ICM*flex*

Partial Discharge Detector, PD Fault Locator, and Tan Delta Measurement System

User Manual

Rev. e2.21

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I General

I.1 About this Manual

This manual describes the hardware, software and usage of the ICM*flex* in its current version including all available configurations. Some of the hardware features of the most recent versions are not available with earlier versions of the instrument. It is possible to upgrade most of the previous instruments to the features of the current instruments. Please contact Power Diagnostix for details.

Software updates are available through Power Diagnostix's website (www.pdix.com). The access to the download area of that website is password protected and requires a valid software maintenance contract. Contact Power Diagnostix for details. Current brochures and revisions of this manual are available for download (PDF format) on that website as well.

I.2 Instrument Safety

Before using the ICM*flex*, read the following safety information in this manual carefully. Especially read and obey the information, which are marked with the words 'Warning' and 'Caution'. The word 'Warning' is reserved for conditions and actions that pose hazards to the user, while the word 'Caution' is reserved for conditions and actions that may damage the instrument, or its accessories, or that may lead to malfunction.

Always obey the safety rules given with the warnings and with this chapter. Especially take care of the safety issues while performing field measurements. Never disregard safety considerations even under time constraints found often with on-line and off-line test on site.

Warning:

- Always provide solid grounding of the instrument. Use the rear side wing nut terminal for ground connection on the ground plate or the multi-contact connectors beside. Never operate the instrument without protective grounding.
- Avoid working alone.
- Do not allow the instrument to be used if it is damaged or its safety is impaired.
- Inspect the ground leads and signal cables for continuity.
- Select the proper coupling circuit and connection for your application.
- Do not use the instrument in explosion endangered environment.
- Use the fiber optic link or the Bluetooth communication to operate the instrument. Do not use any cable not supplied by Power Diagnostix.

I.3 Health and Safety Recommendations

I.3.1 General Safety Procedure Prior to Commence

When working under high voltage conditions, following topics need to be considered strictly prior to the measurement set-up and testing.

1.) The operators must have read the safety instructions and passed the local site safety instructions regarding health and possible hazards.
2.) The sample to be tested must be offline, de-energized, and grounded.
3.) Each operator has to check the safety conditions together with the site responsible and pass the tagout/lockout procedure for the specimen to be tested.
4.) After the tagout/lockout procedure, the specimen needs to be checked for the presence of voltage together with the site responsible by using a suitable HV tester.
5.) The operator has to check the solid work grounding together with the site responsible.
6.) After passing issues 1 to 5, the specimen is in safe condition and may be connected to the equipment.
7.) Check for a safe area as close as possible to the specimen terminals to install the equipment.
8.) Apply demarcation around the full measurement set-up and make use of a safety guard, if necessary.
9.) Prevent working alone.
10.) Only authorized personnel are allowed to access the demarcated test area.
11.) Hold a meeting with other people working close to the hazardous area before energizing the test specimen.
12.) Please check at least the insulation resistance prior to apply external HV potential.
13.) The calibration can be performed.
14.) Remove the calibrator before applying any external high voltage.
15.) Record the requested data and ensure slow and careful voltage ramp-up steps.
16.) Discharge and ground the test specimen after the external high voltage is switched off.
17.) Test the specimen for the presence of high voltage before changing or touching any HV connection with a grounding stick.
18.) The specimen is now in safe condition, necessary changes to the set-up can be done safely.

Please check the detailed Power Diagnostix “Health and Safety Instructions and Recommendations” guideline in case of any ambiguities regarding safety.

I.3.2 Health and Safety Risks

Incautious actions during testing can result in life-threatening hazards such as electrocution. Please be aware that is not only valid for the operators but also for other people working close to the area under high voltage. Please take the necessary personal protection recommendations as mentioned above and in the detailed Power Diagnostix “Health and Safety Instructions and Recommendations” guideline so that testing can be performed in a safe condition at any time.

A specimen under high voltage can produce Ozone due to the presence of partial discharge activity. The maximal allowed Ozone concentration in the open air is fixed on 0.1 ppm (parts per million) in accordance with the European Health commission. Inhaling to much Ozone can cause serious lung problems on short- and/or on long-term. Please make sure that the test area is sufficiently ventilated. When necessary, make use of any required personal protection equipment, and hence, consider this health recommendation during testing.

I.3.3 Environmental Conditions

Care must be taken that the area surrounding the test specimen is in sufficiently clean and dry condition before installing the equipment and starting the tests. We recommend considering particularly the temperature and relative humidity. Temperatures above 45°C can directly affect the performance of the battery. Working under too high humidity conditions can result in additional stray capacitances influencing the tan delta and capacitance values, even the partial discharge measurement. Always make sure that the equipment is clean and leave sufficient space between the parts under high voltage and any other object nearby.

II Principle of Operation

The ICM*flex* is a unique measurement system that covers PD detection, PD fault location on cables, and tanδ measurements (standard ICM*flex*, only). It has been designed to simplify the application and to combine different measurement tasks with one instrument. This new principle minimizes testing and operation time, increases operator's safety, and guarantees highest sensitivity and precision. Main users of these systems are:

- Service groups testing motors, generators, and accessories of the same
- Service groups testing high voltage cables, termination and joints
- Maintenance & repair shops
- High voltage laboratories
- Research & development departments

The system is mainly used for on-site testing, but can be used in laboratories and workshops as well. It operates with any fixed or portable high voltage power supply, like transformers, high pots, resonant test systems, motor generator sets, and VLF systems (cos/square & sine waves), for instance. Power Diagnostix offers complete systems as well as modular components.

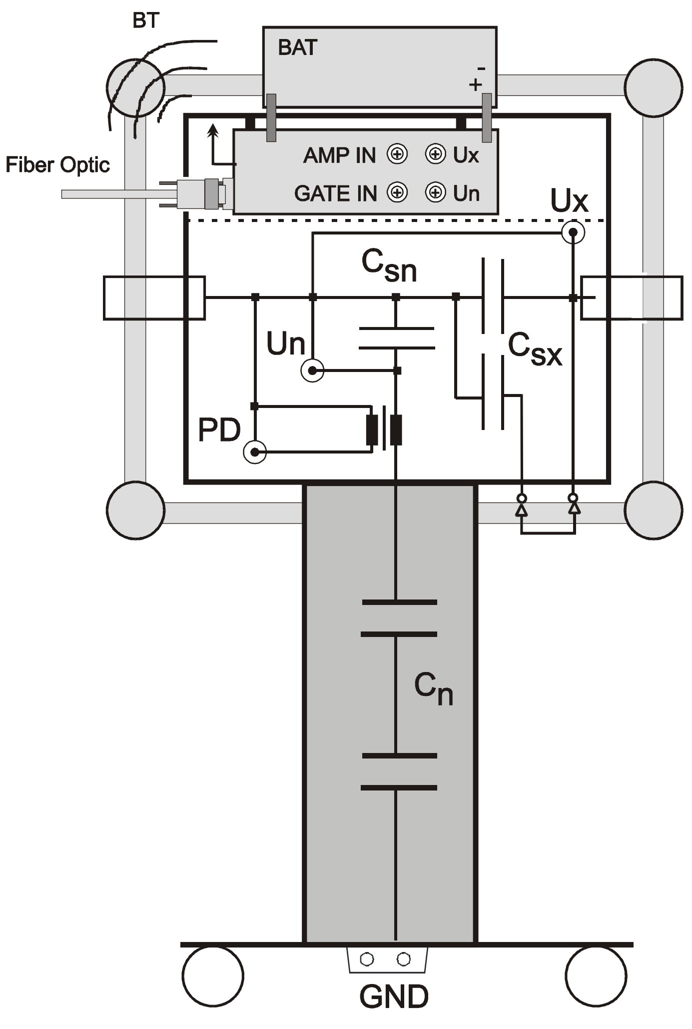


Fig. 1: Design of the ICM*flex*

A complete acquisition system is shown here in figure 1. It consists of a reference capacitor C_n, two shunt capacitors C_{sn} and C_{sx}, a decoupling circuit for PD measurement, an HF current transformer, and the acquisition box with battery module. If PD measurement is not wanted, the decoupling circuit will not be built-in. For systems above 30 kV the main box is surrounded by an aluminum electrode to smoothen the electrical field. The communication from a laptop to the instrument can be established via Bluetooth or via fiber optic serial bus. All measurement values are displayed by the ICM*flex* remote control software on the computer.

Two voltages can be measured with this system. U_x is taken from the capacitive divider between the external capacitance of the test object C_x and the internal shunt capacitor C_{sx}. The reference voltage U_n is provided by the capacitive divider C_n/C_{sn}. The waveform of both voltages is displayed in a special graph in parallel with the absolute values of U_{peak}, U_{rms}, and $U_{peak/sqrt2}$. The correlation of both signals gives further results like the tan delta value, the power factor, and the capacitance C_x of the sample under test. Due to the high sampling rate of 100 MHz with a 16 bit A/D conversion sufficient precision and accuracy can be guaranteed.

The high frequency PD signal is used for PD pattern acquisition and for PD fault location on cables as well, if needed. The PD scope comes with an 8bit resolution vs. phase and amplitude. The pulse counting goes up to 65536 (16 bit) per phase-amplitude position. The sensitivity of PD measurements depends strongly on the quality of the power supply. Power Diagnostix offers various modular filter units to block noise generated by the source (see section III.5). Furthermore, the instrument comes with a built-in gating input to trigger on HF pulses from the input side. External noise signals do not interfere with the measurements as all signals are directly taken on high voltage potential and, therefore, critical ground loops to the instrument are not existent.

