EXPERIENCES WITH AC TESTS AFTER INSTALLATION OF POLYMERIC (E)HV CABLE SYSTEMS

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Abstract

CIGRÉ SC21 published in 1990 and in 1997 recommendations for test after installation of (E)HV extruded cable systems. In 1998 it was decided to establish a Task Force (TF21-05) to collect and review the use, techniques, experiences and results on AC Tests After Installation of (E)HV polymeric cable systems.

TF21-05 has issued a questionnaire. Results were received from fifteen countries. This report presents the results of the questionnaire and the conclusions made at the SC21 meeting of 2001 in Madrid. On the basis of the collated comments, it was concluded that DC testing should be avoided. There is no reason to change the CIGRÉ *1997 recommendations and that the effect of the IEC standardisation work, which is expected to provide more comparable test data, has to be awaited for future work on this subject.*

1 INTRODUCTION

Test after installation of cable systems has the purpose to check the integrity of the system when the installation has been completed. The cables are routine tested in the factory; the accessories are assembled at site. An DC oversheath test and/or an AC insulation test are recommended. For installations where only the oversheath test is carried out, quality assurance procedures during installation of accessories may, by agreement between the purchaser and the contractor, replace the insulation test.

The basic approach for an insulation test after installation of cable systems is that typical faults originated during assembly of accessories should be detected effectively by exposing the system to adequate electrical stresses, without harming the system under test. The crucial question is the level, duration and the availability of test voltages.

In the CIGRÉ 1990 report 21-105 of WG21-09/01 [1], the results were reported of an investigation regarding artificial faults in polymeric cables and accessories and the effectiveness of various test methods. In that report a first recommendation was made for AC testing on site after installation. Investigated were cable systems in the IEC 60840 range. It was concluded: “DC testing was ineffective and could even be dangerous for the system under test. AC voltage withstand testing at levels of 2Uo to 3Uo will give the most reliable results and the alternative using system voltage Uo during one week is still too weak”.

Several countries in Europe and South Africa started using AC testing on site, making use of series resonant sets. In most countries the applied test levels were based on the CIGRÉ 1990 report. Japan started using AC testing on 275 kV circuits, making use of parallel resonance.

CIGRÉ WG21-09/02 published recommendations for on site testing after installation in Elektra 1997 [2]. A recommendation was made for test voltage and duration and also for a quality assurance approach without testing, as applied in France. For 60-110 kV circuits 2Uo, 60 min. is recommended and for 130-150 kV circuits, 1,7Uo, 60 min. For networks with a voltage

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above 150 kV is recommended either 1,7Uo, 60 min (system voltage) or a range starting with 1,4Uo, 60 min for a 220 kV circuit down to 1,1Uo, 60 min for a 500 kV circuit.

Nowadays, IEC has issued IEC 62067 (EHV cable systems) and IEC TC20WG16 is working on Edition 3 of IEC 60840 for HV cables and systems (cable and accessories). The requirements in those standards for test after installation are in line with the CIGRÉ recommendations of 1997, see Annex 1.

2 QUESTIONNAIRE

The questionnaire asked for information regarding the following subjects:
1. AC tests with a (SERIES) RESONANT SET
2. AC tests with NETWORK VOLTAGE
3. DC tests on polymeric cable circuits.
4. Literature regarding test after installation.

The questionnaire was sent to the members of SC21 and to the National Committees. For those countries not being member of SC21. Results were received from fifteen countries (Australia, Belgium, Czech Republic, Denmark, Germany, Ireland, The Netherlands, Switzerland, United Kingdom, Israel, Japan, Korea, Thailand, South Africa and Canada). Unfortunately no response was received from some other countries having experience with AC testing (either with series resonant voltage or with system voltage) and no response was received from some countries having now and then problems during commissioning of (E)HV extruded cable systems.

The results are reported in the following chapters:
- Chapter 3: Reasons for changing from DC testing to AC testing
- Chapter 4: Test methods and test set-ups
- Chapter 5: Test requirements and test results
- Chapter 7: References, containing also literature received

3 REASONS FOR CHANGING FROM DC TESTING TO AC TESTING

Twelve countries reported using AC testing after installation. Japan, Korea and Thailand reported still using DC testing.

