

# Two Years of Experience with a Mobile Resonant Test System for Testing of Installed Medium- and High Voltage Power Cables

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# TWO YEARS OF EXPERIENCE WITH A MOBILE RESONANT TEST SYSTEM FOR TESTING OF INSTALLED MEDIUM- AND HIGH VOLTAGE POWER CABLES

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## Abstract

Since October 1996 one of the largest series resonant test system with variable frequency has been in operation. More than 270 installed medium- and high voltage cables have been tested using this equipment in the Netherlands, Germany, Belgium and in the United Kingdom. The tested cable lines consist of either XLPE, oil-paper or a combination of both insulating materials. The principle of testing is briefly described and the results of these tests, depending on the voltage level, the age and construction of the cable, are statistically evaluated. The experience in on-site testing of power cables is summarized and future testing trends and recommendations are discussed.

## 1. Introduction

Testing on installed cable systems is gaining importance. After laying tests on new cables prove that the cable laying and the accessories installation were carried out correctly. The after laying test fills the "quality assurance gap" between the routine test of the cable drum at manufacturer site and the commissioning of the complete cable system on-site (Fig. 1). Tests on old installed cables should establish that the quality of the cable, the cable joints and cable end terminations is sufficient to allow further operation of the cable system. For on-site tests on installed medium- and high voltage cables several test methods like withstand tests with DC, 0.1 Hz, AC or impulse voltages are known. Depending on the specific test application more or less

good results can be achieved. Installed cables several kilometer in lengths represent a large capacitive load for the test equipment. (E.g. for a 13 km long 150 kV XLPE-insulated cable, test voltage 220 kV, 50 Hz a test power of up to 40 MVA is needed). On-site testing with a conventional test transformer, due to the heavy weight and the high power supply requirement, is not practical. Considering reasonable size and weight DC and 0.1 Hz test systems seems to be the most convenient solution.

But especially for DC tests on extruded polymeric insulated cables (XLPE), there are doubts about the adequacy of the test method due to the difference in stress distribution of DC and AC voltages. DC tests can even be dangerous for the cable under test because of weak points inside the cable insulation caused by electrostatic space charges. This effect could lead to breakdowns during the tests or could decrease the lifetime of the cable system dramatically [1].

The very low frequency test system (0.1 Hz) is normally used for medium voltage cables. For high voltage cable testing this equipment is not available on the market as a commercial product. Furthermore the sensitivity to detect failures with test voltage is only half as compared to the AC voltage test systems [2].

To have, on one hand, the advantage of testing with frequencies close to power frequency and on the other hand a test system which can be handled easily on-site, resonant test systems with variable frequency were developed. This paper describes the more than two years of experience made by a well-known cable manufacturer using this kind of on-site test system.

