Past and Present Requirements for Routine Testing of Crosslinked Polyethylene Insulated Medium Voltage Cables

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Abstract: - The incentives for this paper are the considerable differences among the various European Norms for testing crosslinked polyethylene insulated (XLPE) medium voltage cables and the tendency of making the test requirements stricter over the years even though the quality of the polymeric insulated cables has improved. For this purpose the evolution of two widely used European Norms in addition to the present routine testing requirements are presented. The scope of this paper is to set forth some naturally arisen questions and some recommendations which could create a discussion framework for an agreement on optimum routine testing requirements of XLPE insulated cables.

Key-Words: - XLPE cables, routine tests, voltage tests, partial discharge tests, specifications, type tests, tanδ

1 Introduction

Economical reasons in addition to technical ones such as the simplicity of installation, jointing and the improved current rating compared to paper insulated cables for the same ambient conditions, led to the increasing use of polymeric insulating materials. Polymeric materials such as polyethylene were used as a cable insulant as early as 1943, however the problem of the low melting point was solved later by the conversion of these materials to crosslinked (XLPE) thermosets. Therefore, the XLPE insulated cables surpassed the paper insulated ones as far the thermal capability is concerned.

In the late 60's and early 70's the first crosslinked insulated cables were installed. Crosslinked polyethylene has become the most widely used insulant in U.S.A., Japan and the European countries.

The first editions of the European specifications for XLPE medium voltage cables were published in the 70's. The tests specified for these cables are divided in four categories:

- "Routine tests" carried out on every finished cable length for demonstrating the integrity of the cable.
- "Sample tests" carried out on samples for proving the consistency of the manufacturing procedure.
- "Type tests" carried out on short lengths (10 – 15 meters) of finished cable in order to demonstrate compliance with the characteristics set by the specification. These tests are repeated in case of changes in the insulating material or in the manufacturing process.
- "Site tests" carried out after the installation of the cable.

The routine tests are the following:

- Conductors resistance measurements.
- Voltage test.
- Partial discharge test.

This paper presents the changes of the routine tests requirements over the past years by the use of two widely used European specifications, the IEC specification and the British Standard specification, for XLPE insulated medium voltage cables.

In addition to the above mentioned presentation, this paper deals with the latest requirements of the European Norms in order to point out the need for an agreement among the European countries for the optimum routine testing of XLPE insulated cables.

2 Evolution of routine testing of XLPE medium voltage cables

The voltage test is characterized by two parameters: the high voltage level applied to the cable and the time of application. The first specifications for

XLPE medium voltage cables, for obvious reasons used the same test parameters as paper insulated cables (screen type), which have been in operation since the turn of last century [1].

However the tanδ (dielectric loss angle) measurement against increasing voltage, which demonstrates the quality of the paper insulated cables, could not longer be used for routine testing XLPE insulated cables because they don't have a lapped constructed composite (paper and oil) insulation. Therefore, the tanδ measurement was replaced by the partial discharge measurement, which detects the discharge activity in the voids in XLPE insulation. This activity can lead to insulation breakdown by causing: melting, chemical decomposition or the production of microcracks. The two parameters, which characterize the partial discharge measurement are the maximum level of discharge (in picocoulombs) and the specified voltage level of the measurement.

2.1 Changes of IEC 502 specification for XLPE insulated medium voltage cables.

In the following tables the requirements of four IEC 502 editions (from 1978 up to 1997) for the routine tests are presented.

	Voltage level U_0 (kV)					time (min)
	3.6	**6**	**8.7**	**12**	**18**	
Edition 1978	11	15	22	30	45	5
Edition 1983	11	15	22	30	45	5
Edition 1994	11	15	22	30	45	5
Edition 1997	12.5	21	30.5	42	63	5

Table 1: Requirements for voltage test [2-5]

	Voltage level U_0 (kV)					max value (pC)
	3.6	**6**	**8.7**	**12**	**18**	
Edition 1978	4.5	7.5	10.9	15	22.5	20
Edition 1983	5.4	9	13	18	27	20
Edition 1994	5.4	9	13	18	27	20
Edition 1997	6.2	10.4	15.1	20.8	31.1	10

Table 2: Requirements for partial discharge [2-5]

It's observed that up to 1994, for almost 20 years, there was no change in the voltage test and partial discharge parameters. However, in 1997 the partial discharge requirements became much stricter, reduction of the allowable maximum partial discharge value in combination with an increase of the measurement voltage level. Moreover, the voltage level of the voltage test increased considerably, almost reaching the level required for testing the immediate higher insulation category (i.e. 65 kV for 30 minutes are required for testing 26/45 kV cables based on the IEC 60840/2004 specification for high voltage cables [6]. Finally in 1997 the DC testing for XLPE insulated cables stopped being an option to AC voltage testing.