The following table shows the most common combinations and configurations of the ICM*flex*. Adaptable high voltage filters are available for all systems.

Type	Rated Voltage U_r (RMS)	Rated Current I_r (RMS)	Frequency Range f	Reference Capacitor C_n	Shunt Capacitor C_{sn}	Shunt Capacitor C_{sx}	Comment
ICM*flex*	20 kV	1A	2–265 Hz	1000 pF	2 µF	5µF/30µF	
	30 kV	5 A	2–265 Hz	1000 pF	3 µF	10µF/100µF	
	30 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	3 µF	40µF/400µF	
	50 kV	1 A	2–265 Hz	500 pF	2.5 µF	10µF/100µF	
	50 kV	100 mA	0.02–0.2 Hz (2–265Hz)	500 pF	4 µF	40µF/400µF	
	100 kV	1 A	2–265 Hz	1000 pF	10 µF	10µF/100µF	
	100 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	10 µF	40µF/400µF	
	150 kV	1 A	2–265 Hz	1000 pF	15 µF	10µF/100µF	
	150 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	15µF	40µF/400µF	
	20 kV–1000 kV	to be specified	2–265 Hz	to be specified	to be specified	to be specified	available on request

Typical filter units are listed in the table below. Please contact Power Diagnostix if modified versions are needed.

Type	Rated Voltage U_r (RMS)	Rated Current I_r (RMS)	Frequency Range f	Filter Config.	Blocking Capacitor C_b	Damping Factor @100 kHz	Comment
T30/1	30 kV	1 A	DC–300 Hz	L-C-L	6.7 nF	>100	
T50/1	50 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100	
T100/1	100 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100	
T100/70	100 kV	70 A	DC–300 Hz	L-C-L	10 nF	>100	
T150/1	150 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100	

The following picture shows a 50 kV set consisting of a T-filter T50/1 (left) and the ICM*flex* model for 50 kV (right).

Fig. 2: 50 kV test set

Due to the different needs, it is possible to order the ICM*flex* acquisition system in different configurations. The following table illustrates this modularity. Please contact Power Diagnostix to specify the individual configuration.

Type	Comment
ICM*flex* Basic system	The basic system offers voltage measurement, frequency measurement, and both communication ports like Bluetooth and fiber optic serial transmission. The black acquisition box is placed in the head of the gray case. The system is not usable without one of the following options.
ICM*flex* Option TD	This option enables all features for loss factor measurements. The system will come with customized shunt and reference capacitors. The software calculates the following values: C_x : Capacitance of the test object $\tan\delta$: Loss factor of the sample under test $\cos\varphi$: Power factor of the sample under test Optionally, the system can be fitted with a C_x bypass to avoid overstressing of the shunt capacitor if the test object's capacitance is too high.
ICM*flex* Option PD	This option is needed if PD measurements shall be taken from the test object. The system comes with a built-in measuring impedance on HV potential. The software displays all PD activities in a PD scope graph, allows PD pattern acquisition, and indicates the precise PD magnitude Qp.
ICM*flex* Option LOC	This option can be chosen in addition to the option PD. A special high speed sampling board with 16 bit 100 MS A/D converter enables the pulse measurement vs. time. This option is mandatory for PD fault location on cables. The software offers a special TDR (Time Domain Reflectrometry) graph and further evaluation tools.

III Measurement Set-up

III.1 Verifying the Part List

Before starting the installation it is recommended to check if all parts are available. The standard package consists of the following items:

- Acquisition unit ICM*flex*,
- HV filter (optional),
- 2 battery packs; type BAT2A,
- Battery charging device,
- Fiber optic cable (10 m); USB to Sub-D
- Laptop incl. software ICM*flex*,
- PD calibrator CAL1B or similar incl. connection set (optional),
- Set of cables:
  - 0.5 m HV cable (grey) with multi-contact connectors (male/female),
  - 1.0 m HV cable (grey) with multi-contact connector (male) at one end and clamp connector at the other end,
  - 1.5 m grounding lead (yellow/green) with multi-contact connectors (male/female),
  - 2.0 m grounding lead (yellow/green) with multi-contact connector (male) at one end and clamp connector at the other end,
- Set of spare connectors; type multi-contact (male/female),
- User manual.

Please contact Power Diagnostix in case that something is missing or that you need spares or updates.

III.2 High Voltage Cabling

Please be aware that the delivered high voltage cables are non-shielded cables which may not touch any ground potential. The insulation of the high voltage cables supplied by Power Diagnostix can stand a maximum voltage 13.8 kV with direct contact to ground. However, the cable must be installed at a safe distance from any grounded objects. Surface discharge activity will incept from 3 kV in case of direct contact. Please check the detailed Power Diagnostix "Health and Safety Instructions and Recommendations". The minimum distances in open air conditions, which are to be respected in relation to the applied voltage, are specified in appendix 3.

Fig. 3: High voltage connectors

III.3 Location

As mentioned above in the general procedure prior to installation, please search for a safe location close the specimen to install the equipment. Ask for a scaffold, delineation, or covered area, if required, and prevent environmental conditions with high relative humidity and extreme temperatures.

Fig. 4: MV cable testing on-site

III.4 Parts of the ICM*flex* under High Voltage Potential

The ICM*flex* is designed via a unique concept. The entire acquisition unit is directly placed under high voltage right at the position were the necessary signals are. This offers the advantage that no additional signal cables are needed. The filter units are constructed via the same principle. The parts that are under high voltage are marked with warning signs so that no confusion can happen during set-up (see images in section III.5).

The complete head box, including the corona cage surrounding the top of the reference capacitor and both MC connectors on the in- and output, is under high voltage potential. The bottom plate of the ICM*flex* and corresponding filter unit are at ground potential.

III.5 Connecting the ICM*flex*

Please read the application notes for medium and high voltage cables and rotating machines for their specific set-up overview. In general, the main connections are explained below.

The appropriate connection of the HV source (HV transformer, resonance test set, VLF high potential) to the filter and/or ICM*flex* is mentioned on the top covers of both filtering unit and ICM*flex*. Please follow the connection indicators accordingly.

The HV cable of the power supply has to be connected to the female input connector of the filter (at the left-hand side of figure 5) or, if a filter is not needed, directly to the input of the ICM*flex*. A bridge needs to be established from the male output connector of the filter (at the right-hand side of figure 5) to the female connector of the ICM*flex*. Finally, the male connector of the ICM*flex* needs to be connected to the specimen.

Fig. 5: ICM*flex* and filter connectors

This can be a motor terminal or the conductor of a shielded high voltage cable or a stator bar. Of course, the interconnection between filter and ICM*flex* is not necessary, if no filter is used.

The coaxial output of the filter (left picture below) serves for the analog noise gating. A noise decoupling circuit is directly built into the filter to capture any noise originating from the high voltage supply itself. A coaxial connection between filter output and ICM*flex* input (right picture below) need to be established for the use of the gating option. Please prevent direct contact of the coax cable with the high voltage cable between filter and ICM*flex.*

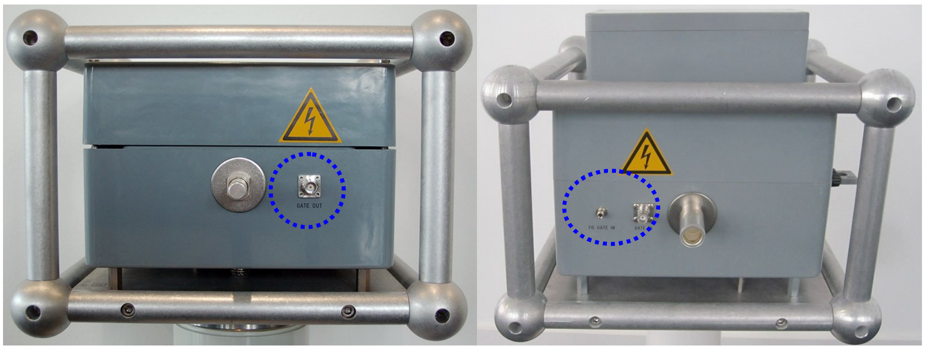


Fig. 6: Coaxial gating connector for filter (left) and ICM*flex* (right)

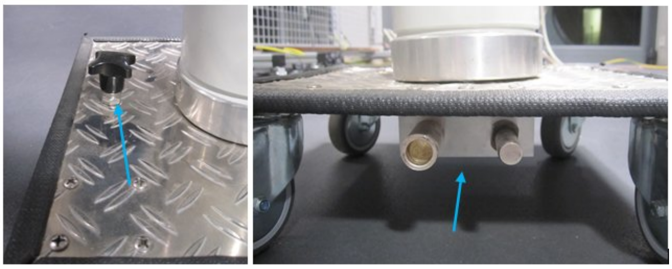


Fig. 7: Ground connection points

Very important is the ground loop of the measurement setup. A bad grounding has a strong influence on the sensitivity due to the background noise. The main ground of the power supply has to be connected with the ground terminal of the filter unit or in case no filter is used, directly to the ICM*flex*. Connection points are foreseen on the metallic grounding plates. The connection can be made by using a cable lug or a multi-contact. Use the supplied short cables to interconnect the grounding of the filter and the grounding of the ICM*flex* and prevent any loop since this will act as an antenna and influence the noise behavior. Finally, a connection, which should be as short as possible, needs to established between the ICM*flex* and the main grounding of the test specimen. Please choose a solid grounding and ensure a good contact. The interconnection between the grounding of the filter and the ICM*flex* is not necessary, if no filter is used.