The reasons for applying series resonant testing or network voltage testing were:
- Inefficiency of DC testing; no detection of faults
- Flashover on terminations
- Breakdown of joints and terminations because of difference in stress control between AC and DC voltage; faults induced by DC testing
- Possible space charge effect with DC testing
- CIGRÉ recommendations of 1990 [1] and CIGRÉ recommendations of 1997 [2]

Japan reported that they continue with DC testing at site for the 66-77 kV voltage range and also for the 110-187 kV voltage range. Japan stated that they could not find any decisive reason to give up DC testing on polymeric cables, even for the future. For EHV cables (275 kV and above) Japan decided in 1993 to change to AC testing with parallel resonance, tuned to power frequency, with addition of PD measurement.

4 TEST METHODS AND TEST SET-UPS

4.1 Series resonance

A reactor is put in series with the cable under test, creating a series resonant circuit [3]. The system may consist of a reactor with a fixed inductance value, delivering a resonant frequency depending on cable length or of a reactor with a variable inductance delivering resonance at power frequency. The energy is delivered via an exciter transformer. For variable frequency test sets the frequency of the input voltage has to be tuned to the resonant

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frequency of the test circuit. The variable frequency system has a better weight to power ratio than the fixed frequency system, allowing testing of longer lengths [24. 32]. At least twenty-three systems are in operation all over the world.

Nearly all systems are built according to the “roll-on/test/roll-off” principle. The systems became even more powerful in time and the frequency range was widened to 20-300 Hz. Depending on the network voltage cable lengths up to 30-40 km can be tested by using two test systems in parallel. Cables with a network voltage above 245 kV can be tested either by one single test system or by two test systems in cascade, depending on the properties of the test system. For parallel or system operation two or more test systems may operate in master-slave mode.

The earlier systems were designed to fulfil the recommendations made in the CIGRÉ 1990 report [1]. The recent systems were designed to fulfil the CIGRÉ recommendations published in 1997 [2].

Systems are in operation in industrialised and in newly industrialising countries where polymeric HV cable circuits are installed. No problems related to service experience were reported.

4.2 Parallel resonance

Japan applies parallel resonance testing, using shunt reactors of the transmission lines to enable testing of long distance cables. The test frequency is tuned to power frequency. The test voltage is maximum 1,3Uo. With the addition of PD measurement this is justified, see 4.5.

4.3 Network voltage testing

4.3.1 Phase to Phase voltage (1,7Uo)

This method is only applicable in case of a network with insulated neutral. One of the conductors has to be connected to ground and then the system will be powered. The other two conductors will then have phase to phase voltage to ground.

Only the Netherlands (50 kV and 150 kV) reported this method. Faulty accessories were detected in several cases. However in two cases damage to other components was reported because of voltage transients during breakdown. This method is not applied anymore.

4.3.2 Phase to ground voltage (1-1,1Uo)

For very long cable lengths or when other test methods are not available, this will be the only method applicable.

Australia, Czech Republic, Denmark, Ireland, Israel and Canada reported the regular use of this method. Belgium, Germany, the Netherlands and the United Kingdom do not apply network voltage testing anymore. One country reported a failure during test at 1,1Uo. Two countries reported a failure after the test during service operation. One failure was because of water ingress in service. Rumours regarding experiences in some countries were heard about failures during service after phase to ground testing.

4.3.3 Current limitation and protection measures

Countries using this method reported changes in the settings of the protection system. Some countries reported that they decreased the available short circuit power be feeding the circuit under test via the low voltage side of a step-up transformer.

Israel reported that they use a voltage of 1,1Uo, obtained by proper setting of the tap-changer of the step-up transformer.

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Some countries reported that they connect the cable under test directly to their network, without any precautions.

4.4 DC voltage

Japan, Korea and Thailand reported that they use DC testing only.

All countries using either the series resonant test method or the network voltage test method stated that they changed from DC testing to AC testing because of the problems that may be related to DC testing and because of the CIGRÉ recommendations, see chapter 3.

Japan stated that they continue to use DC testing for HV cable circuits up to 187 kV network voltage, because of the positive results in Japan.

