MODERN ON-SITE TESTING AND CONDITION ASSESSMENT OF DISTRIBUTION AND TRANSMISSION POWER CABLES USING DAMPED AC VOLTAGES

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Modern on-site testing and diagnosis of transmission power cables up to 230kV consists of voltage testing, partial discharge detection and dissipation factor measurements. Applying AC voltages for this purpose has become in last year a common use. In addition to continuous AC energizing more and more the use of damped AC energizing is getting worldwide attention. In this paper, the use of modem technological solutions in power electronics and signal processing as well as in technical design and production methods will be discussed on the basis of damped AC systems up to 350 KV.

Keywords: high voltage testing, damped oscillation, damped alternating current, DAC, BAUR, OWTS.

DAC HV40 system (for 500kV power cables) during testing of a high-voltage cable system in Singapore

INTRODUCTION

An insulation failure of a power cable can occur as a result of the normal operational voltage or during a transient voltage due to lightning or switching surges. Most failures can occur if localized electrical stresses are greater than the dielectric strength of dielectric materials in the area of the localized stress or if the bulk dielectric material degrades to the point where it cannot withstand the applied voltage. Therefore, together with type testing and routine testing makes on-site testing (including diagnostic measurements such as partial discharges), a part of the reliability improvement of power cables [1-10]. In particular, the on-site tests (see fig. 1) are applied to assess two characteristics of a cable circuit.

- Quality and cable system integrity;
- Availability / reliability of the cable circuit.

In general, for on-site acceptance test for newly installed or repaired circuits one of the two following approaches is typically followed:

- Potentially destructive withstand tests by over-voltage stresses applied to the test object, e.g. for 1 hour, or
- Alternatively a voltage test of 1xU0 (nominal voltage phase to ground) as applied for 24 hrs.

The first approach is based on the assumption that a healthy (defect-free and/or non-aged) insulation can withstand higher levels of voltage stress above the nominal stress and that in case of present insulation defects or ageing defects should have a lower level of withstand voltage which should produce a breakdown under over voltage during the designated test time. The outcome of the test is a simple pass or fail.

It is known, that the application of the overvoltage withstand test without monitoring of other parameters such as partial discharges, is not always sufficient to identify all manufacturing and installation problems. Moreover it has to be considered that:

- Due to the applied test voltage stresses which are higher than the operational stresses, the test may be destructive even if no failure occurs.
- Although the duration of the over-voltage test is developed from test experiences (e.g. 1 hour) it cannot be excluded that after e.g. 1 hour and 10 minutes a failure will occur.

It has been observed that after the cable successfully passed the over voltage withstand tests, failures have occurred during the initial operation (up to several months) [5, 6]. It has been found that insulation defects in the cable insulation and cable accessories are responsible for these failures. Therefore to detect the weak spots in the cable insulation and cable accessories following the installation or repair of the cables, the insulation condition assessment