Fig. 8: SUB-D input connector

The most convenient way to communicate with the instrument is via Bluetooth interface. Here, no further cabling is needed. In case, a Bluetooth connection cannot be established, it is possible to use the fiber optic serial link instead. The SUB-D female connector of the cable has to be connected to the male connector on the upper side of the ICM*flex*. The USB connector of the cable can be connected to any free USB port at the computer. As the fiber optic cable provides a galvanic separation from the high voltage potential, there is no risk for the operator.

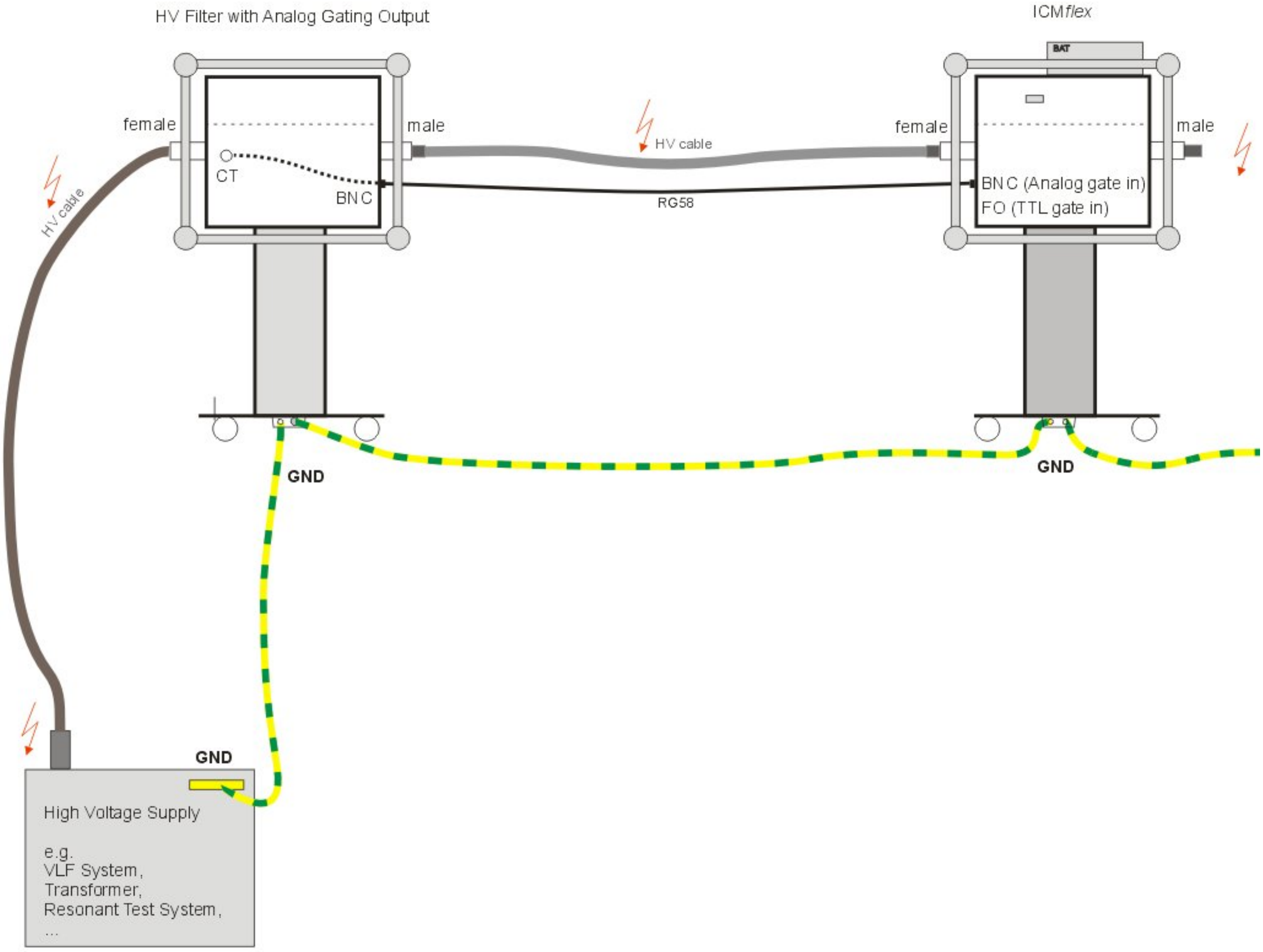


Fig. 9: General connection diagram for ICM*flex*

IV Software & Driver Installation

The ICM*flex* comes with a Windows based software package on USB stick or CD. The software can be installed on every windows (XP, Vista, 7, …) operating system of 32-bit or 64-bit architecture. If a computer is provided by Power Diagnostix, the software and the instrument drivers are preinstalled and readily configured. No further action is needed to start. In all other cases some preparations must be done as explained next.

IV.1 Installing the ICM*flex* Software

Please start the setup.exe file that can be found within the ICM*flex* directory on CD or USB stick. If new software has been downloaded from the internet, it is mandatory to unzip all files to a local directory on the target system first. After starting the setup.exe file, a window as shown below will pop up.

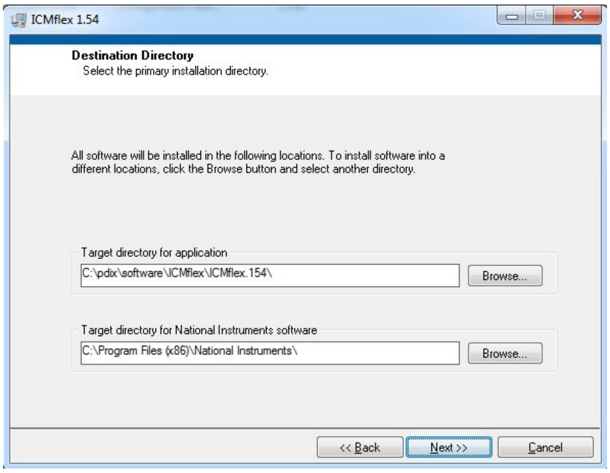


Fig. 10: Software installation setup

Please choose individual installation directories, if wanted, and click 'Next'. The installation kit automatically detects earlier versions and updates only newer files provided by this release. This software has been developed under National Instruments LabWindows/CVI. Therefor, additional DLLs and libraries will be installed automatically within the Windows system directory. Administrator rights are necessary to complete the installation of this software product. Please contact your system administrator in case insufficient rights are given on this machine. After finalizing the software installation procedure the system restarts automatically.

Fig. 11: Desktop icon

The ICM*flex* software can be started directly by clicking on the appropriate icon on the desktop. Before starting to communicate with the instrument further preparations must be completed as it will be explained next.

IV.2 Setting up a Bluetooth COM Port

All Bluetooth devices on computer systems can provide so called virtual COM ports. These COM ports will be used to establish a connection with the ICM*flex*. Standard laptops come with built-in Bluetooth interfaces. If not, it is possible to use external USB-Bluetooth devices. Power Diagnostix can provide such devices for USB, PCI, or other connections, if needed. The Bluetooth interface on any computer provides an automatic scanning function. Please start this procedure to find the ICM*flex* Bluetooth device.

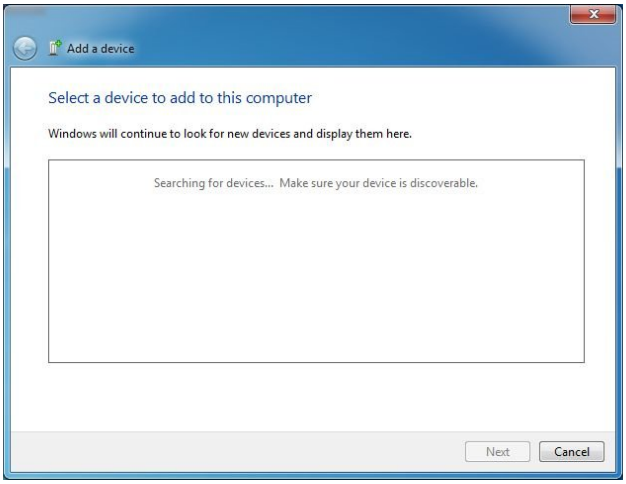


Fig. 12: Bluetooth connection wizard

Fig. 13: Adding a Bluetooth device

The express mode will guide through this setup. Click 'Next'. The search routine can take a few minutes. A pop-up window will display all devices found in range. Select the 'ICM*flex*' entry and continue the installation procedure.

It is mandatory to set the device code for the ICM*flex* connection to "**0000**".

