Nexans

Insulation Resistance Testing
of Low Voltage Cables in the Field

Table of Contents

References

CSA C22.2 No. 2556 / UL 2556, "Wire and Cable Test Methods"
IEEE 525, "Guide for the Design and Installation of Cable Systems in Substations"
NETA ATS-2009, "Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems"

Warning:

Insulation resistance testing should be done by qualified personnel, familiar with both insulation resistance testing and with the safe operation of the test equipment. Consult the insulation resistance test equipment manual or manufacturer for insulation resistance testing procedures and recommended safety guidelines. This document is intended to be a guideline only.

1. Background

The following is a summary of insulation resistance (IR) testing (commonly referred to as "megger testing") of low voltage cables (rated less than 5 kV), recognized by Nexans. This document will focus only on the tests that are of importance for field installers which are described as "Installation" and "Maintenance" tests. Testing should be done by qualified personnel, familiar with both insulation resistance testing and with the safe operation of the test equipment. Nexans cannot provide actual insulation resistance values since they depend on a number of factors, such as:

- Insulation material;
- Conductor size;
- Conductor insulation temperature (i.e. if directly exposed to sunlight);
- Humidity (i.e. if the cable is wet);
- Cable length; and
- Cable end condition (i.e. insulation not stripped back, cable ends not separated).

There are 4 types of insulation resistance tests for wire and cable that are recognized by Nexans:
1. Type test / qualification test / conformance test;
2. Factory test;
3. Installation test; and
4. Maintenance test.

Type testing (also referred to as qualification testing or conformance testing) is typically performed on a new or modified cable design, usually for the purpose of proving conformance to either CSA or UL standards. This type of test is not performed on production runs of cable.

Factory insulation resistance testing is performed when required at the factory of manufacture to ensure conformance to applicable standards / specifications. This test is performed according to a designated test method (e.g. as defined by CSA or UL).

Installation tests are performed directly after cable installation, and before termination to any equipment or accessories. Installation insulation resistance tests are only to be performed on new wire and cable. This type of test is a "go / no go" type of test, and is to determine if the insulation has been damaged during installation.

Maintenance insulation resistance testing can be performed on a regular basis, and the collected data used to indicate if the conductor insulation is deteriorating over time. This type of test is a form of preventative maintenance. If the insulation resistance falls below an accepted (user dictated) value, or falling rapidly over time, then cable replacement is considered.

Although 4 tests are listed above, this document will focus only on the tests that are of importance for field installers which are described as "Installation" and "Maintenance" tests.

1.1. Before Making Measurements

Insulation resistance test results are dependant on a number of factors, such as temperature and humidity. For this reason, care must be taken to properly prepare the cable to be tested. For best results:

1. Remove the cable from service, disconnecting all other circuits or devices, as well as any cable accessories and protective end caps, and open the cable at both ends and ensure conductors are isolated from each other;

2. Only test a cable if the temperature of the conductor is above the dew point – otherwise, moisture will form on the surface of the insulation, and could be absorbed by the cable causing the test to fail;

3. Make sure that the conductor surface is free of carbon, or any other material that may be conductive;

4. Do not exceed the recommended test voltage of the cable – otherwise, the conductor insulation can be overstressed, or even damaged; and

$\mathcal{N}$exans

5. Measure the temperature of the conductor insulation before each set of insulation resistance measurements – otherwise, the measured insulation resistance may seem abnormally high or low.

1.2. How to Apply the Temperature Correction Factor

It is important to note that the insulation temperature may be significantly higher or lower than the ambient air temperature. When the insulation temperature and the insulation resistance at that temperature are known, the insulation resistance for any other temperature can be calculated. As an alternative, the insulation resistance temperature correction factor can be looked up from a table, for a given standard temperature (15 ºC, as determined by CSA and UL).

1.2.1. Calculation

The insulation resistance can be calculated using the following formula:

$$R_{S\tan dard} = \frac{R_{Measured}}{e^{(T_{S\tan dard} - T_{Measured}) \bullet \ln(K)}}$$

Where:

- $R_{Measured}$ is the measured insulation resistance, typically in mega-ohms or giga-ohms;
- $R_{S\tan dard}$ is the insulation resistance at the desired temperature, in the same units as the measured insulation resistance;
- $T_{Measured}$ is the measured insulation temperature, in degrees Celsius;
- $T_{S\tan dard}$ is the desired insulation temperature, in degrees Celsius; and
- K is the coefficient of the insulation material.

