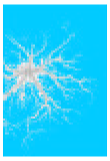
HIGH VOLT

# AC Resonant Test Systems
# for On-Site Testing and Off-Line Diagnostics
# of Medium Voltage Cables and Electric Machines

8.03/3

# Situation and Application



# Fundamentals

**Medium-voltage cable systems** are tested on site for commissioning and for diagnostic purposes. High-Voltage (HV) testing with direct voltage (DC) worked well for the traditional oil-filled power cables with relatively high dielectric losses. Quantitative information were derived from DC tests mainly the value of leakage current or some resistive values. Gradually extruded medium voltage cables have been introduced. Today they dominate the application almost exclusively. Studies by numerous researchers have indicated serious concerns about DC testing of extruded cables intended for use in alternating voltage (AC) power systems. The experts agree that a DC test does not prove the suitability of extruded cables at all. It is even dangerous, because the insulating material, mainly XLPE, has a memory that is caused by space charges and stipulated by unipolar stress. It takes a very long time to lose the DC bias. If AC voltage is applied to that cable, the DC bias plus the AC stress can be enough to fail the cable.

**The general principle** of the HV test technique is that a test voltage shall simulate the stress under operation conditions of the test object. Traditional AC test systems were too large for on-site application. As a next step test voltages of very low frequency (VLF, 0.1 Hz) have been introduced which enable partial discharge (PD) and dielectric loss (tanδ) measurement. But also VLF tests cannot fulfil the above general principle: The resistive stress distribution at VLF is much different from the capacitive at power frequency. Also the number of stress cycles is very much lower (A 50 Hz test of 15 min has the same numbers of cycle as a VLF test of 125 hours!).

**The way out** is the use of AC resonant test systems tuned into resonance by the frequency of the exciting voltage. This leaflet describes HIGHVOLT AC resonant test systems of variable frequency, type WRV ... TM.

**The application** of systems, type WRV ... TM, covers the full range of medium-voltage cable systems with extruded and oil-paper cables up to 36 kV rated voltage. The test currents of the standard systems enable the testing of capacitances of more than 4 µF. This corresponds to about 15 km of cables and covers also the full range for electric machines. The systems, type WRV ... TM, can be completed by detectors for partial discharge measurement and location as well as for dielectric loss measurement. This offers the chance for a direct comparison of the factory and field tests, and for the transfer of the wealth of factory test data to the on-site testing and diagnostics.

- The test simulates service conditions.
- In addition to a voltage withstand test partial discharge and loss factor values can be recorded for diagnostic application.
- Partial discharge defects of a certain magnitude can be located.
- The weight, the size and the three-phase power demand of the WRV test system are minimum.
- For higher voltage or power demand systems can be connected in series or in parallel.
- Adapted technology for connecting the test object and for transportation is available.
- HIGHVOLT systems type WRV have proven high efficiency and reliability.

Key advantages of variable frequency AC testing

**A capacitive load C** (Fig. 1) and a HV reactor of fixed inductance L form a HV oscillating circuit of the natural frequency

$$f = 1/(2\pi\sqrt{CL}).$$

By exciting this HV circuit with an AC voltage of its natural frequency, which is supplied by a frequency converter via the exciter transformer, the system is tuned into resonance and delivers a high test voltage $V_T$ and a high reactive test power $P_T$. The relation between these parameters and the exciter voltage $V_E$, respectively the feeding power $P_F$, is characterized by the quality factor

$$Q = P_T / P_F \approx V_T / V_E.$$

**This quality factor** of a WRV system is about twice of that of resonant test systems with tunable inductance and fixed frequency. This means for identical test frequency the power demand of a frequency-tuned resonant test system is about half of that of an inductance-tuned one. With respect to testing oil-paper cables and electric machines of higher losses the systems, type WRV ... TM, are optimized with respect to the minimum weight of the reactor.
The maximum capacitive load causes the lowest test frequency and the maximum test current (Fig. 4)

$$I_{max} = 2\pi f_{min} \times C_{max} \times V_T.$$

The selection of the frequency range ($f_{min}$, $f_{max}$) determines the obtainable wide load range ($C_{min}$, $C_{max}$) according to

$$C_{min} / C_{max} = (f_{min} / f_{max})^2.$$

**For WRV test systems** described in this leaflet $f_{min}$ = 20 Hz and $f_{max}$ = 300 Hz is selected, which gives a wide load range of $C_{max}$, / $C_{min}$ = 225. Because $f_{min}$ is about half of the power frequency at maximum load the power demand and consequently the weight-to-power ratio (kg/kVA) is reduced to about one quarter of that of inductance-tuned resonant systems. This causes the advantage of HIGHVOLT systems type WRV ... TM (Fig. 2). Usually the capacitance of the voltage divider (Fig. 1) can be designed as basic load for operating the system without test object at $f_{max}$ = 300 Hz. The relation between load and frequency is given in the load characteristics (Fig. 3). Fig. 1 shows a WRV test system with options for PD and tan δ measurement (explanation of the numbers in the following text).