4.5 PD measurement during AC testing

Germany, Switzerland and the United Kingdom reported use of PD measurements during series resonant testing, Japan during parallel resonant testing and Australia and the Netherlands with live network voltage.

Germany reported that during series resonance testing in a joint of a 380 kV cable circuit PD's were measured. The cause was found and the joint was repaired. During withstand testing there was no breakdown.

Japan reported that from 1993 up to 1997 three faults in 275 kV circuits were detected with PD measurements. Japan relies on PD measurement only, performed with a voltage up to 1,3Uo at maximum. Because of improved quality control at site and approval by the government, AC test at system voltage is considered to be sufficient nowadays.

The Netherlands reported that one of the utilities performs a regular PD measurement on terminations in his 150 kV network using live voltage. Defective terminations were found. The results are reported in papers. Reference is made to the relevant CIGRÉ Report [4] for the methods used and for more detailed information.

5 TEST REQUIREMENTS AND TEST RESULTS

The results and requirements used by several countries are reported per subject. Faults detected during or after the test are discussed in chapter 5.4.

5.1 Series resonant and parallel resonant

5.1.1 HV extruded cable systems (IEC 60840 range)

Total reported cable length tested is more than 3000 km in more than 650 circuits. The maximum cable length tested was 52 km.

Switzerland, the Netherlands and Germany are mainly using test voltage levels based on the CIGRÉ 1990 report [1]. That means a voltage level of 2,5Uo, with a rather short duration (different per country). The other countries apply mainly voltage levels based on the CIGRÉ recommendations of 1997 [2]. That means a lower voltage level with a longer duration.

The Netherlands reported also AC testing on mixed circuits (XLPE + oil-pressure)) and on oil-pressure circuits. Voltage level used is 80% of the level for XLPE cable circuits (2Uo).

For service aged circuits some countries apply a reduced voltage level.

5.1.2 EHV extruded cable systems (IEC 62067 range)

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The total number of circuits reported is 53, the total cable length 493 km and the maximum cable length tested was 13,5 km with series resonant equipment and 32,5 km with the parallel resonant method.

Test voltage level used is mainly the network voltage (U = 1,7Uo) in Canada, Germany, Ireland and Switzerland. Germany reported for 380 kV systems the use of a test sequence with two test voltage levels (1,7Uo-1,5Uo) per test, in combination with PD measurement. Ireland applied mainly a test level based on the CIGRÉ recommendation of 1997 [2]. Japan reported for 275 kV systems the use of 1,3Uo with PD-measurement.

5.2 Network voltage

The Netherlands reported the use of a test voltage level of 1,7Uo. The other countries used or use Uo or 1,1Uo with duration of 24 hours. The Netherlands, Belgium and Germany reported that they have stopped with testing with network voltage. Australia, Czech Republic, Canada, Denmark and Israel reported that they apply only testing with network voltage (1-1,1Uo).

5.3 DC voltage

Japan, Korea and Thailand reported that they apply only DC testing. All other countries reported that they stopped with applying DC testing. The voltage level used ranges from 4Uo down to 2,4Uo for service aged circuits. Japan stated that they see no reasons to apply AC testing for cables in the voltage range up to 187 kV.

5.4 Faults during and/or after the test

5.4.1 Series resonant testing (IEC 60840 range)

Thirty-five faults during test were reported and nine faults afterwards. During the test twenty-nine joints, two terminations and four service aged cables failed. After the test seven joints and two terminations failed. Most faults reported were in taped joints. Also faults in moulded and epoxy joints and in terminations were reported. Causes were bad workmanship, problems with taping and vulcanisation of tape windings. No faults in new cable were reported.

The test voltage level used by the countries reporting these faults, was mainly 2Uo or above. One country reported one failed joint with testing at 1,6Uo.

Failures after test were reported in 70 kV and 110 kV networks, while using 2Uo as test voltage level (with duration of 30 min) and in a 132 kV network while using 1,5Uo.

Failures during test only were reported in 150 kV networks, while using a test voltage of 2Uo or above.

Because of the series resonant principle, the damage on the breakdown spot during test is limited. In most cases a clear reason for the faults could be detected.