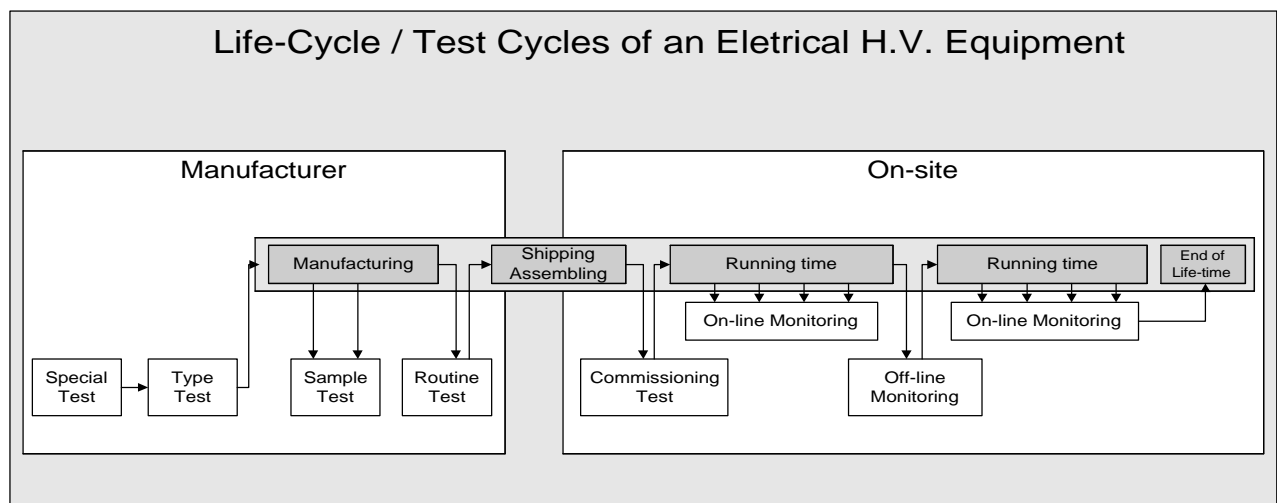


Figure 1: Life-cycle / test cycles of a cable system

## 2. Design of the on-site AC test system

The resonant test system with variable frequency mainly consists of the frequency converter, the exciting transformer, the coupling capacitors and two high voltage reactors with fixed inductance (Fig. 2). To be independent from a stationary power supply a motor-generator set is used. The frequency converter generates a variable voltage and frequency output which is applied to the exciter transformer. The exciter transformer excites the series resonant circuit consisting of the reactor's inductance  $L$  and the cable capacitance  $C$ . Even though the frequency converter creates harmonics the output voltage shows a pure sine wave [3]. The resonance is adjusted by tuning the frequency of the frequency converter according the formula:

$$f = \frac{1}{2\pi \cdot \sqrt{L \cdot C}}$$

The tuning range of the test system is determined by the converter's frequency range:

$$\frac{C_{\max}}{C_{\min}} = \left( \frac{f_{\max}}{f_{\min}} \right)^2$$

Depending on the voltage level and the capacitance of the cable the test system can be extended by a second reactor. For longer power cables up to 150 kV and more than 10 km, the second reactor is connected in parallel. For test voltages up to 440 kV a series connection of the two reactors has to be realized (Fig. 3).

The quality factor "Q" of the resonant system determines the relation between testing power and the required power supply [4]. For the XLPE cable testing a system quality factor in the range of 100 - 150 and for paper-insulated cables 50 - 90 were achieved. The high quality factor of the high voltage reactors leads to a compact and lightweight system design.

The ratio between weight and testing power of this resonant test system is only a quarter of a comparable conventional test transformer.

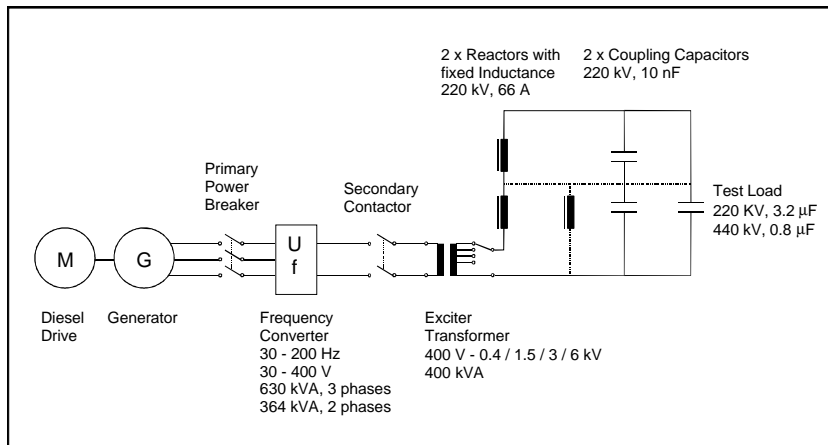
The power supply has only to deliver 1 to 3 % of the required testing power. The technical data and the test capabilities of the resonant test system are shown in Table 1.