EXAMPLE OF ON-SITE TESTING USING SINUSOIDAL DAMPED AC VOLTAGES

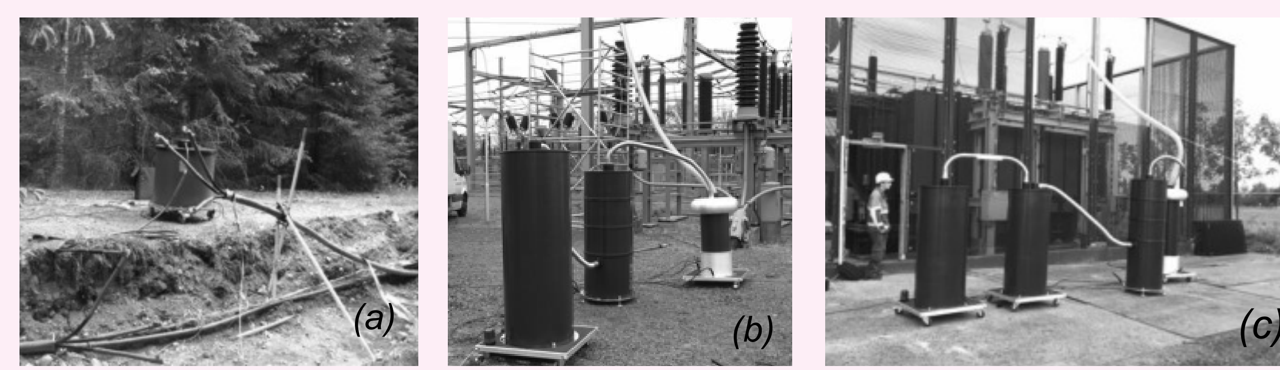

Fig. 1: (a) after-laying testing by DAC MV system of a 13 km long 10 kV XLPE insulated cable; (b) diagnostic testing by a DAC 190 kV system of a 8km long 150kV oil-filled service aged cable; (c) after-laying testing by a DAC 270kV system of a 6 km long 150kV XLPE cable

ON-SITE DAC TESTING PROCEDURES FOR POWER CABLES [7]

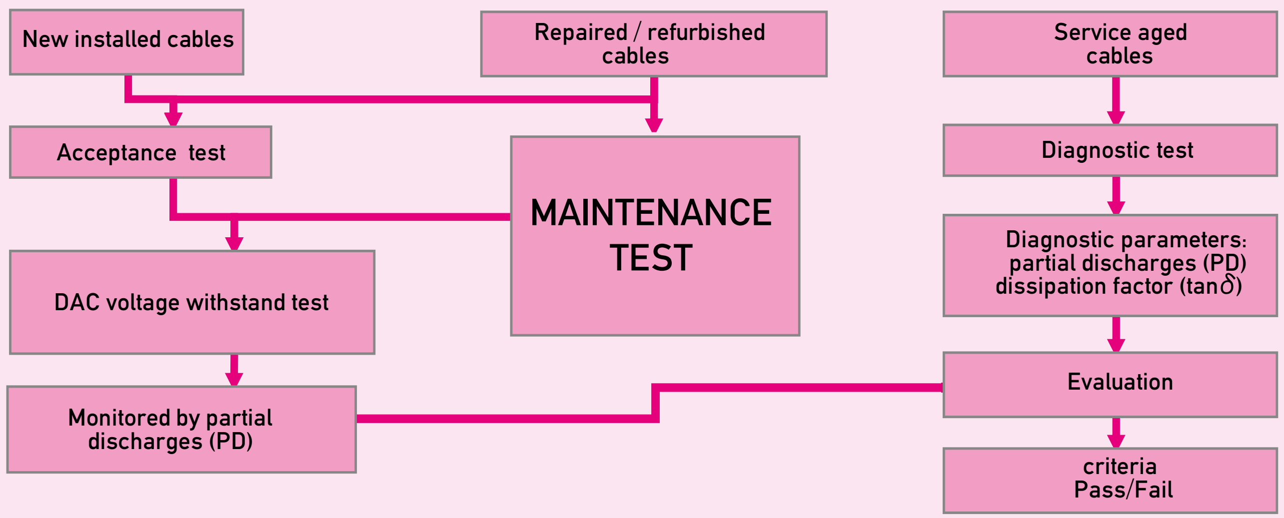

Fig. 2

during on-site testing (so-called monitored testing) is becoming nowadays more and more common practice, see for example fig. 2.
It is known that monitored testing consists of a voltage withstand test combined with a diagnostic test, e.g. partial discharge measurement.

In the field of diagnostic testing, over-voltages (stresses higher than U0) can have a significantly destructive influence on the remaining service life of a particular cable circuit. Therefore it becomes crucial to apply sensitive diagnostics at stresses up to and above U0. The practical realization of such tests becomes more attractive if modern on-site testing methods are available, especially if they are characterized by:

- Lightweight and high level of mobility of the test system;
- Test system compactness versus output voltage;
- Easy system assembly and low voltage erecting effort;
- Low power demand for testing long cable lengths;
- Possibility of sensitive standardized PD detection and dissipation factor measurement.

In this paper the use of damped sinusoidal AC voltages (DAC) for monitored testing of power cables will be discussed based on general considerations and practical examples.