5.4.2 Network voltage testing (1-1,1Uo)

One country reported 2 faults after the test, one in a joint and one in a termination. Another country reported one fault in a joint during the test and on another circuit one fault in a joint after the test.

5.4.3 DC testing

One country reported that three terminations failed during test due to DC nature of the test voltage. Three countries reported in total six failures in joints and one failure in a termination after the test. They stated that these faults would have been detected with AC testing. Those countries abandoned DC testing on extruded cable systems. One country reported that one cable piece failed after the test, however the reason is unknown. Japan reported that they are

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quite satisfied with the results of DC testing. They reported that they detect faults during testing (no numbers were given) and that there occur faults after testing.

5.5 Discussion of the results

Twelve of the fifteen countries abandoned DC testing because faults induced during installation were not detected, or faults were induced during DC testing because of the difference in stress control between AC and DC stress or because of possible space charges. They confirmed strongly the use of AC testing after installation

For AC testing on extruded cable systems, the CIGRÉ 1990 recommendation [1] focused on the IEC 60840 range and was based on a constant factor for all network voltage levels. The factor recommended (2-3Uo) was based on investigations on real size test objects with artificial faults. For the IEC 62067 range (EHV range) it is quite clear that a factor of 2-3Uo is quite too high. Most of the countries followed reduced factors for the IEC 62067 range. For instance Germany applies 2,5Uo, 30 min. for their 110 kV circuits and applied 1,7/1,5Uo for the 400 kV circuits in Berlin. The Netherlands applies 2,5Uo, 10 min for the IEC 60840 range and Switzerland is using a variety of test voltages and test times. Germany reported after 2,5Uo, 30 min (110 kV circuit) a fault after testing, that could have been developed or increased afterwards under service stresses such as thermo-mechanical forces.

The CIGRÉ 1997 recommendations [2] focused on the IEC 60840 range and on the IEC 62067 range. These recommendations are based on the philosophy of constant electrical stress at critical parts of accessories, i.e. the interfaces. Three countries reported faults after tests. They used either shorter test time or lower test voltage than recommended, so they did not follow for 100% the recommendation. Japan reported for their 275 kV circuits 3 faults during testing with 1,3Uo.

It is concluded that the basic approach for test after installation of cable systems should be that the cable system should be exposed to certain electrical stresses more or less independent from the rated voltage of the cable system. It is clear that no after laying test can reveal a fault, which was not yet present.

It may be concluded that for the IEC 60840 range the test voltage and duration should be more or less in line with the recommendations made by CIGRÉ WG21-09/01 in their 1990-report [1]. Countries using test voltage levels mainly based on that CIGRÉ report reported that they detected faulty components during the test, without failures afterwards. Countries using test voltages mainly based on the CIGRÉ recommendations of 1997 [2] reported failures during the test and after the test.

From the data it is clear that the large majority of tests were not performed exactly in line with the CIGRÉ recommendations of 1990 [1] and of 1997 [2]. A lot of them were performed following internal or customer rules, rather than adopting the exact test parameters recommended by CIGRÉ or IEC drafts. That makes it difficult to draw up firm conclusions..

From the results reported it is obvious that the series resonant test using a test voltage above the phase to ground or the phase to phase operating voltage will detect the largest number of faulty accessories. With the series resonant method the best test results were achieved and it should be applied when available.

Network voltage testing (1-1,1Uo) is much less effective than series resonant testing because of the difference in test voltage level that can be applied. However a network voltage test (1-1,1Uo) over 24 hours may be a practical alternative when series resonant systems are not applicable or available.

Countries applying PD-measurements, mainly for EHV extruded cable circuits reported the effective use of a lower voltage. Defects were found with PD-measurement. There was no need to perform a breakdown test to find the defect. Applying PD-measurement seems to justify a decrease of the test voltage level.

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The list of collated literature, requested by the questionnaire, is given in reference [5] till [33]. In these publications experiences are presented from several countries. These experiences are partly included in the results of the questionnaire and partly not. To avoid misunderstandings the experiences presented in these publications are not included in chapter 5 of this report.