2.2 Changes of BS 6622 specification for XLPE insulated medium voltage cables.

The first edition of BS 6622 specification was published in 1985 and up to now two more editions have followed. The requirements of all editions for the routine testing are presented in the following tables:

	Voltage level U_0 (kV)					time (min)
	3.8	**6.35**	**8.7**	**12.7**	**19**	
Edition 1985	11	15	22	30	45	5
Edition 1991	11	15	22	30	45	5
Edition 1999	15	25.5	35	51	76	15

Table 3: Requirements for voltage test [7-9]

	Voltage level U_0 (kV)					max value (pC)
	3.8	**6.35**	**8.7**	**12.7**	**19**	
Edition 1985	5.7	9.6	13.1	19.1	28.5	10
Edition 1991	5.7	9.6	13.1	19.1	28.5	10
Edition 1999	7.5	12.5	17.5	25.5	38	10

Table 4: Requirements for partial discharge test [7-9]

In the late 90's, as for the IEC specification, drastic changes in the parameters of the routine testing occurred. Particularly even though the allowable maximum partial discharge level remained the same, the measurement voltage level increased from $1.5U_0$ to $2U_0$. In addition, the changes of the voltage test parameters were more noticeable. Not only the time of voltage application tripled (from 5 minutes to 15 minutes) but the voltage increased so much that the voltage level required for the immediate higher insulation class in the previous edition is lower than the one required in the latest edition for the immediate lower insulation class (i.e. in 1991 edition 45 kV for 5 minutes were required for testing 30 kV cables and now 51 kV for 15 minutes are required for 20 kV cables). As mentioned previously based on the IEC 60840/2004 65 kV for 30 minutes is the required voltage level for the voltage test of 45 kV cables when based on the BS specification 76 kV for 15 minutes is the requirement for voltage test for 30 kV cables.

The changes of BS specification were so dramatic that even though the older editions were almost the same as the IEC ones, now the differences are considerable.

3 An overview of the current specifications in Europe

As it's mentioned in the previous section nowadays there are considerable differences among the various European specifications for the routine testing of the XLPE insulated medium voltage cables.

In the tables 5 and 6 the current requirements for routine testing are presented. The source of this table is the HD 620 S1:1996/A2:2003 [10] which is recognized by the majority of the European countries (Austria, Belgium, Denmark, France, Germany, Greece, United Kingdom etc) and it's a detailed presentation of all test methods and the requirements for the routine, type and sample testing for the XLPE insulated medium voltage cables.

It's obvious by just reading the information presented in tables 5 and 6 that the differences among the voltage test are great. In order to comprehend the extent of these differences the equation showing the relation between life and stress can be used [1]:

$$E^n . t = \text{constant} \quad (1)$$

For polyethylene insulated cables n is between 9 and 20. Even in the case of the lowest exponent the difference between a voltage test of 3.33 U_0 for 5 minutes and 5 U_0 for 15 minutes is enormous.

In respect to the partial discharge test not only the difference of the measurement voltage is considerable (lowest value 1.5 U_0, highest value 2.5 U_0) but the differences of the allowable maximum partial discharge values are even greater (lowest value 2 pC, highest value 10 pC).

Parts / Section	Voltage level (kV)	Time (minutes)
Part5 / Section B	4 U_0	5
Part5 / Section F	3.5 U_0	15
Part5 / Section G1	3.5 U_0	5
Part5 / Section G2	3.5 U_0	5
Part5 / Section J	3.33 U_0 – 5 U_0	15
Part5 / Section K	3.33 U_0 – 5 U_0	5
Part5 / Section M	3.33 U_0 – 5 U_0	15
Part5 / Section O7	4 U_0	15
Part5 / Section O8	4 U_0	15
Part5 / Section O9	4 U_0	15
Part6 / Section A	3.5 U_0	5
Part6 / Section F	3.5 U_0	15
Part6 / Section J	3.33 U_0 – 5 U_0	15
Part6 / Section K	3.33 U_0 – 5 U_0	5
Part6 / Section M	3.33 U_0 – 5 U_0	15
Part6 / Section O4	4 U_0	15