	1 reactor (1S1P)	2 reactors parallel (1S2P)	2 reactors in series (2S1P)
Nominal voltage	220 kV	220 kV	440 kV
Nominal power	14.5 MVA	29 MVA	29 MVA
Max. test load	1.6 $\mu$ F	3.2 $\mu$ F	0.8 $\mu$ F
Frequency range	30 Hz - 200 Hz		
Tuning - range	1 : 44.44		
Load duty cycle	1 h ON / 2 h OFF, 6 x in 48 h		
Weight including trailer	40 t		
Length	13.6 m		
Width	2.5 m		
Height	4 m		

**Table 1:** Technical data of described resonant test system



**Figure 3:** Test set-up to reactors in series ( 2S1P)



**Figure 2:** Electrical diagram of the described resonant test system

### 3. Operating experience

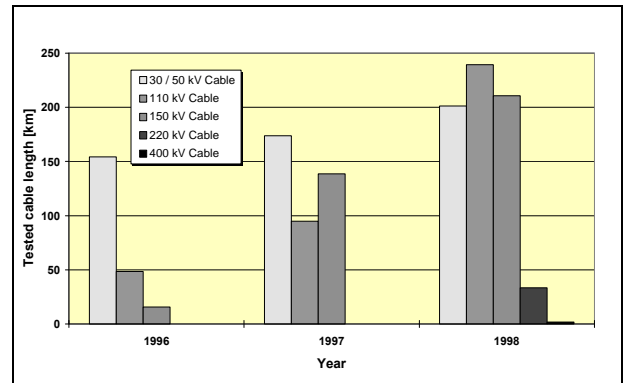
Since October 1996 the 440 kV, 29 MVA resonant test system has been in operation. More than 270 installed medium- and high voltage power cables with a total length of approx. 1'600 km has been tested. The demand for on-site testing on cables is increasing rapidly. E.g. between 1997 and 1998 the growth rate was 70 % (Fig. 4)!

To operate an on-site test system economically a short set up time has to be considered. Due to the easy operation and the fast connection of the test system to the cable under test the typical installation time is approx. an hour.

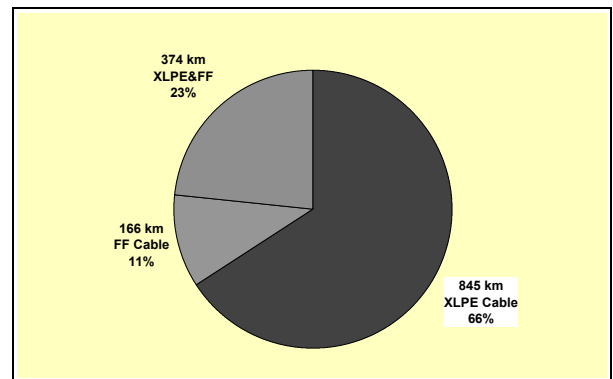
Most of the tested circuits consist of polymeric (XLPE) cables. Also fluid filled (FF) and fluid filled mixed with polymeric (XLPE&FF) has been tested (Fig. 5).

The performed on-site tests have been made on new laid cables (38 %) as well as on old installed cables (68 %) (Fig. 6).

Depending on the voltage level, type and age of the cable system different test procedures have been used. Often the customer defines his own special test procedure. Most tests have been performed according the Dutch Standard NEN 3630 [5]:



**Figure 4:** Tested cable length by NKF Kabel from 4.10.96 till 14.12.98 with the 440 kV resonant test system



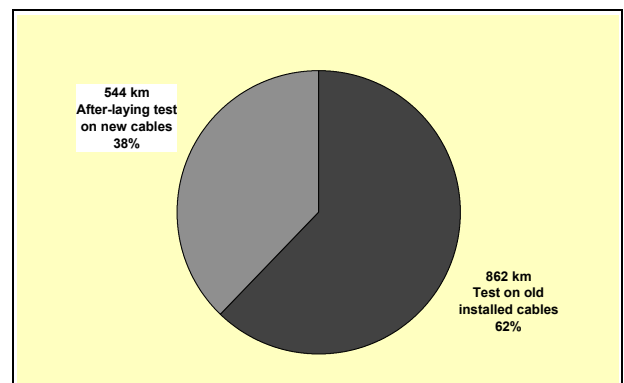
**Figure 5:** Statistic of tested cables depending on the cable type

