, and both voltage levels and phasing remained stable and within acceptable limits.

If tripping occurred, a diagnostic procedure would have been initiated. First, the circuit breaker relay would be inspected to verify its proper function. If the relay was found to be operating normally, an IR test would be conducted to assess the cable insulation's integrity. Should the IR test yield satisfactory results, the cable would then undergo a pressure test, involving the application of the rated 11 kV voltage for one minute. If the cable failed this pressure test, it would be connected to a thumping set to accurately locate the fault. After fault detection and repair, the cable would be required to pass the full sequence of tests, including soaking, IR, and pressure tests before being approved for commissioning and operation. This rigorous process ensures the system's reliability and safety.

The results of all electrical tests conducted in this study highlight the significant impact of environmental conditions on the accuracy and consistency of power cable testing. Since testing was carried out in open areas, several uncontrolled factors such as rain, mud, sand, dust, and varying land surfaces contributed to inconsistent test results. Narrow and inaccessible installation areas increased the likelihood of cable contamination with impurities that were difficult to remove, thereby affecting insulation values before and after installation.

One of the most influential environmental factors is soil moisture [10] [14]. Moist conditions not only accelerate cable degradation but also introduce errors during insulation resistance testing. If the exposed cable core comes into contact with damp surfaces, moisture (being conductive) can allow current to bypass insulation and flow to the screen, skewing test readings [15] [16]. This phenomenon compromises the accuracy of results, as part of the test current is diverted to ground.

Temperature is another critical factor [17] [18]. The resistance of insulating materials decreases with temperature; generally, for every 10˚C increase, resistance is halved, and for every 10˚C decrease, resistance is doubled. Since testing was conducted in broad daylight and some cable sections were exposed to direct sunlight for extended periods, temperature differences between cable portions likely contributed to inconsistent readings. Although time-resistance and step-voltage techniques are relatively insensitive to temperature fluctuations, conventional IR and DAR tests can vary significantly with thermal changes.

In addition to environmental influences, inconsistent insulation removal lengths across cable phases also played an important role [5]. Uneven insulation lengths result in variable dielectric properties between phases, which can lead to unbalanced test results, even when other parameters remain constant.

Another major contributor to test result inconsistency is inadequate grounding during pre-jointing tests. Accurate testing requires a complete circuit, and this is only achievable with proper, low-resistance grounding. According to Tenaga Nasional Berhad (TNB) specifications, effective grounding should have a resistance of less than 3 Ω. In this study, prior to jointing and termination, temporary grounding was used, with tester probes connected only to the copper tape screen which was not properly earthed. This led to imperfect grounding, causing test current to flow unpredictably and producing unreliable readings.

After all cable segments were jointed and terminated, and connected to a circuit breaker with a solid ground (resistance < 3 Ω), both phase-to-earth and phase-to-phase readings became consistent. The DAR values also improved significantly. This outcome confirms the critical role of solid grounding in achieving reliable test results. It also underscores the necessity of grounding all non-energized metallic parts in the vicinity of high-voltage testing. Doing so minimizes overvoltage risks on insulation gaps and surge protectors in the event of a test failure.

Furthermore, cables subjected to high-voltage testing can retain residual charge due to dielectric absorption. If these cables are not grounded for a sufficient period after testing, they may pose safety hazards due to voltage buildup. Thus, proper post-test grounding procedures are also essential.

4. Conclusion

The dielectric characteristics of the new type 3C 500 MMP XLPE cables were thoroughly evaluated prior to the commissioning of a new substation using IR tests and DAR measurements. The results demonstrated that each layer of the power cable contributes significantly to its overall dielectric performance due to its distinct electrical properties. Accurate stripping and preparation of each layer, in accordance with the jointing and termination manual, were essential to ensuring reliable test results. This careful attention to detail led to consistently positive outcomes for the jointed and terminated cable segments. Additionally, the continuity and overall performance of the cables prior to energization were verified to be in good condition, as all segments successfully passed both the continuity and 24-hour soaking tests. Upon successful completion of the soaking test, and with approval from the Distribution Control Center, the power cables were officially commissioned and energized under load.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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