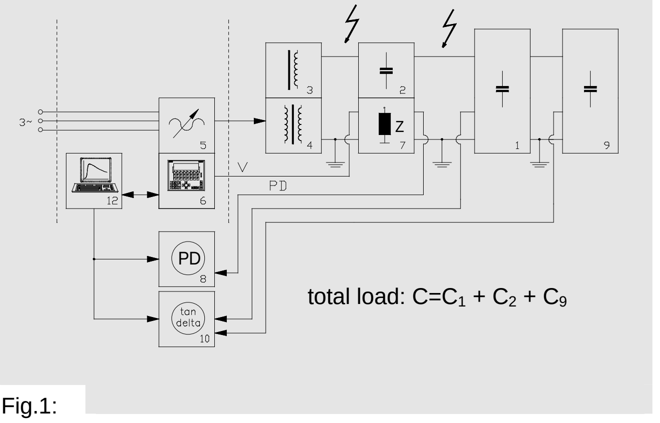
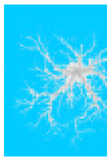



Fig.1:



**The HV oscillating circuit** of an on-site test system consists of the capacitive test object (Fig. 1, no. 1), a cable system or a rotating machine and the following components:

- the powerful oil-insulated **HV reactor (no. 3)** in metal tank design, available for different rated voltages and currents (see HIGHVOLT Data sheet 8.14),
- the **voltage divider (no. 2/7)** which can be integrated into the tank of the reactor or realised by a separate unit. It acts also as the mentioned **basic load** and can be utilised as the **coupling capacitor** for PD measurement, and
- the separate **exciter transformer (no. 4)** which supplies the power loss into the oscillating circuit by low-voltage power of variable frequency generated in the control and feeding unit.

**The control and feeding unit (no. 5/6)**, type RSE 70 (Fig. 2, see also HIGHVOLT Data Sheet 8.15) contains

- the **frequency converter** for converting the three-phase mains voltage (50/60 Hz) into a pulse-width adjusted square-wave voltage (20 ... 300 Hz) (**no. 5**),
- a **micro-controller**, which generates the necessary control signals for tuning the frequency into resonance with the HV oscillating circuit,
- an **operator panel** for controlling the whole test procedures in connection with programmable logic controllers (PLCs) (**no. 6**),
- the **peak voltmeter**, type MU 18 (see HIGHVOLT Catalogue Sheet 5.55) for the voltage measurement.

The described components are a complete system for withstand voltage tests on-site.

Fig. 2 Control area inside a van

Fig. 3 (Photo: Courtesy of FGH Mannheim)

**Optional components** complete the test system for diagnostic off-line measurements:

- a **PD measuring system (Fig. 1 no. 8)** including measuring impedance (no. 7) and special components for the adaptation to frequency-tuned resonant systems enables PD measurement according to IEC 60270 and PD fault location for cables up to a length of about 4 km (see LDIC Catalogue Sheet LDS-6). For longer cables instrumentation for non-conventional methods of PD measurement can be supplied.
- a **C/tan d measuring system (no. 10)** including a **compressed gas capacitor** (**no. 9**, see HIGHVOLT Catalogue Sheet 5.31) are provided for automatic and continuous C/tanδ measurement (see LDIC Catalogue Sheet LDV-5).
- both systems are computer-aided (**no. 12**) and the measurements of PD and tan δ can be performed synchronously. In this case both systems are integrated in one instrument.
- **computer control and monitoring (no. 12)** of the on-site test and the measurements is very helpful. It is performed by help of the same computer which is utilised for PD and tan δ measurement, too. Hardware and software of the computer-aided control and measuring system CMS 23 is described in the HIGHVOLT Catalogue Sheet 1.52.

**The on-site testing** by the systems WRV ... TM becomes more convenient by the following optional features:

- **The HV connection** is realised to an adaptation cable within a metal enclosed box on top of the reactor (front figure, Fig. 2). Then the whole test system is shielded and very safe for operation. Also an “open” version is available.
- **Warning and protection** during on-site tests can be guaranteed by warning lamps and the equipment for a safety loop. The control and feeding unit is equipped with an internal safety system and the emergency-off switch. In case the test objects fails the system is detuned from resonance, the voltage collapses nearly to zero and the power supply is switched off.
- **For transportation** of system WRV ... TM a solution with a van or mini-van (cover figure) or with standard containers can be supplied. Details can be adapted to the users demand (Fig. 3).

