Test Fields, Systems and Components for HV Routine Tests of Extruded Cables
Requirements for Routine Cable Testing

A routine test verifies both, the correct production and the sufficient quality of the cables with extruded insulation. It has to be performed according to the relevant standards, mainly based on the IEC Standards 60502 (1 kV to 30 kV cables), 60840 (above 30 kV to 150 kV cables) and 62067 (above 150 kV to 500 kV cables), for each delivery length after production. The routine tests include the following procedures:

**HVAC withstand tests** are mandatory and are performed with test voltages according to the above and national standards (ranging between 4 \( U_0 \) for medium-voltage cables down to 2 \( U_0 \) for extra-high-voltage cables). The test delivers a clear yes/no result and is sensitive especially for heavy production failures. Therefore it has to be combined with a sensitive PD test.

**Partial discharge (PD) tests** are able to detect even small weak points which may endanger the reliable operation of the cable after years. Therefore a high sensitivity of the PD test is required. For the clear measurement of an apparent charge of 5 pC (maximum acceptable level), the basic PD noise level must be below 2.5 pC. HIGHVOLT is able to supply technical solutions of the test field with PD noise levels below 1 pC.

**Measurement of conductor resistance** is a further routine test procedure, which is performed as a traditional four wire measurement, and does not require any special conditions. HIGHVOLT supplies such instruments. The necessary equipment (Fig. 1) for the realization of these test procedures is described in the following, additional equipment can be supplied on request.

AC Resonant Test Systems

Extruded cables are a pure capacitive load of a HVAC test system, therefore the most efficient way to generate the AC test voltage is the application of a resonant circuit (Fig. 1). The capacitive load and the variable inductance of the HV test reactor create an oscillating circuit of the natural frequency \( f = 1/2\pi\sqrt{L/C} \). By tuning the inductance this frequency becomes equal to the power frequency (50 or 60 Hz). This means resonance and only the power losses (usually below 3% of the test power) must be supplied into the circuit. For cable testing, HIGHVOLT applies the principle of series resonance to generate an ideal sinusoidal AC voltage. It has to be mentioned that resonance can only be reached in a certain range of capacitive load (usually \( C_{\text{min}}:C_{\text{max}}=1:20 \)). It is recommended that the basic load of voltage divider, filter and coupling capacitors is equal to \( C_{\text{min}} \) which allows the operation of the test system without cable for checking its proper operation. The AC resonant test systems consists of the following components (compare the components in Fig. 1).

**HV reactor**: Its inductance is tuned by an adjustable gap in the magnetic core. There are two different designs:

- **Steel tank reactors** are supplied for rated voltages up to 350 kV and can be equipped with taps for an optimum adaptation of output voltage and power (extension of the load range). They are characterized by low space demand, optimum combination with the shielded room (Fig. 1) and very good cooling behavior (heavy duty cycles), for details see Data Sheet 1.20.

- **Insulating case reactors** are usually applied for rated voltages above 400 kV by combination of two or more reactor modules (with nominal voltages between 250 kV and 350 kV, for details see Data Sheets 1.21 and 1.22). An adaptation of voltage and power to the cable under test is realized by series or parallel connection of the modules. All required test power is available.

**Power supply and regulation**: The mentioned loss power is supplied to the oscillating circuit from the grid (Fig. 1) via the switching cubicule, the regulator transformer (for adjusting the value of voltage) and a HF power filter (for the suppression of high-frequency noise) to the exciter transformer (a separate unit or built into the reactor tank). For adaptation to the test conditions, also the exciter transformer is equipped with taps.

**Basic load**: All capacitances on the HV side act as the basic load (Fig. 1, for details see Data Sheet 1.31). They are also described in the following clauses.

**Control and measuring system** (Fig. 1). It contains the combination of the HV control (realized by an operator device (BG 5 R) and by distributed programmable logic controllers (PLC) connected by an optical bus system PROFIBUS), the peak voltmeter MU and the PD and tan \( \delta \) measuring instruments. All components can be connected to one industrial personal computer (IPC), for details see Catalogue 1.52.

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Key Advantages of HIGHVOLT Equipment

* system solutions which include all necessary components
* series resonant test systems of ideal sinusoidal wave shape
* optimum shielded room ready for operation
* lowest PD noise level down to values below 1 pC
* interference-free control system with optical bus
* full integration of control and measurement into one control IPC
* software adaptable to all required test procedures
* connection to local computer networks and INTERNET
* remote service by HIGHVOLT
The connection of the cable to be tested to the HV coupling capacitor (Fig. 1) requires special measures to control the voltage in a proper way and to avoid PD or even flashovers between the conductor on HV potential and the grounded cable screen. Depending on the test voltage of the cable and the test technology different end terminations can be applied:

1. up to 50 kV: semi-conducting paint (not very reliable)
2. up to 100 kV: oil-cup end terminations
3. up to 120 kV: slip-on stress cones (part of typical cable accessories)
4. up to 1000 kV: water-controlled end terminations.