ON-SITE ENERGIZING METHOD AT DAMPED AC VOLTAGES

DAC testing can be used as simple withstand test or in combination with partial discharges (PD) and dissipation factor (DF) measurements. As a result, the use of damped AC voltages for testing power cables is in compliance with the most accepted international standards.

An international survey showed, that in the majority of the cases where DAC has been applied so far, voltage withstand tests have been combined with advanced diagnostic measurements (e.g. partial discharges and dielectric losses). For a voltage withstand test, a predetermined number of DAC excitations is applied, see fig. 3. Due to the shorter duration of the excitation and decaying characteristics of the voltage, DAC test results obtained can differ from those obtained by continuous AC withstand voltage testing.

DAMPED AC VOLTAGE WITHSTAND TESTING

The application of withstand tests can be divided into two classes:

- Non-monitored DAC hold test – a number of DAC excitations is applied and the ability to hold the maximum DAC voltage (i.e. no breakdown occurs) is recorded. The intent of a simple DAC withstand test is to cause weak points in

the cable insulation to fail during voltage application (with minimal fault current) at a time when the impact of the failure is low (no systems or customers affected) and repairs can be made more cost effectively. If a failure occurs during the test, then the failure should be located through a fault location process, repaired and the circuit retested. The results of these tests are described as either Pass or Fail.
- Monitored DAC hold test – a number of DAC excitations is applied and one or more additional attributes are measured and used to determine whether the cable passes or fails the DAC test. These additional attributes are advanced diagnostic properties such as partial discharge detection. The development in time of the measured property can also be used to monitor the effect of the test on the cable system during voltage application.

Due to additional information as provided by PD detection, the monitoring insulation properties during a DAC withstand test and the effect of the test voltage during its application can improve the evaluation of the insulation condition. For all types of tests voltage levels and the number of DAC excitations should be consistent with the purpose of the test. From the point of view of a shielded power cable system quality and reliability, two aspects are important for field tests and results evaluation:

- The DAC test parameters like the maximum test voltage level (see table 1),

SCHEMATIC OVERVIEW OF ONE DAC EXCITATION. THE MAXIMUM DAC VOLTAGE LEVEL IS DETERMINED BY THE VOLTAGE PEAK VALUES (V_{DAC}) AND RESPECTIVE RMS-VALUES ($V_{DAC}/\sqrt{2}$) OF THE 1ST DAC CYCLE [7]

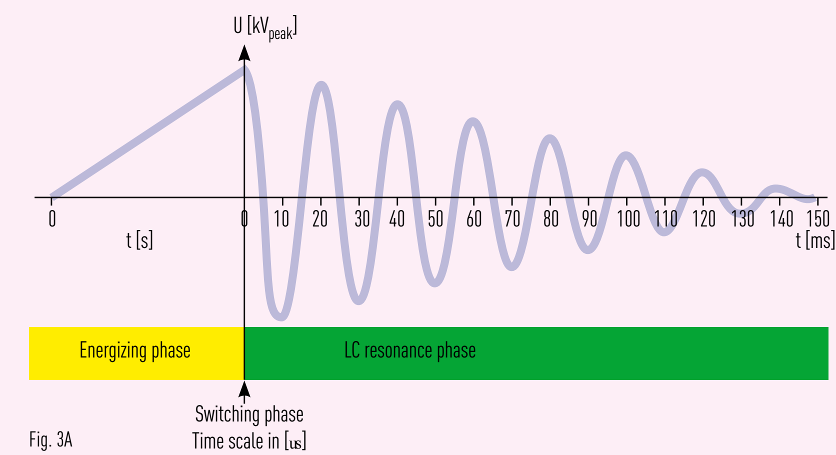

Fig. 3A

SCHEMATIC DIAGRAM OF DAMPED AC SYSTEMS FOR ON-SITE TESTING AND PD DETECTION OF DISTRIBUTION AND TRANSMISSION POWER CABLES [7]