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6 CONCLUSION

Conclusion from the data collected is that DC testing of (E)HV cable systems should be avoided. The statements in the CIGRÉ recommendations of 1990 and 1997 are confirmed. Two countries reported that they have no other possibility available then DC testing. One country reported that they see no reasons to apply AC testing for cables in the voltage range up to 187 kV.

Conclusion from the evaluation of the practical test results of AC testing after installation, collated by TF21-05, is that in a lot of cases these results could scarcely be assigned to one of the CIGRÉ recommendations of 1990 and 1997. In these cases actual test parameters deviated from those recommended by CIGRÉ. Nevertheless, it has to be stated that no clear case was found where tests, performed in line with CIGRÉ, proved to be inadequate, i.e. that successfully tested systems failed shortly after test in service, due to undetected failures already present during the test. This suggests that, at least as long the contrary is not proven, the present CIGRÉ recommendations, as given in the 1997 edition, have to be considered as the best practical approach available nowadays. Consequently, CIGRÉ SC21, represented by TF21-05, confirms today the adoption of its recommendations within the relevant revised IEC standards, see Annex 1.

TF21-05 expresses its expectation that the confusion in the past with non-comparable test parameters would be overcome by the clear definitions now being published within the new IEC standards. This should provide a future option for broader and more consistent test results and should allow a better based evaluation as at present.

TF21-05 invites utilities, manufacturers, test institutes and universities to participate in the ongoing attention of CIGRÉ SC 21 to this issue. They are invited to adopt the IEC test procedures and to collect and provide their results and experiences for a possible future review and update of the requirements for the test after installation.

TF21-05 proposes to establish a new task force after some years with the task to:

- collect experiences and results of the (standardised) Test After Installation methods,
- perform a sensitivity analysis for the test voltage and duration, related to the electrical stresses in cable systems, for series resonance testing and for network voltage testing
- include possible reasons for problems in certain types of accessories (see also the results of JTF 21/15) and
- include results of investigations to the breakdown cause of failed components.

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Annex 1

IEC 62067, Edition 1; Clause 14 and Draft IEC 60840/Edition 3, Clause 15

14/15 Electrical tests after installation

Tests on new installations are carried out when the installation of the cable and its accessories has been completed.

An oversheath test according to 14.1 and/or an a.c. insulation test according to 14.2 is recommended. For installations where only the oversheath test according to 14.1 is carried out, quality assurance procedures during installation of accessories may, by agreement between the purchaser and contractor, replace the insulation test.

14/15.1 DC voltage test of the oversheath

The voltage level and duration specified in clause 5 of IEC 60229 shall be applied between each metal sheath or concentric wires or tapes and the ground.

For the test to be effective, it is necessary that the ground makes good contact with all of the outer surface of the oversheath. A conductive layer on the oversheath can assist in this respect.

14/15.2 AC voltage test of the insulation

The a.c. test voltage to be applied shall be subject to agreement between the purchaser and the contractor. The waveform shall be substantially sinusoidal and the frequency shall be between 20 Hz and 300 Hz.

IEC 62067 The voltage shall be applied for 1 h, either with a voltage according to table 10 or with 1,7 U_0, depending on practical operational conditions.

IEC 60840/Edition3 Draft A voltage according to table 4, column 9, shall be applied for 1 h.

Alternatively, a voltage of U_0 may be applied for 24 h.

NOTE – For installations, which have been in use, lower voltages and/or shorter durations may be used. Values should be negotiated, taking into account the age, environment, history of breakdowns, and the purpose of carrying out the test

Table 10 - AC test voltages after installation (IEC 62067), either 1,7Uo or the voltage of the table

Rated voltage *U* (kV)	Rated voltage *Uo* (kV)	Test voltage (phase-to-ground) kV r.m.s.
220 to 230	127	180
275 to 287	160	210
330 to 345	190	250
380 to 400	220	260
500	290	320

Table 4, Column 9 – AC test voltages after installation (IEC 60840/Ed. Draft)

Rated voltage *U* kV	Rated voltage U_0 kV	Test voltage (phase-to-ground) kV r.m.s.
45 to 47	26	52
60 to 69	36	72
110 to 115	64	128
132 to 138	76	132
150 to 161	87	150

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