New XLPE-insulated cable systems		
Cable Class [kV]	Test Voltage	Test duration [min]
50	2.5 U <sub>0</sub>	10
110	2.5 U <sub>0</sub>	10
150	2.5 U <sub>0</sub>	10

Old XLPE-insulated cable systems		
Cable Class [kV]	Test Voltage	Test duration [min]
50	2.5 U <sub>0</sub> x 80 %	10
110	2.5 U <sub>0</sub> x 80 %	10
150	2.5 U <sub>0</sub> x 80 %	10

Old paper-insulated cable systems		
Cable Class [kV]	Test Voltage	Test duration [min]
50	2.5 U <sub>0</sub> x 80 %	15
110	2.5 U <sub>0</sub> x 80 %	15
150	2.5 U <sub>0</sub> x 80 %	15
380	2.5 U <sub>0</sub> x 80 %	15

mixed cable systems		
Cable Class [kV]	Test Voltage	Test duration [min]
50	2.5 U <sub>0</sub> x 80 %	10
110	2.5 U <sub>0</sub> x 80 %	10
150	2.5 U <sub>0</sub> x 80 %	10



**Figure 6:** Statistic of tested cables depending on the cable age

In some cases the circuit capacitance had to be increased by additional load capacitors to fulfill the customers specification of a test frequency e.g. less than 100 Hz.

Some test arrangements due to limited space on-site or because of cable terminations installed within a building required an additional 200 m feeding cable connecting the test system to the cable under test. This feeding cable has also been used as an additional load capacitance for testing short cable length to lower the test frequency.

Of 230 cable systems tested, two failed in the cable insulation and four in the accessories. Three installed accessories broke down after 5 to 20 min of applied test voltage. Only one accessory and two cable insulation failed during the voltage rise of the test voltage.

Five of the six failed cable circuits were in operation several years. The only new cable circuit which failed during the after-laying test was due to an accessory.

From the tested cable circuits which fulfilled the test requirements no failure has occurred during service until now.

#### 4. Conclusion

More than 270 cable circuits has been tested with the variable frequency series resonant test system. Due to the easy handling, low specific weight and high reliability of resonant systems with variable frequency and the achieved test experiences the AC high voltage on-site testing is a useful tool to prove the quality of the commissioning work of a new laid cable system and to verify the reliability of an old installed cable system. Therefore a further increase of AC high voltage on-site tests on high voltage cables could be expected.

When on-site testing becomes a subject of standardization different test procedures and test levels for after-laying tests on new cable system and tests on old installed cable circuits should be taken into consideration. The testing experience documents shows that the CIGRE recommendations „After laying tests on high voltage extruded insulation cable systems“ [1] have not been applied. The tests showed that the breakdown voltage of the failed accessories were in any cases higher than the test levels given in the CIGRE recommendations. E.g. for the 150 kV equipment the breakdown voltage of the accessories were  $\geq 2 U_0$  (CIGRE recommendation  $1.7 U_0$ ) and for the 220 kV equipment  $\geq 1.7 U_0$ . (CIGRE recommendation  $1.4 U_0$ ). If a sensitive partial discharge locating system is used a reduction of the above described test levels could be expected. For operating of this PD measuring system pairs of sensors have to be installed in the joints of the laid cable. Based on the time differences of the PD signal measured by each sensors the PD in cable joints can be located and verified [6].

To reduce the test level for installed old cable systems the quality of the cable insulation as well as the quality of the accessories has to be tested by a sensitive partial discharge measurement. Therefore a further improve-

ment of the conventional PD measurement has to be done. This might be realized by using digital filters to suppress interfering noise [7].

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