Fig. 14: Bluetooth device successfully added

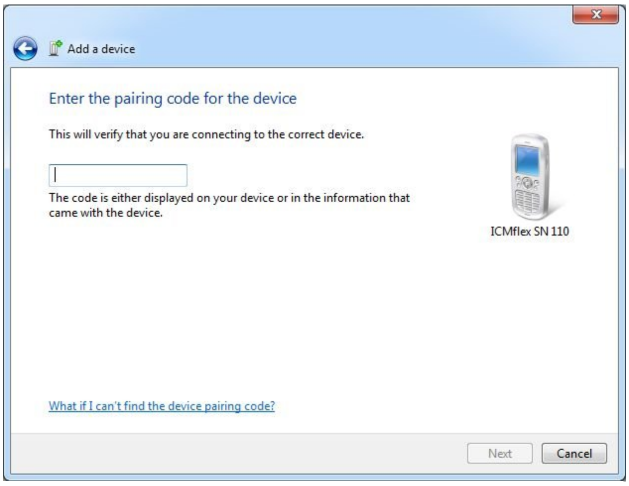


Fig. 15: Entering device code

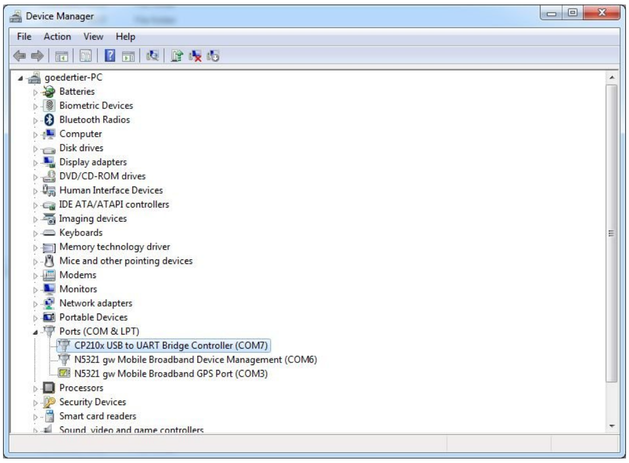


Fig. 16: Device manager

If successful, the hardware manager of Windows will automatically install virtual a COM port for the new device. Typically, two COM ports will be installed for the ICM*flex*. Enable both ports with the ICM*flex* software interface settings as described in section V.2.

IV.3 Setting up a Fiber Optic Communication Port (USB Serial COM)

The ICM*flex* comes with a special fiber optic cable. The SUB-D male connector has to be connected to the COM TTL female connector of the instrument box. The case of the SUB-D plug contains the hard-wire to fiber optic converter. The default length of this cable is 10 meters. Individual lengths can be supplied on demand. The side with the USB-A connector contains a fiber optic to USB converter. This end can be connected to any free USB port of the laptop or PC. The driver for the fiber optic cable will be installed with the software. Please do not connect the cable with the computer before the software is installed! If the driver is not installed correctly, Windows will start the Hardware Installation Wizard when connecting the USB connector the first time to the computer.

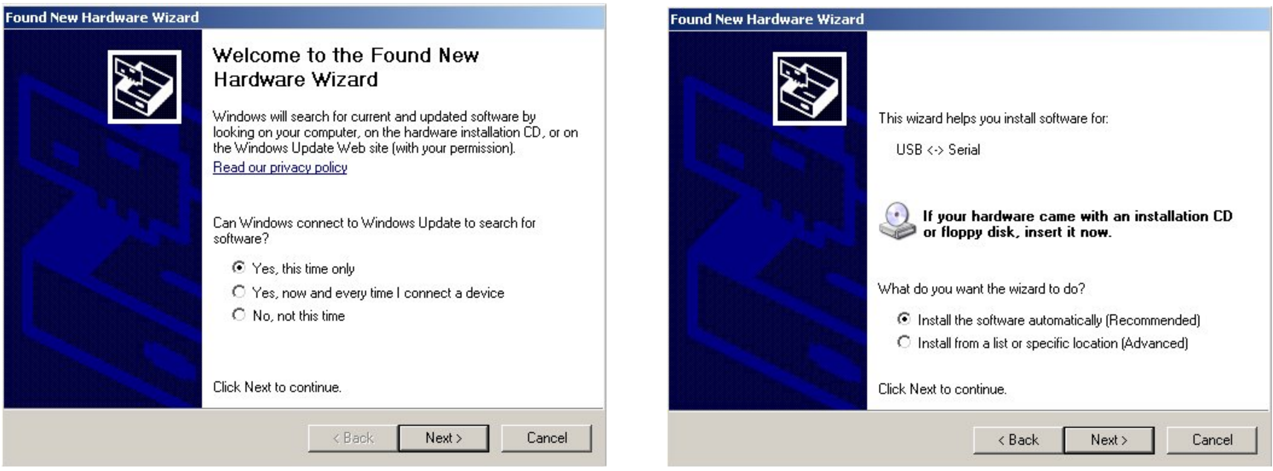


Fig. 17: Driver installation wizard

To guarantee a correct installation it is recommended to perform this installation procedure while being connected with the internet. The Windows hardware manager searches the Windows driver library on the internet to find a suitable driver for this new device. Please contact Power Diagnostix in case of any problems.

If the computer does not recognize the cable, you need to install the drivers manually. Go to the device manager and select the related COM port. After a right mouse click you can select 'update driver'. You can find the driver in the following location on the computer:

C:\pdix\Software\ICMflex\ICMflex.160\USB Driver\CP210x_v4.40.

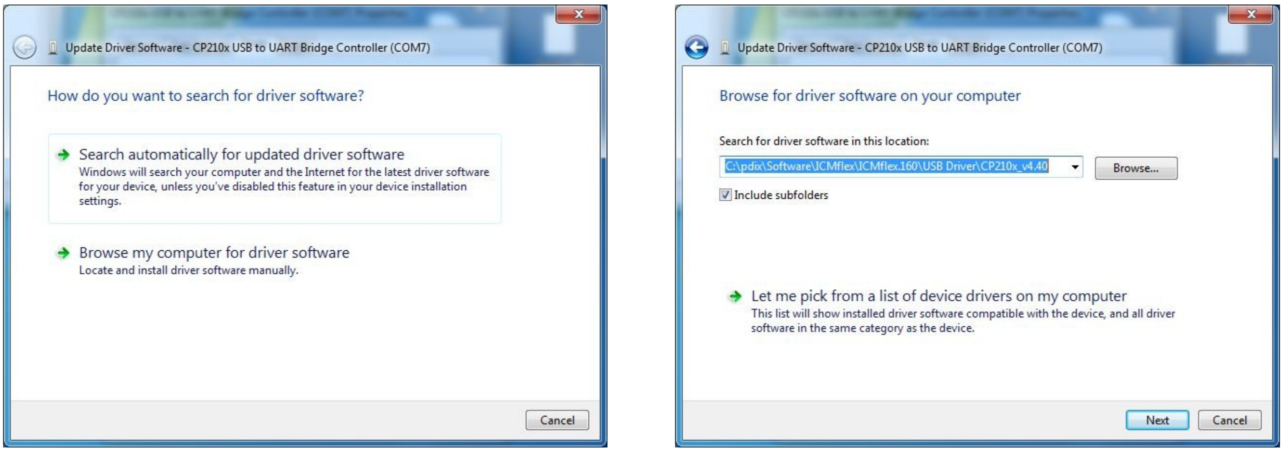


Fig. 18: Driver installation

This procedure must be performed twice. A first time for the USB cable itself and a second time for the cable converter.

The setup routine will automatically install the USB serial COM port, if found, and a new COM port (e. g. COM7) will be displayed with the device manager.

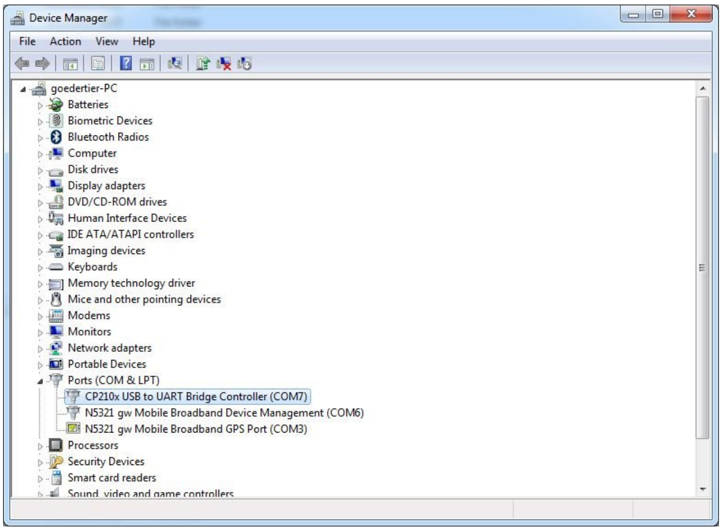


Fig. 19: Device Manager

Please note that the COM port number has to be enabled with the interface settings of the ICM*flex* software (see section V.2). After a restart of the computer the software will automatically search for the COM port in use. If the software can't trace the COM port, you can check manually in the device manager

V ICM*flex* Software

V.1 First Steps

The ICM*flex* software comes up with default factory settings after startup. All settings will be saved when closing the application. Settings affecting the acquisition circuit are sent to the ICM*flex* acquisition box when being changed. The instrument acts as slave, the software acts as master.

Remark: If the application window appears very small when started on a PC with Windows 10, please refer to section XI.2 "Troubleshooting" on page 79.