Table 5: Requirements for voltage test [10]

Parts / Section	Voltage level (kV)	max value (pC)
Part5 / Section B	2 U_0	2
Part5 / Section F	2.5 U_0	5
Part5 / Section G1	1.73 U_0	10
Part5 / Section G2	1.73 U_0	10
Part5 / Section J	1.7 U_0 / 1.33 U_0	10/5
Part5 / Section K	1.5 U_0	5
Part5 / Section M	1.5 U_0	5
Part5 / Section O7	2 U_0	10
Part5 / Section O8	2 U_0	10
Part5 / Section O9	2 U_0	10
Part6 / Section A	2 U_0	5
Part6 / Section F	2.5 U_0	5
Part6 / Section J	1.7 U_0 / 1.33 U_0	10/5
Part6 / Section K	1.5 U_0	5
Part6 / Section M	1.5 U_0	5
Part6 / Section O4	2 U_0	5

Table 6: Requirements for partial discharge test [10]

4 Conclusion

Questions, naturally arising from this paper, can lead to a broader discussion on the testing requirements for XLPE insulated medium voltage cables which could result to a required harmonization of the European Norms.

In respect to the voltage test even though the national standards started from the same origin, now they are surprisingly diverse. It's not known if the reason for this diversity is the different fault records of the national utility companies. However in setting the voltage testing requirements the negative effect of unreasonably overstressing the cables should be considered. Since the failure mechanism at high voltage is completely different from the one taking place at the much lower stress in service application excessive voltage may itself create more incipient faults than it detects. Nevertheless the diversity in the test requirements can be rationalized when it is observed at the beginning of a product for which high reliability is expected. However, after the use of a product for more than 30 years, a generally accepted specification based on the experience all of the parties involved could be developed.

As far as the partial discharge measurement is concerned, the tendency of lower maximum allowable partial discharge values at higher measurement voltages is observed. However taking into account the sensitivity of XLPE insulation to partial discharge it's recommended that the new editions of the specifications should set a requirement for the absence of detectable charges up to maximum permissible operating voltage (1.2 U_0).

Finally the higher quality of the insulation materials and the improvement of the production techniques surprisingly led to stricter routine tests the execution of which requires higher costs rising from the need of testing transformers with higher power rating and the use of terminations for routine voltage tests the execution of which based on the older editions didn´t require it (i.e. 76 kV for 15 minutes compared to 45 kV for 5 minutes for testing 30 kV cables).

References:

[1] D. McAllister, "*Electric cables Handbook*", Granada Publishing Ltd, 1984.

[2] International Standard IEC 502, "Extruded solid dielectric insulated *power cables for rated voltages from 1 kV up to 30 kV"*, International Electrotechnical Commission, 1978.

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[4] International Standard IEC 502, "Extruded solid dielectric insulated *power cables for rated voltages from 1 kV up to 30 kV"*, International Electrotechnical Commission, 1994.

[5] International Standard IEC 60502-2, "*Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um =1.2 kV) up to 30 kV (Um =36 kV)"*, International Electrotechnical Commission, 1997.

[6] International Standard IEC 60840, "*Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um =36 kV) up to 150 kV (Um =170 kV). Test methods and requirements"*, International Electrotechnical Commission, 2004.

[7] British Standard BS 6622, "*Specification for cables with extruded cross-linked polyethylene or ethylene propylene rubber insulation for rated voltages from 3800/6600 V up to 19000/33000 V"*, British Standard Committee, 1985.

[8] British Standard BS 6622, "*Specification for cables with extruded cross-linked polyethylene or ethylene propylene rubber insulation for rated voltages from 3800/6600 V up to 19000/33000 V"*, British Standard Committee, 1991.

[9] British Standard BS 6622, "*Specification for cables with extruded cross-linked polyethylene or ethylene propylene rubber insulation for rated voltages from 3.8/6.6 kV up to 19/33 kV"*, British Standard Committee, 1999.

[10] Harmonization Document HD 620 S1:1996 /A2, "*Distribution cables with extruded insulation for rated voltages from 3.6/6 (7.2) kV to 20.8/36(42)kV"*, CENELEC members, 2003.