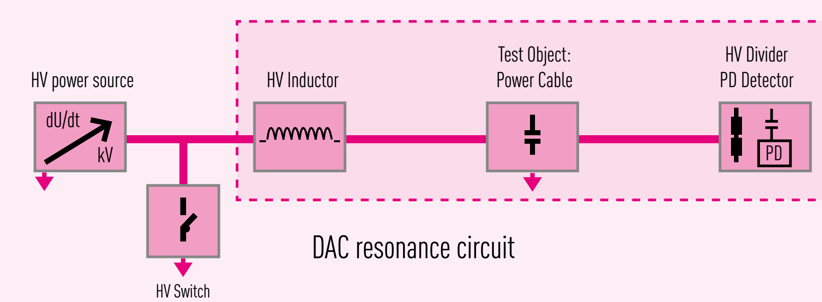

Fig. 3B

DAC TEST VOLTAGES LEVELS (20 HZ...500 HZ) AS USED FOR DAC TESTING (50 DAC EXCITATIONS) OF NEW INSTALLED POWER CABLES [IEC 60502, IEC 60840, IEC 62067]

Power cable rated voltage [kV] Phase-to-phase	Uo [kV]	DAC test voltage level VT [kVpeak]
3	3	6
6	4	12
10	6	17
15	9	26
20	12	34
25	15	43
30	18	51
35	21	60
45–47	26	74
60–69	35	99
110–115	64	181
132–138	77	187
150–161	87	212
220–230	127	254
275–287	159	296

Table 1

as well as the duration of an over-voltage application shall be chosen in such a way as to prevent or minimize the shortening of service lifetime due to the field test. In the case of withstand tests the impact on a defective insulation needs to be high enough to cause a breakdown or to exceed a critical level of a monitored property.

– The voltage level and number of DAC excitations (which has an impact on the test duration) are important and inseparable elements of the test and after-test performance of the cable circuit. The recommended test voltages and durations for tests (given in this document for DAC testing) are based on literature [1], international recommendations [11-15] and several years of collection field-experiences as obtained by different users of the DAC technology. Arbitrarily increasing the voltage or extending the test duration from the recommended values can potentially increase the probability of an early failure in service.

PRACTICAL EXAMPLES

The application of damped AC voltages for testing and diagnosis of distribution and transmission power cables up to 230 kV has a history of more than 12 years. In this section, an example of testing a HV cable and an example of testing a MV cable are presented and discussed to highlight the importance of monitored testing.

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Fig. 4A. On-site testing of a 220kV 13.3km long XLPE cable circuit.

Example 1: A newly installed 13.3 km long, 220 kV XLPE insulated underground cable circuit has been tested using DAC resonance system at 49 Hz, applying up to 1.3xUo, see fig. 4-5. It has been decided to perform a monitored withstand testing. As the DAC test voltage was increased, and starting from 0.2Uo, PD activity has been observed in phase L1. An increase in the test voltage has resulted in an increase of PD activity and at 0.4xUo test voltage, a breakdown in the discharging site has occurred. Using PD mapping the PD concentration at 5.3km has indicated the breakdown position in the cable. As a result the after-laying testing using damped AC voltage proved to be effective for monitored testing of a long length 13.3 km newly installed 220 kV cable. The defect produced PD before an actual breakdown occurred, and with TDR analysis the PD defect location could be determined. The other 2 phases have fulfilled the after laying conditions and successfully passes the test. No internal PD activity in the cable insulation and accessories and no breakdown occurred during the complete test. The measurement was repeated from the other side of the cable. Again the PD activity occurring before the breakdown could be localized at 8 km, which is the same location seen from the other side (13.3 – 8 = 5.3 km).

CONCLUSIONS

Based on the above presented results the following can be concluded:

- According to the most recent developments, monitored voltage withstand testing is becoming more and more a common practice. The use of PD measurement helps to detect and to localize discharging defects in the insulation and in accessories of power cables.
- For testing of transmission and distribution power cables, damped AC voltages in combination with PD detection can be applied as an alternative to continuous AC test voltages.
- Regarding breakdown and as compared to non-monitored continuous AC voltage testing in

INFORMATION

DAMPED INTELLIGENT AND ENORMOUSLY COMPACT TESTING OF POWER CABLES RATED UP TO 400 KV

Swiss DAC, – pioneer on-site high voltage, has signed last autumn a partnership contract with another leader in high and medium voltage diagnostic market from Austria, BAUR Prüf- und Messtechnik GmbH.