If not yet connected to an instrument the software displays all data of the last measurement. These data are saved with an .flx file into a specified storage directory, e. g.:

c:\pdix\software\ICM*flex*\ICM*flex*.154\icm*flex*.flx

All optional program preferences like colors, interface settings, etc. are stored in a file called:

c:\pdix\software\ICM*flex*\ICM*flex*.154\icm*flex*.ini

The main program appears as a shortcut link on the desktop, in the 'Start->Programs' folder, and can be started directly from the installation directory.

c:\pdix\software\ICM*flex*\ICM*flex*.154\icm*flex*.exe

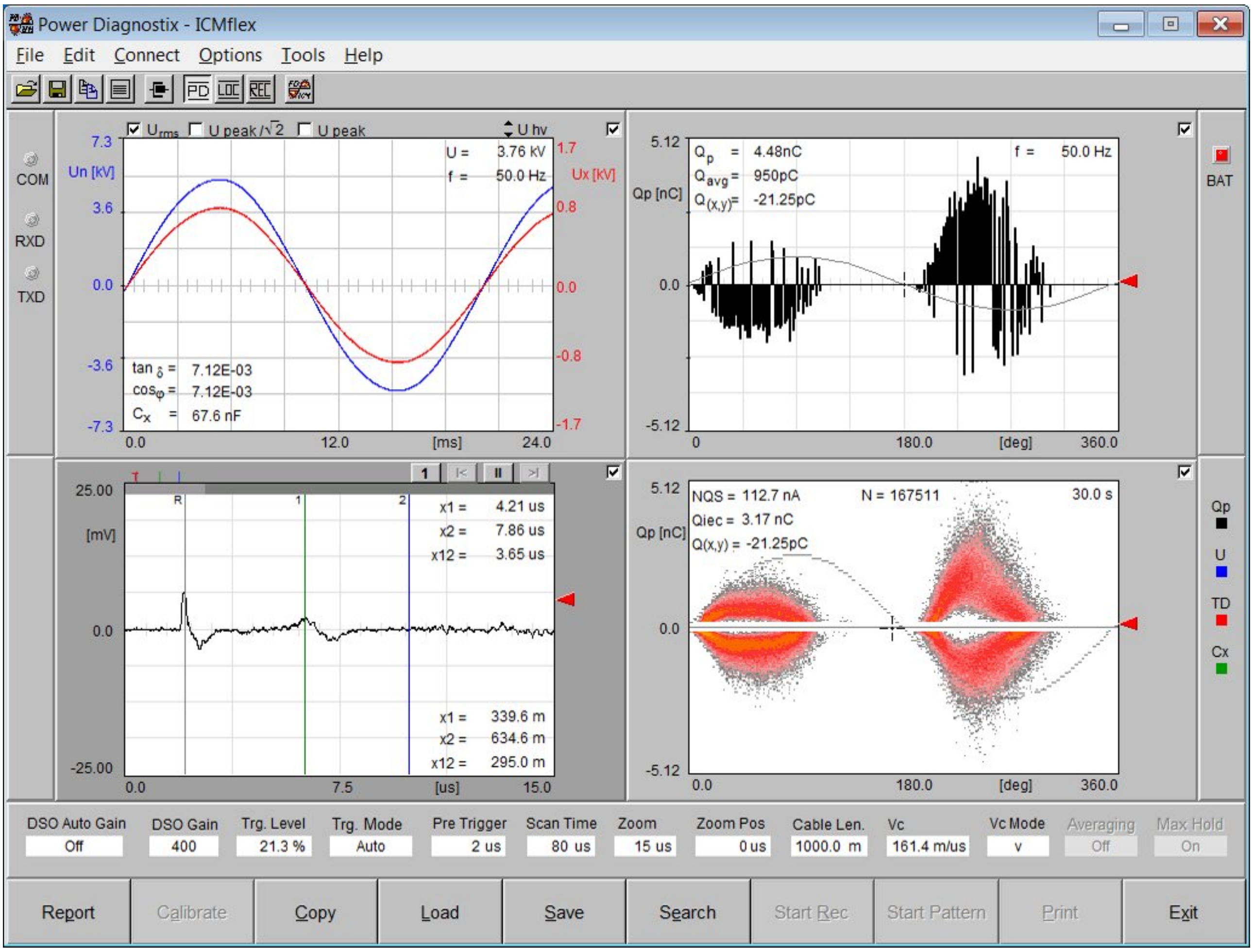


Fig. 20: Main screen of the ICM*flex* software

V.2 Connecting to the Instrument

Before connecting to the instrument it is recommended to check the COM port settings in the menu 'Options-> Interface Settings'. Enable the port number as specified for Bluetooth or USB communication (see section IV.2 and IV.3). Normally, the software will search the instrument automatically when the check box 'Search Device at Startup' is selected. The COM port in use will be indicated by the * symbol. If not, the correct settings can be found with the device manager of Windows.

Make sure that only one COM port is enabled. First, disable all ports by pressing the button 'Disable All'. Then select the COM port from the list by enabling the corresponding checkmark. All other settings remain unchanged and do not need to be modified during standard operation.

All changes will become active after closing this panel by pressing the button 'Ok'. The 'Cancel' function closes this window without any changes of the values. Pressing the button 'Standard' enables the default COM ports and sets all timeouts back to the following default values.

Search Timeout: 2 s

Run Timeout: 5 s

Baud rate: 921600 kBit/s

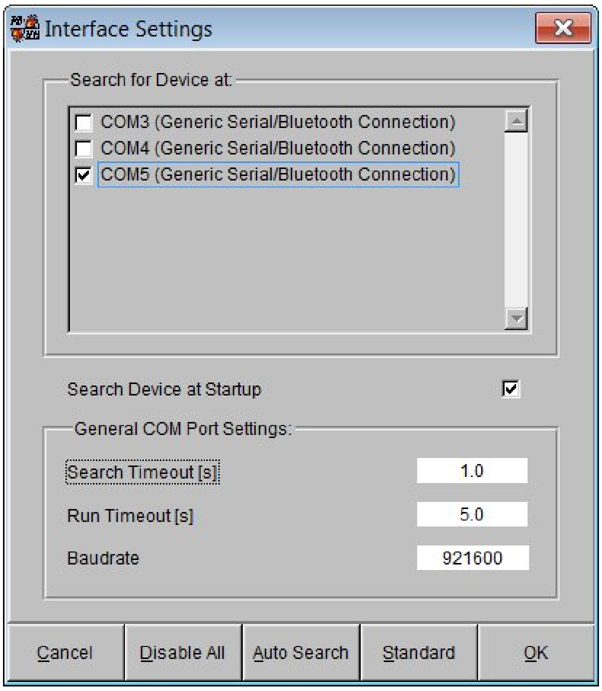


Fig. 21: Interface settings

To establish a connection to an instrument press the 'Search' button on the front panel. This function can be started by the command button at the bottom of the window, or by selecting the 'Search' function from the function keys at the bottom of the window. The most important functions can also be activated by shortcuts. For the search routine press the function key F5.

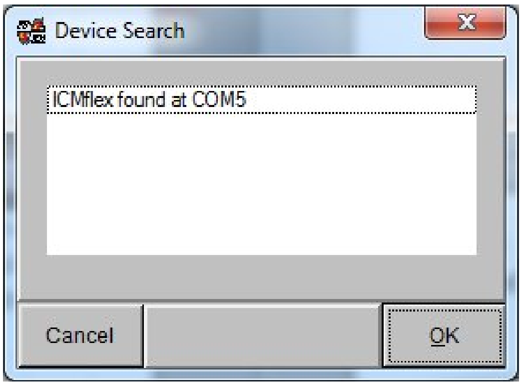


Fig. 22: Searching for ICM*flex* COM ports

The search pop-up window indicates if an instrument was found and successfully connected. If new firmware for the acquisition unit is available with the software, it is possible to flash the instruments program memory directly. A pop-up window (see figure 22) will appear and can be confirmed by the user. Please do not interrupt any flashing procedure and contact Power Diagnostix in case of any problems. Usually, the latest firmware will be stored into a new instrument.

V.3 Firmware Updates and Configuration Files

After a software upgrade, it may be, that a pop-up window shows up that announces the availability of a new firmware version. Do not hesitate to install the update as it includes important recent improvements for the unit.

Fig. 23: New firmware pop-up

Fig. 24: Configuration file pop-up

Updates of firmware version >= 1.26 require a configuration file after the first launch. Normally, the latest ICM*flex* units are configured at the factory. If not or in case of older instruments, please contact the Power Diagnostix software department (software@pdix.com) and indicate the instrument's serial number.

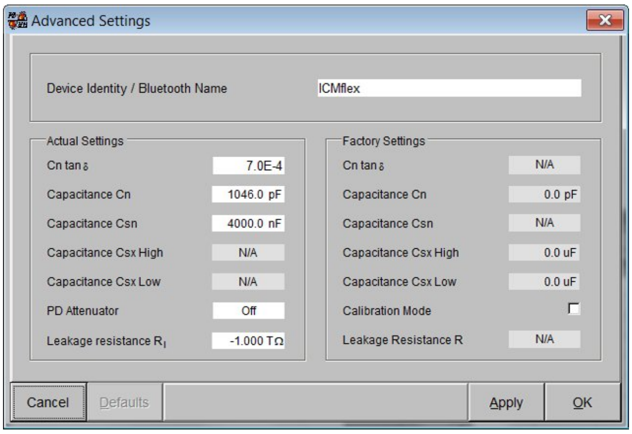


Fig. 25: Advanced settings

Once stored into the device, this configuration must not be repeated anymore in future. The configuration files contains all important information of the instrument such as the capacitor values according to the voltage calibration, C_n and C_{sn} and the shunt capacitor C_{sx} high & low. These settings can always be cross checked via the menu 'Edit-> Advanced Settings" (see figure 25).