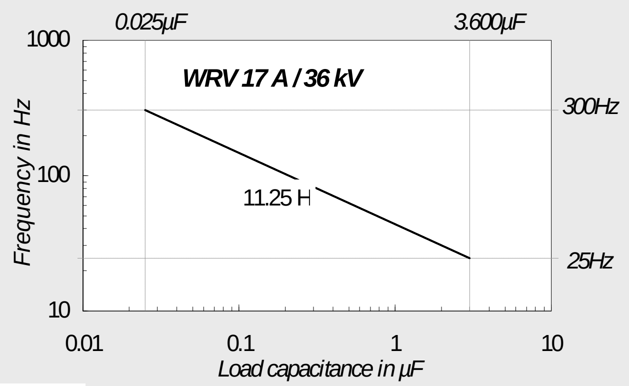



Fig. 4

# World-Wide Use of HIGHVOLT WRV Systems

**AC resonant test systems** of variable frequency manufactured by HIGHVOLT have proven efficiency and reliability in on-site testing of extruded high and medium voltage cables, gas-insulated substations (GIS), instrument transformers and other components of power systems. There is a certain logic for a wider application of this principle on the testing of medium voltage cables, especially for off-line PD and tanδ diagnostics. Because the electric failure mechanism of extruded cables at stresses in the frequency range 20 ... 300 Hz is identical to that at power frequency (50/60 Hz), the WRV systems are the ideal tool for the combination of diagnostic measurements and withstand tests on site. Numerous publications about the experience with WRV systems confirm the advantages of the method.

Fig. 5 shows a test system WRV 17/36 TM (36 kV, 17 A; left control and feeding unit RSE 70, right reactor DE 1000/36). The reactor is equipped with a elbow bushing and inserted bushing plug. The system is operated by TU Chemnitz.

Fig. 5

| Type | WRV 10/36 TM | WRV 17/36 TM | WRV 6/50 TM | WRV 23/45 TM | WRV 21/45 TM* |
|---|---|---|---|---|---|
| rated voltage<br>rated current<br>load capacitance | 36 kV<br>10 A<br>12 … 1770 nF | 36 kV<br>17 A<br>25 ... 2500 nF | 50 kV<br>6 A<br>6.5 ... 650 nF | 45 kV<br>23 A<br>25 ... 2450 nF | 50 kV (25)<br>12.5 A (25)<br>13 ... 1300 nF<br>(52 … 5200 nF) |
| duty cycle | 30 min ON – 60 min OFF, 6 cycles per day | | | | |
| frequency range | 20 ... 300 Hz | | | | |
| reactor type<br>(data sheet 8.14) | DE 720/36-6 | DE 1000/36 | DE 500/50 | DE 2000/45 | DE 1000/50* |
| control & feeding unit type<br>(data sheet 8.14) | RSE 70 | RSE 70 | RSE 70 | RSE 70 | RSE 70 |
| total weight | 1100 kg | 1400 kg | 1100 kg | 2700 kg | 1900 kg |

Table 1: Standard Types of WRV ... TM

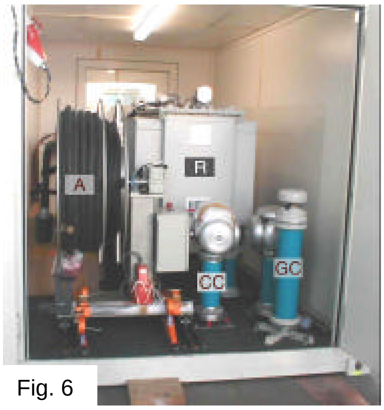



Fig. 6

Fig. 6: The combination of two systems WRV 12.5/50 enables the testing at rated values 100 kV / 12.5 A, 50 kV / 25 A and 25 kV / 50 A. This is sufficient for testing capacitance of more than 10 µF at 25 kV (corresponding to approximately 35 km of cable). The system is under operation at Pirelli Cables and Systems Delft.

The front page shows a Mercedes Sprinter with a System WRV 10/36 TM operated by KEMA-IEV Dresden.

**The type designation** of a frequency-tuned resonant test system for on-site testing of medium-voltage cables and other test objects of high capacitance is given by

| | | |
|---|---|---|
| **WRV a/b TM** | with | a – rated current and<br>b – rated voltage |
| Example: | WRV 17 / 36 TM means a system for 36 kV and 17 A with a metal tank reactor for medium voltage | |

For inquiries of systems type WRV ... TM use the HIGHVOLT Questionnaire G, please. Main parameters of some standard systems are given in Table 1.

**For further information please contact:**

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