HIGHVOLT supplies oil-cup end terminations (Data Sheet 7.71) and a sophisticated series of water-controlled end terminations (Data Sheets 7.90/7.93/7.95). The latter one covers the full range with types of 75 kV up to 1000 kV for testing of medium-voltage up to extra-high voltage cables.

Water-controlled end terminations use water of a specific and adjustable conductivity to control the voltage distribution in a very precise way. By a new concept of the water processing unit with a fully automatic control of the water conductivity, the temperature and the filling and emptying process, these end termination systems are perfectly suited as a part of a modern cable test field. Easy handling and operation guarantees a high productivity of the test process. Its remote control can be integrated into the computer control and measuring system of the test field.

Accessories: For sealing preparation of both ends of a termination casting molds, silicon compound and hardener are supplied. For the preparation of the cable, the necessary special tools are available. For the termination itself an automatic lifting device is available. An additional water recooling system might also be helpful under heavy climatic conditions.

PD measurement can indicate weak points of the insulation. The PD pulse is decoupled from the HV circuit by a measuring impedance (MI, see Data Sheets 6.31, 6.32) connected to the coupling capacitor (Fig. 1). The PD signal is processed to the apparent charge in the PD instrument (PD, see Data Sheet 6.21) and displayed on the monitor of the IPC. The PD circuit is calibrated by an external calibrator (PD cal, see Data Sheet 6.33). A permanent calibration during the test can be realized by a second calibrator and a HV injection capacitor (CI).

In case of a PD failure (PD signal higher than the basic noise level) the failure can be identified by a phase-resolved PD pattern recognition (see Data Sheet 6.21) and located by PD reflectrometry (see Data Sheet 6.22). This PD cable fault location is based on the measurement of the time between the arrival of the PD pulse and its reflection at the far end.

The sensitivity of the PD measurement down to about 1 pC depends strongly on the noise level. Therefore the measures to reduce the basic noise level are described in the clause about shielding and grounding.

The dissipation factor (\(\tan \delta\)) is an indicator for overall properties of the cable insulation. Therefore it is often measured as a supplement to the PD measurement. HIGHVOLT supplies the necessary equipment consisting of the \(\tan \delta\) measuring instrument, the standard capacitor (Fig. 1: MCP) and related sensors in the cable end termination. Different \(\tan \delta\) measuring instruments from manually operated up to computerized solutions in combination with the PD measuring device are available.

![Fig. 1: Principle scheme of a routine test field (explanations in the text)](image)
The required high sensitivity of PD measurement requires the following measures to prevent the penetration of external noise signals (electromagnetic waves from broadcasting stations, radars, welding arcs, etc. as well as wire-connected noise like switching signals from thyristor controllers, circuit breakers, drives, etc.) into the test room:

**Shielded test room:** Inside a so-called “Faraday cage” there is no electromagnetic field from external sources. Therefore HIGHVOLT also supplies the shielded room with the following characteristics (Fig. 1 and 2):

- subdivision into test room, control room and power supply area (also directly flanged metal tank reactor and exciter transformer)
- optimum selection of dimensions with respect to size and number of cable drums to be tested, material handling and test facilities
- smooth test technology
- lighting, emergency measures and adaptation to climatic environment by air conditioning
- self-carrying mechanic design of steel structure and panels with special doors
- damping characteristics for electrical field 110 dB for 1 kHz to 1 GHz, for magnetic field >60 dB for 10 kHz and >100 dB for >100 kHz.

**Grounding system:** The shielded test room includes its optimum grounding which is also optimum designed for the grounding of the HV test system and the cable under test.

**Filters:** For suppression of wire-connected noise, it is necessary to apply high-frequency filters (Fig. 1). The power line filters are fixed to the walls of the shielded room or – if reactors and exciter transformer are in one tank – fixed to that tank. Additional filters are used for control and communication lines.

**Accessories** like illumination, warning and emergency lamps, safety loop including door switches, small bridge crane for fixing the ends of heavy HV cables during preparation, etc. complete the installation of the shielded room.

**Remark:** Occasionally customers wish to erect the shielded test rooms by themselves. For such cases HIGHVOLT offers consulting by its specialists and supplies necessary special components (e.g. doors).

The computer control system (Fig. 1 and 3) of the test field covers the full control of the AC resonant test system, the PD and tanδ measuring equipment, the cable end termination system and the safety system of the shielded test room. It supplies help functions for the operator, enables the comfortable performance of the tests, guarantees the recording of all test data and their evaluation including printing a test record. The high reliability of the system is based on the application of standard industrial components (e.g. PLC of type Simatic S7, industrial PC) and interference-free optical links. The software can simply be adapted to all necessary test procedures (for details see Data Sheet 1.55).

The computer control can be integrated into the local area network (LAN, e.g. Ethernet) for internal data transfer (e.g. data of the cables under test, test parameters, test results). Furthermore a connection to wide area networks (e.g. Internet) is provided and enables communication between different factories of one company or remote service by HIGHVOLT (for details see Data Sheet 7.20). In the latter case HIGHVOLT can supply software updates or support the trouble shooting by overtaking the control system to Dresden. The application of these modern information technologies improves the cooperation between customers and HIGHVOLT.

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