Firmware and configuration files can be uploaded by using the device update function, available via the menu 'Tools->Device Information'. A firmware file is identified by the extension .bin, a configuration file by the extension .cfg.

After a successful upload the communication with the instrument will shortly be interrupted and reestablished automatically after rebooting the acquisition box.

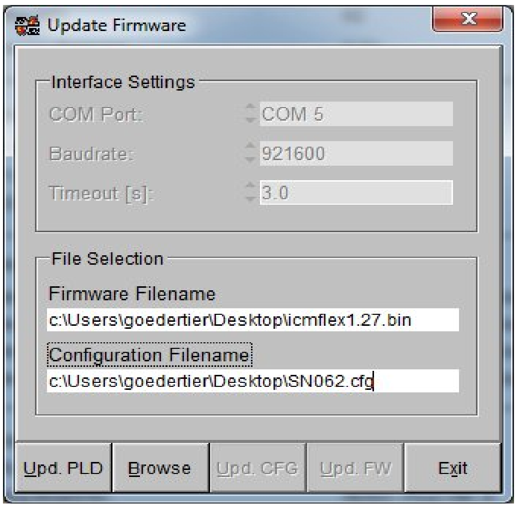


Fig. 26: Firmware update window

The device configuration panel shows detailed information about the instrument, e. g. the serial number and installed firmware version. To get full information connect to the instrument and open the device Information panel again. Since the instrument can be ordered in different configurations, check if all features are available as expected, e. g.

- Partial discharge measurement
- Partial discharge fault location for cables
- Tan delta and loss factor measurements incl. voltage and frequency acquisition

Besides the instrument options, the information panel also shows the battery monitoring parameters such as the battery voltage, current, charge, and battery lifetime.

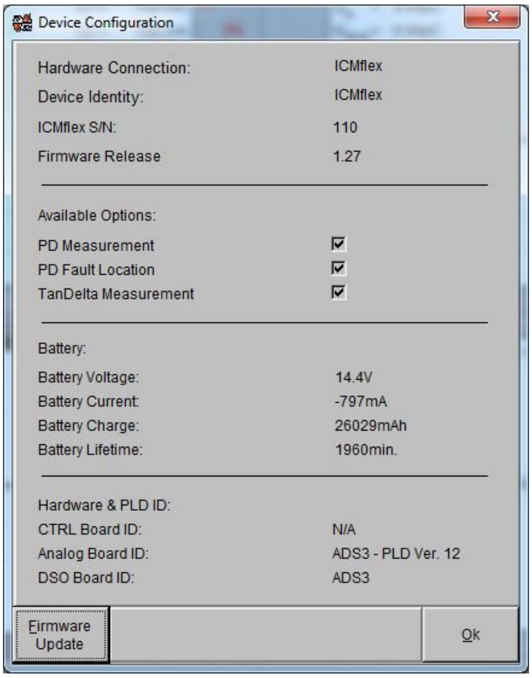


Fig. 27: Device configuration panel

V.4 Principle of Operation

The ICM*flex* software is a typical front panel system that gives access to all main functions, graphs, and settings. This panel, as displayed below, is divided into four main areas. These areas can vary, depending on the display mode that is chosen. Available display modes are: PD, LOC, and REC.

V.4.1 PD Display Mode

The PD display mode mainly is for PD measurements and required calibration of the apparent charge's amplitude. For cable testing the cable length and pulse velocity can be calibrated in this screen as well.

The upper left area of the window shows the voltage shapes (12-bit resolution) of the voltage dividers U_{sn}

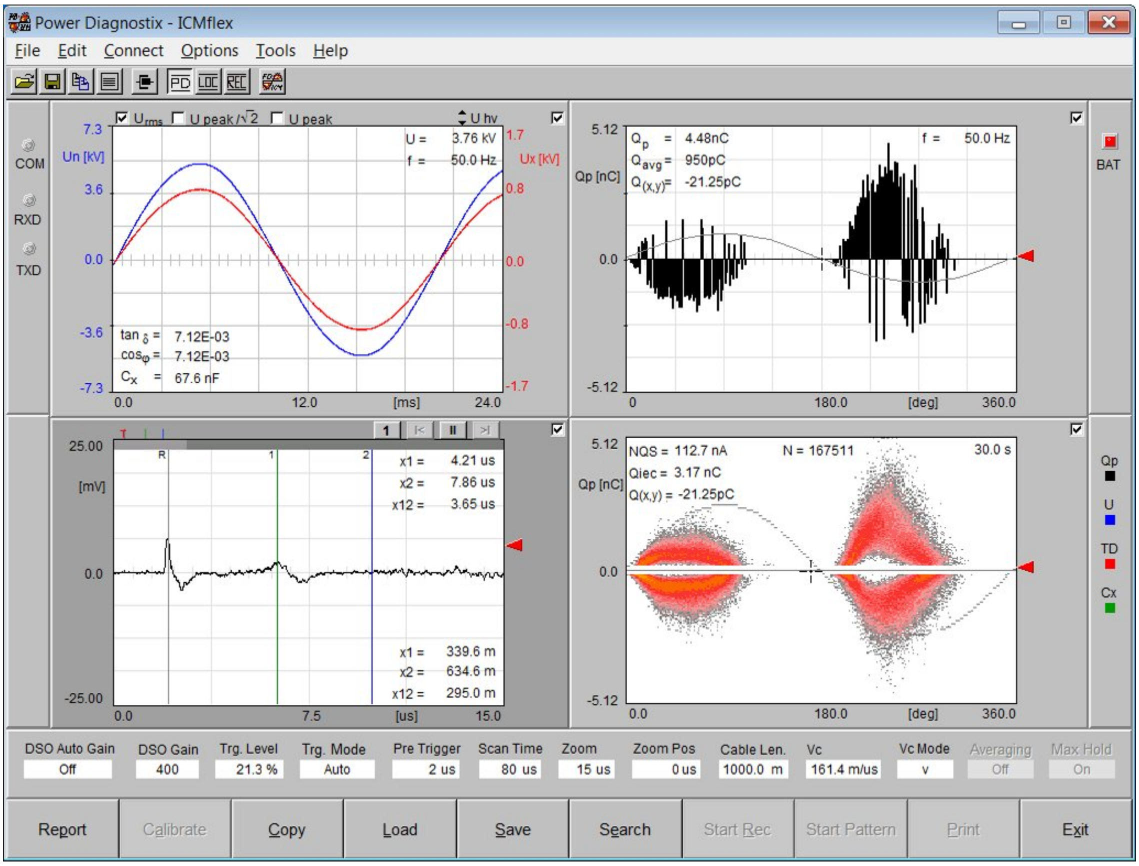


Fig. 28: PD display mode

(reference path) and U_{sx} (specimen path), the voltage and frequency values, and, if part of the system, the loss factor and capacitance values. The graph in the screen on the upper right-hand side displays continuously the PD activity in a 2-dimensional representation, accumulated of multiple refresh cycles vs. phase. Additionally, the current PD peak magnitude is shown in the upper left corner of this graph. The magnitude has to be calibrated (see applications notes in section V.7). The time domain graph in the lower left area can be used to evaluate single PD events and the reflections of pulses, as detected on medium and high voltage cable insulation systems on a time based curve (resolution of 100 Msamples/second). The different cursors will help to determine the exact fault position and to get precise results. In the area on the lower right-hand side, a 3-dimensional PD pattern acquisition can be started and visualized. The display has a resolution of 1024 bits and allows further interpretation of failures within the insulation system and its cause. Besides the pattern itself, the related discharge levels, set time, and the number of events are shown.

V.4.2 LOC Display Mode

The second display mode is called LOC mode and serves to perform PD fault location measurements on medium and high voltage cables. An ICM*flex* with option LOC for cable fault location comes with a digital storage oscilloscope (DSO) to process partial discharge signals on a time based curve. Single PD pulses can be triggered with a time resolution of 10 ns (100 Msamples/s) and a maximum display range of 320 µs (firmware version >= 1.25) corresponding to a theoretical maximum cable length of approximately 22 km for a cable with a pulse velocity of 140 m/µs. The DSO panel is the lower left graph in the software panel in PD and LOC mode. Besides the DSO chart, both PD representation charts remain available in upper and lower screens on the right-hand side. In the upper left screen the summary of the measured reflections can be represented versus the position of occurrence along the cable length.