For example, we can calculate the insulation resistance at a desired insulation temperature, given the following details:

$K = 1.16$
$T_{Measured} = 50\ ºC$
$R_{Measured} = 2.7\ MΩ$
$T_{S\tan dard} = 15\ ºC$

Using the formula above, the insulation resistance at this desired temperature (15 ºC) would be: 487 MΩ.

1.2.2. Multiplication Factor Lookup

Alternatively, the insulation resistance can be determined by looking up the insulation resistance correction factor from a table of values (listed in Appendix A of this document). In this case, a standard temperature of 15 ºC has been selected. The insulation resistance correction factor is applied using the following formula:

$$R_{S\tan dard} = R_{Measured} \bullet F$$

Where:

- $R_{Measured}$ is the measured insulation resistance, typically in mega-ohms or giga-ohms;
- $R_{S\tan dard}$ is the insulation resistance at the standard temperature (15 ºC), in the same units as the measured insulation resistance;

- F is the insulation resistance temperature correction factor from the table in Appendix A.

For example, we can determine the insulation resistance at the standard temperature of 15 ºC, given the following details:

K = 1.16

$T_{Measured}$ = 50 ºC

$R_{Measured}$ = 2.7 MΩ

From the table in Appendix A, we find that the insulation resistance temperature correction factor (F), for the insulation material with a coefficient of 1.16 is: 180.31. Applying this factor, we calculate the insulation resistance at the standard temperature (15 ºC) to be: 487 MΩ.

1.3. "Go / No Go" Minimum Acceptable Insulation Resistance Value

"Go / no go" testing is performed on new cable installations to determine if the insulation has been damaged during installation. The minimum acceptable insulation resistance value is calculated using the following formula:

$$R_{Insulation} = (V_{Rated} + 1) \bullet \left(\frac{304.8}{L} \right)$$

Where:

$R_{Insulation}$ is the minimum acceptable insulation resistance value, in mega-ohms;

V_{Rated} is the rated voltage of the cable (typically printed on the cable), in kilovolts; and

L is the length of the cable, in meters (if the cable length is in feet, replace the number 304.8 with 1000).

For cables rated 600 V, the minimum acceptable insulation resistance values for cable lengths from 100 to 1000 feet would be as shown in the following table, from IEEE 525.

Table 1: Minimum Acceptable Insulation Resistance for 600 V Cable, from 100 to 1000 Feet

Length of Cable		Minimum Acceptable Insulation Resistance Value
m	ft	MΩ
30.5	100	16
61.0	200	8
91.4	300	5.3
122	400	4
152	500	3.2
183	600	2.7
213	700	2.3
244	800	2
274	900	1.8
305	1000	1.6

2. Installation Testing

An insulation resistance test is typically performed on de-energized wire and cable immediately after installation, and before termination to any equipment or accessories. This test is used to detect conductor insulation damage that may have been caused during installation. This type of test is commonly referred to as "go / no go testing" (or dielectric withstand test), since the cable passes the test if no break-down occurs.

The test voltage selected for this type of test is less than 5 kV, and is applied for up to one minute, or until the measured insulation resistance value stabilizes. The test voltage is the rated voltage of the cable (the line-to-line voltage). Any voltage larger than this may stress the cable and cause premature failure.

2.1. Procedure

For each cable that is to be tested:

1. Record the following data from the reel or coil tag:
    *   Reel / coil number;
    *   Date of manufacture;
    *   Cable length;
    *   Type of cable; and
    *   Conductor size.

2. OPTIONAL – Measure and record the conductor insulation temperature. For a cable with multiple conductors, the insulation temperature for one of the conductors will suffice. This temperature may be different than the ambient air temperature, especially if the cable is exposed to direct sunlight.

3. Strip back the cable at each end, as if it were to be connected to the supply and load equipment (remove the jacket, separate the conductors, and strip the ends of the conductors of any insulation). The cable must be disconnected from any equipment at both ends. This includes switches, receptacles, and any other kind of device that may be connected to the conductors. An open switch connected to the cable could present a low resistance path, making the cable appear to fail.