With this agreement BAUR is extending its product portfolio to HV and EHV testing and diagnostics products. The new product line DAC Technology Test System is exclusively distributed by BAUR in the most regions of the world.

The both partners complement one another, BAUR with the best connected network and on-site with the best technology in high voltage field.

DAC VOLTAGES AND PD PATTERNS AS OBSERVED DURING DAC MONITORED VOLTAGE WITHSTAND TESTING

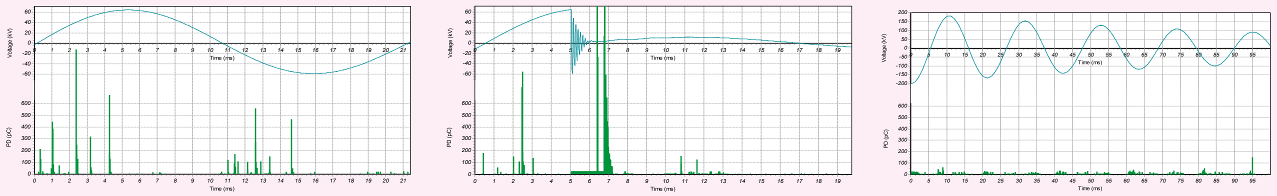

Fig. 4B
a) example of PD pattern at 0.2Uo of phase L1; b) example of PD pattern at breakdown voltage of 0.4Uo of phase L1; c) PD pattern at 1.3Uo of phases L2 and L3

PD MAPPING AS MADE UP TO 1.3U_0 DURING DAC ON-SITE TESTING OF A 220KV 13.3 KM LONG CABLE CIRCUIT. THE PD CONCENTRATION AT 5.2 KM DISTANCE INDICATES THE BREAKDOWN SITE OF PHASE L1 (LEFT). MEASUREMENT FROM THE OTHER SIDE CONFIRMED THIS LOCATION AT 8.1 KM SEEN FROM THE OTHER SIDE (RIGHT)

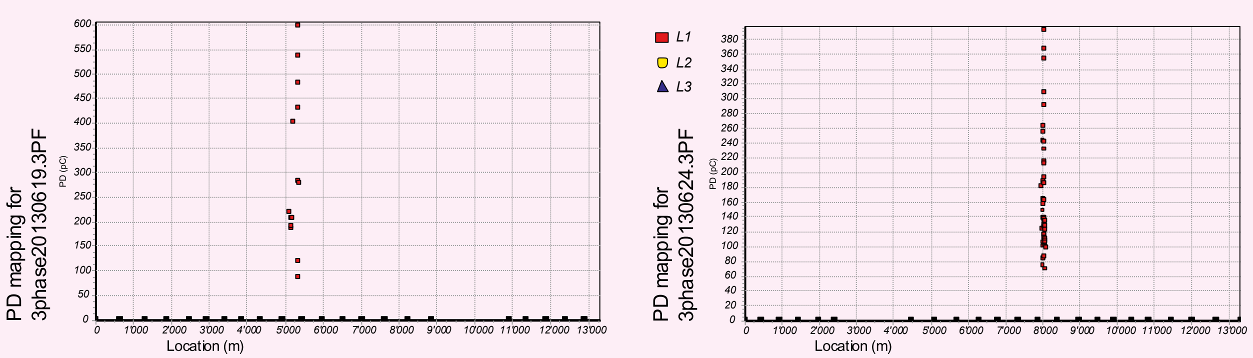

Fig. 5

case of non-homogeneous defects (PD occurrence), monitored testing using damped AC voltages can be less destructive and more sensitive (in case there is no breakdown observed) to detect and to localize discharging defects in the accessories.

4. The use of damped AC voltages is applicable for after-laying testing of newly installed cables, maintenance testing of repaired cables as well as for diagnosis and condition assessment of service aged cables.
5. The application of DAC voltage testing in combination with standardized PD measurements, can provide PD-pattern information, advanced PD pulse analysis (TDR) to localize single or multiple PD sites and estimation of the dielectric dissipation factor.

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