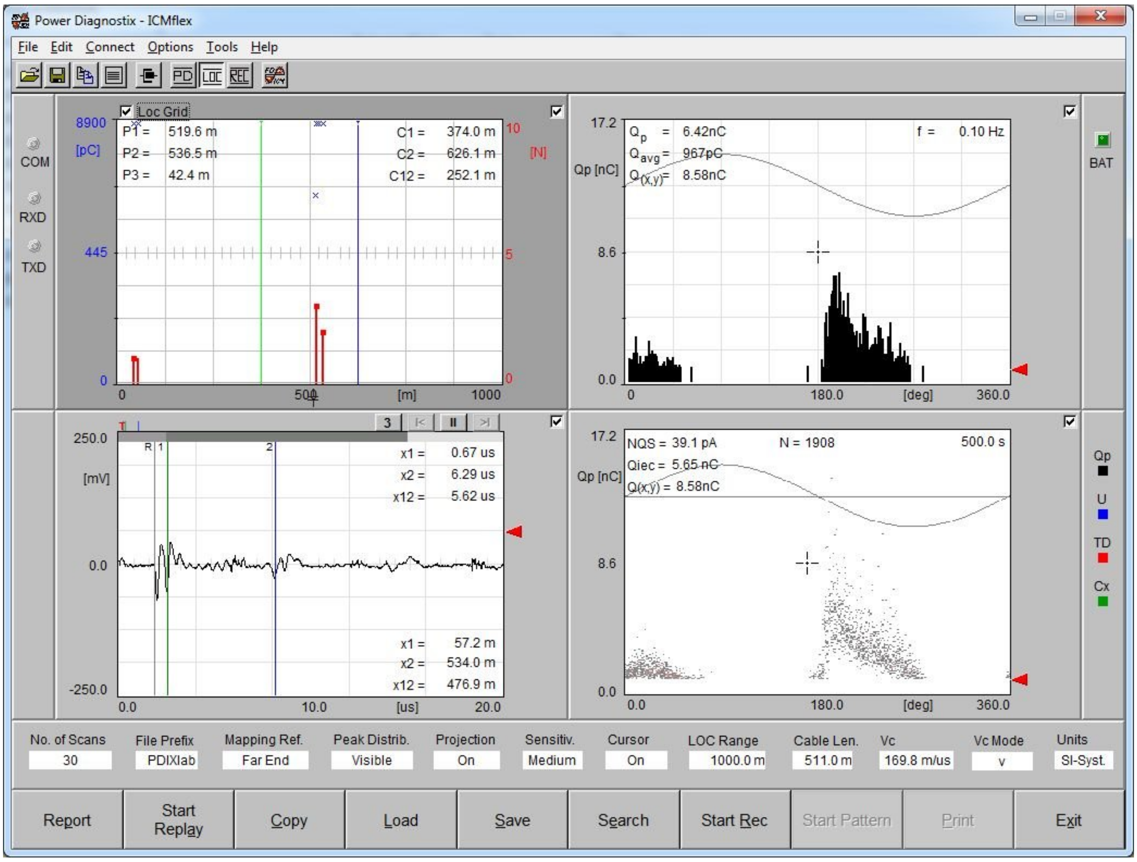


Fig. 29: LOC display mode

To perform cable fault location (LOC), the length of the cable and/or the pulse velocity of the cable must be known in advance. The time domain reflectometry (TDR) is based on the travel time of pulses. Since a cable behaves as a wave conductor, the TDR principle can be used to locate sources of partial discharges along the full cable length.

A partial discharge pulse that is caused by an insulation imperfection travels to both ends of the cable if the cable has two open ends. With an open end means a cable hasn't its characteristic impedance at the end terminations. In this case, each partial discharge pulse occurring somewhere in the cable will be reflected to the opposite end, when reaching one of the cable end terminations. The distance of the PD source to the near and/or far end of the cable can be calculated using the time difference between the arrival times of pulses at the measuring impedance (coupling capacitor).

The principle of the time domain reflectometry is illustrated with figure 30. The travel paths of the first three reflections of the original partial discharge pulse that enters the coupling unit of the ICM*flex* are displayed in three different colours.

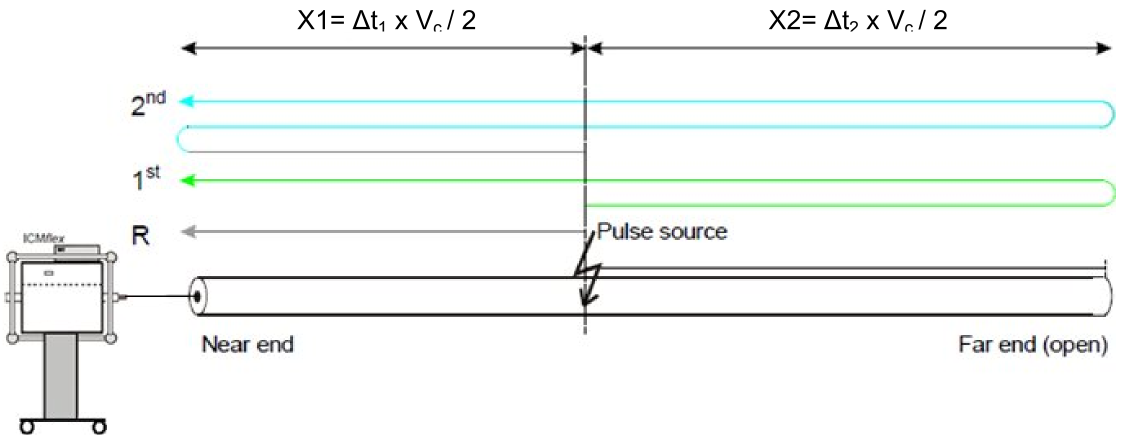


Fig. 30: TDR principle

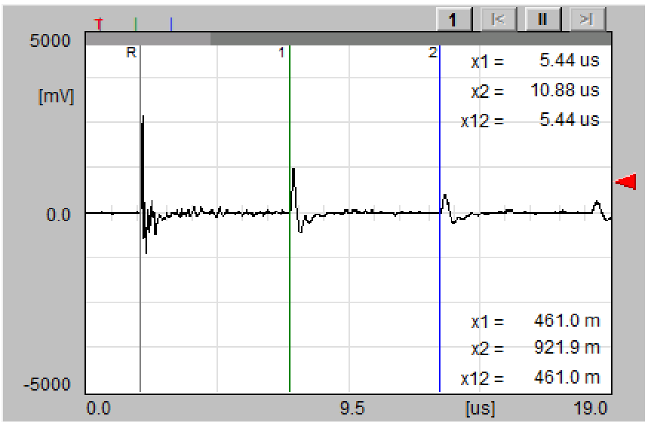


Fig. 31: ICM*flex* DSO screen

The reference pulse (R, black cursor) travelled directly from the pulse source to the coupling unit. The first reflection (1, green cursor) travelled first in the opposite direction of the coupler and then got reflected at the open end of the cable. This resulted in a time delay Δt1 that indicates the distance of the PD source from the far end of the cable. Finally, the second reflection (2, blue cursor) shows the time delay between the reference pulse and its reflection at the far end. The time difference between the first and the second reflection results in a time delay Δt2 representing the distance of the pulse source from the near end of the cable. See applications notes in section VI.1 for a detailed example.

V.4.3 REC Display Mode

The third display mode is called REC mode. It is used to plot results into a summarizing table or graph. The collected data can be displayed vs. time or vs. voltage. The voltage graph in the upper left area remains unchanged. The strip chart at the upper right-hand side always shows the actual measurement readings, while the lower left chart shows the readings triggered in the data table of the lower chart on the right-hand side. Figure 32 shows the data represented versus time. By changing the setting of the X-axis to 'vs. Voltage', the recorded values will be shown as a function of its related voltage level. The table shows an overview of the voltage, tan delta and tan delta tip-up (see also section XI.1), the specimen capacitance, and the peak discharge level at the moment of triggering.