4. Separate the conductors from each other, and from any ground conductors, to allow for the best possible insulation resistance reading.

5. Thoroughly clean the exposed conductor ends to remove any dirt or debris. They should also be completely dry at the time of measurement. This will also improve the measurement.

6. Conduct the insulation resistance test according to test set manufacturers instructions. We suggest applying voltage between each pair of insulated conductors, and insulated conductors to bare grounds, shields and armour. All of the bare ground conductors are to be bonded together, and to any shields and / or armour that may exist in the cable, and grounded. Each insulated conductor should be tested separately and the results recorded. For a 3-phase cable, containing 3 insulated conductors (A, B, and C), cabled with a bare ground (G), the suggested tests would be from:
    *   A to B;
    *   B to C;
    *   C to A;
    *   A to G;
    *   B to G; and
    *   C to G.

7. Review the recorded measurements. Ultimately, this is a "go / no go" type of test, meaning that all insulation resistance measurement values must be greater than the "go / no go" acceptance value calculated, as shown in Section 1.3, above. Values that show an extremely large value (i.e. peak meter value) would indicate that there was a possible connection issue in the system. Values that are at or near zero (0) would indicate that either the insulation has failed somewhere along the length of the cable, or the cable to be tested was poorly prepared (i.e. equipment still connected to the cable, insulation not stripped back, cable ends not separated). If there is any issue with interpreting the results, please consult Nexans for assistance.

3. Preventative Maintenance Testing

Preventative maintenance testing is typically performed on a cable that has already been in service for an extended period of time (many months or years). This test is used to monitor any degradation in insulation performance over

time. Accurate records of the date of test, insulation resistance, as well as conductor insulation temperature must be kept. This data may be used to determine insulation deterioration.

The test voltage selected for this type of test is less than 5 kV, and is applied for up to one minute, or until the measured insulation resistance value stabilizes. The test voltage is the rated voltage of the cable (the line-to-line voltage). Any voltage larger than this may stress the cable and cause premature failure.

3.1. Procedure

For each cable that is to be tested:

1. Measure and record the cable length. Also record the cable type and conductor size.

2. Measure and record the conductor insulation temperature. For a cable with multiple conductors, the insulation temperature for one of the conductors will suffice. This temperature may be different than the ambient air temperature, especially if the cable is exposed to direct sunlight.

3. Disconnect the cable from any equipment or devices at both ends. This includes switches, receptacles, and any other kind of device that may be connected to the conductors. An open switch connected to the cable could present a low resistance path, making the cable appear to fail.

4. Separate the conductors from each other, and from any ground conductors, to allow for the best possible insulation resistance reading.

5. Thoroughly clean the exposed conductor ends to remove any dirt or debris. They should also be completely dry at the time of measurement. This will also improve the measurement.

6. Conduct the insulation resistance test according to test set manufacturers instructions. We suggest applying voltage between each pair of insulated conductors, and insulated conductors to bare grounds, shields and armour. All of the bare ground conductors are to be bonded together, and to any shields and / or armour that may exist in the cable, and grounded. Each insulated conductor should be tested separately and the results recorded. For a 3-phase cable, containing 3 insulated conductors (A, B, and C), cabled with a bare ground (G), the suggested tests would be from:
    *   A to B;
    *   B to C;
    *   C to A;
    *   A to G;
    *   B to G; and
    *   C to G.

7. Review the recorded measurements. These measurements are recorded for historical reasons, and are only to be compared with past values from the same cable. It should be noted that in order to be compared, all insulation resistance values must be taken at the same conductor insulation temperature, or scaled for temperature. This type of testing is intended to be performed on a regular basis. Nexans suggests on an annual or bi-annual (every other year) basis. If there is any issue with interpreting the results, please consult Nexans for assistance.

4. Summary

This document summarizes Nexans' recommendations for insulation resistance testing of low voltage cables (rated less than 5 kV). Testing should be done by qualified personnel, familiar with both insulation resistance testing and with the safe operation of the test equipment. Nexans cannot provide actual insulation resistance values since they depend on a number of factors, such as:
*   Insulation material;
*   Conductor size;
*   Conductor insulation temperature (i.e. if directly exposed to sunlight);
*   Humidity (i.e. if the cable is wet);

- Cable length; and
- Cable end condition (i.e. insulation not stripped back, cable ends not separated).

The following table summarizes the possible field insulation resistance tests.

Table 2: Summary of Field Insulation Resistance Tests

	Installation	Maintenance
Type of Test	Go / No Go	Subjective
Reel or Coil Number	Required	Not Applicable
Date of Manufacture	Required	Not Applicable
Cable Length	Required	Required
Type of Cable	Required	Required
Conductor Size	Required	Required
Insulation Temperature	Optional	Required
Test Voltage	$V_{Test} = V_{Rated}$	$V_{Test} = V_{Rated}$
Test Duration	Up to 1 Minute	Up to 1 Minute
Record Measured Insulation Resistance	Optional	Required
Minimum Acceptable Insulation Resistance	$R_{Insulation} = (V_{Rated} + 1) \bullet \left(\dfrac{304.8}{L} \right)$	Based on Historical Data Collected

Appendix A: Insulation Resistance Temperature Correction Factors

Temperature (C)	Nexans' PVC Correction Factor	Temperature (C)	Nexans' PVC Correction Factor	Temperature (C)	Nexans' PVC Correction Factor
5.0	0.23	28.5	7.42	52.0	242.63
5.5	0.24	29.0	7.99	52.5	261.32
6.0	0.26	29.5	8.60	53.0	281.45
6.5	0.28	30.0	9.27	53.5	303.13
7.0	0.31	30.5	9.98	54.0	326.48
7.5	0.33	31.0	10.75	54.5	351.63
8.0	0.35	31.5	11.58	55.0	378.72
8.5	0.38	32.0	12.47	55.5	407.90
9.0	0.41	32.5	13.43	56.0	439.32
9.5	0.44	33.0	14.46	56.5	473.16
10.0	0.48	33.5	15.58	57.0	509.61
10.5	0.51	34.0	16.78	57.5	548.86
11.0	0.55	34.5	18.07	58.0	591.14
11.5	0.59	35.0	19.46	58.5	636.68
12.0	0.64	35.5	20.96	59.0	685.73
12.5	0.69	36.0	22.57	59.5	738.55
13.0	0.74	36.5	24.31	60.0	795.44
13.5	0.80	37.0	26.19	60.5	856.72
14.0	0.86	37.5	28.20	61.0	922.71
14.5	0.93	38.0	30.38	61.5	993.79
15.0	1.00	38.5	32.72	62.0	1070.35
15.5	1.08	39.0	35.24	62.5	1152.80
16.0	1.16	39.5	37.95	63.0	1241.61
16.5	1.25	40.0	40.87	63.5	1337.25
17.0	1.35	40.5	44.02	64.0	1440.26
17.5	1.45	41.0	47.41	64.5	1551.21
18.0	1.56	41.5	51.07	65.0	1670.70
18.5	1.68	42.0	55.00	65.5	1799.40
19.0	1.81	42.5	59.24	66.0	1938.02
19.5	1.95	43.0	63.80	66.5	2087.31
20.0	2.10	43.5	68.72	67.0	2248.10
20.5	2.26	44.0	74.01	67.5	2421.28
21.0	2.44	44.5	79.71	68.0	2607.79
21.5	2.62	45.0	85.85	68.5	2808.68
22.0	2.83	45.5	92.46	69.0	3025.04
22.5	3.04	46.0	99.59	69.5	3258.07
23.0	3.28	46.5	107.26	70.0	3509.05
23.5	3.53	47.0	115.52	70.5	3779.36
24.0	3.80	47.5	124.42	71.0	4070.50
24.5	4.10	48.0	134.00	71.5	4384.06
25.0	4.41	48.5	144.33	72.0	4721.78
25.5	4.75	49.0	155.44	72.5	5085.51
26.0	5.12	49.5	167.42	73.0	5477.26
26.5	5.51	50.0	180.31	73.5	5899.19
27.0	5.94	50.5	194.20	74.0	6353.62
27.5	6.39	51.0	209.16	74.5	6843.06
28.0	6.89	51.5	225.28	75.0	7370.20

Notes