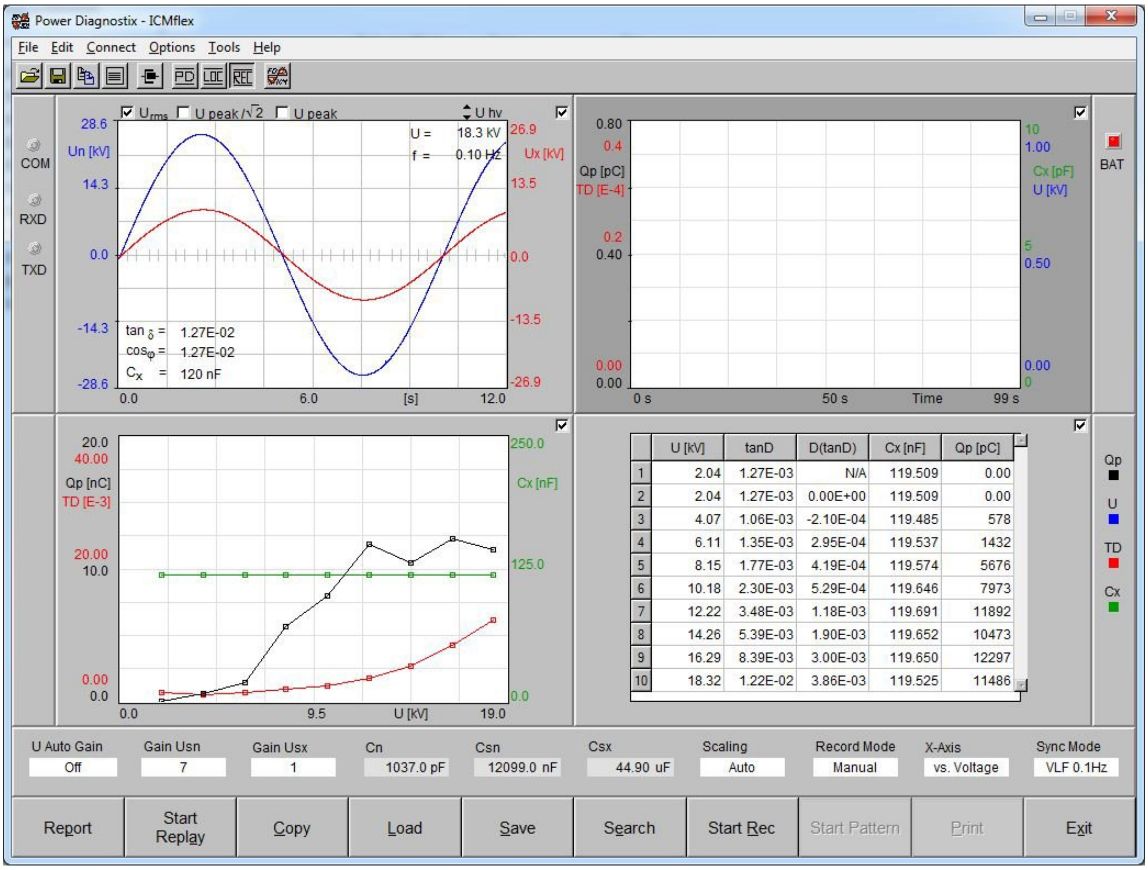


Fig. 32: Record display mode

The strip charts in the corner on the upper right-hand and lower left-hand side show the following values:

- Green: Capacitance of the sample under test (C_x)
- Blue: Supplied voltage level (U), represented in RMS, peak, or peak/√2
- Black: PD magnitude in pC (Q_p)
- Red: Loss factor value (TD)

With each data refresh from the instrument the refreshed actual values are shown in the two upper charts. Recording a full measurement can be done manually or automatically by defining a measurement sequence.

For using the manual mode, it is mandatory to start the measurement by pressing the button 'Start Rec'. To accumulate readings, the button 'Trigger' can be used, when reaching a required voltage step. The relevant data, such as the applied voltage, tan delta, tan delta tip-up value, capacitance, and apparent charge levels, will be registered and represented in a graph versus voltage or time in the lower left chart.

An automatic trigger mode is included and selectable by setting the record mode to 'Sequence'. The button 'Trigger' changes to 'Sequence' and allows defining the measurement sequence. The desired voltage steps can be entered manually via the panel for the manual sequence or can be calculated via an automatic sequence after entering the specimen's ratings.

Additional settings to be set are the voltage tolerance between the measured and the desired voltage levels, the number of values to be triggered at each voltage step, the time to stabilize before conducting any readings, and the period between consequent values at a fixed voltage step. Once a sequence is defined, it can be saved and loaded for consecutive measurements.

Besides a recording with a manually defined sequence, the software also offers an automatic sequence mode. Here, the required voltage steps are calculated automatically according to the set specimen voltage represented as phase to phase or phase to ground voltage and the number voltage steps.

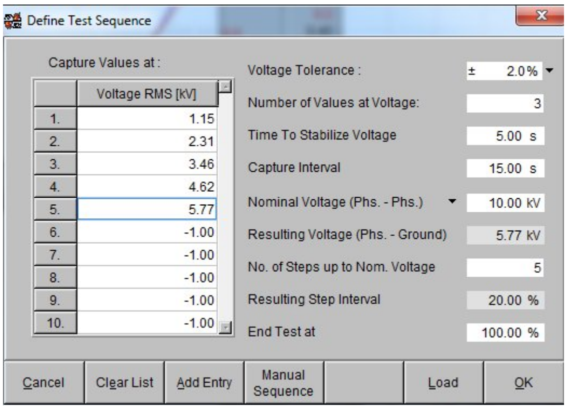


Fig. 33: Automatic sequence wizard

Depending on the high voltage source and frequency, we recommend selecting a appropriate value for stabilize time and capture interval. At power frequencies a period refresh takes 16–20 milliseconds, while at a very low frequencies a period refresh takes more than 100 seconds. Ensure that the instrument has at least the chance to complete three refreshes in order to have accurate and useful data shown into the data table.

V.5 Display Mode Settings

Settings affecting the individual graphs or measurements can be found in the lower area of the window above the functional keys. Depending on the graph or area activated (indicated by a dark gray area in the background) different settings will be displayed. To toggle between the different setups just click once with the left mouse button on the area or graph that you intend to modify.

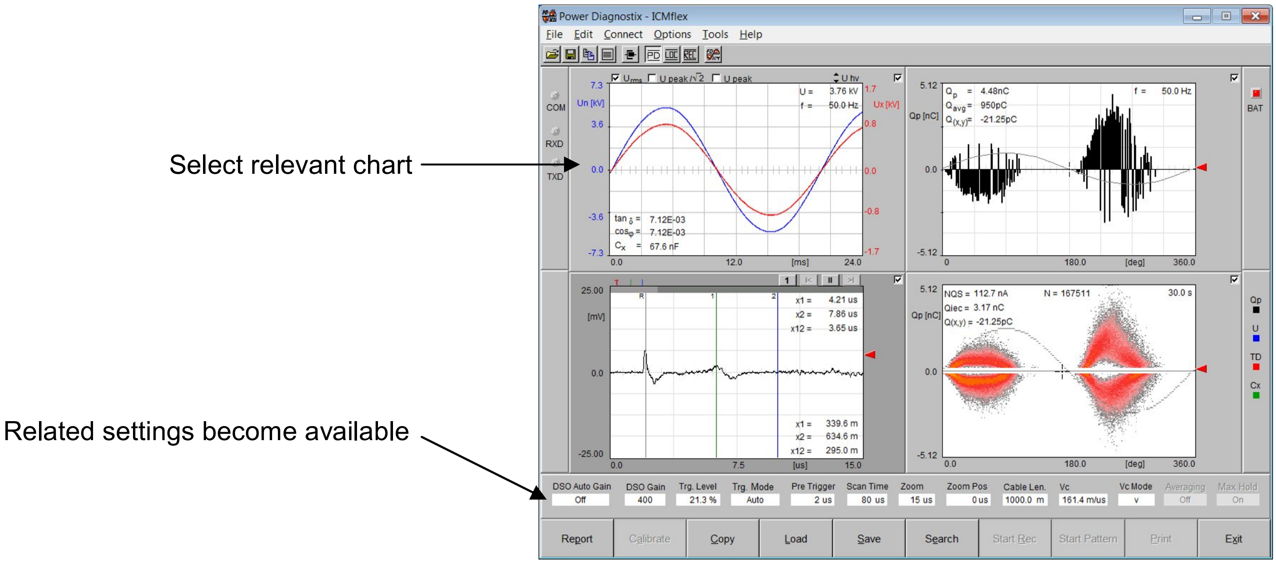
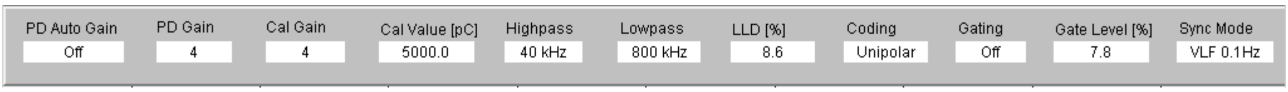


Fig. 34: Chart settings

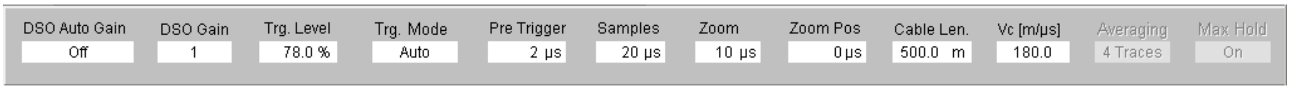
V.5.1 Settings for Partial Discharge Measurement



Setting	**Values / Range**	**Explanation**
PD Auto Gain	On / Off	The automatic gain adjustment can help to find the best gain setting for the PD measurement path. If the PD signal rises 95% of the Y-scale, the software automatically decreases the level. If the level drops down below 10%, the gain level will be incremented. If the PD level is bouncing strongly, it could make sense to disable the automatic mode.
PD Gain	1,2,4,8,10,20,40,80, 100,200,400,800,10 24,2048,4096	The signal amplification can be set manually by selecting an adequate factor from the list. An optimal PD level is given, if the highest peaks appear in a range of 60 to 90% of full scale.
Cal Gain	1,2,4,8,10,20,40,80, 100,200,400,800,10 24,2048,4096	This entry indicates the gain value as it was set during calibration. This value will be modified automatically during calibration and cannot be set manually.
Cal Value	1pC–10000pC	This value has to be set according to the PD level that is used during calibration.
Highpass	40 kHz, 80 kHz, 100 kHz	Depends on the lower cutoff frequency of the PD bandpass filter.

Lowpass	250 kHz, 600 kHz, 800 kHz	Depends on the upper cutoff frequency of the PD bandpass filter.
LLD	0–100%	LLD stands for Low Level Discriminator. This is the minimum trigger level for PD pulse acquisition. A minimum level of 2% should be set to eliminate small noise pulses. The level refers to the 100% full scale of the Y-axis of the PD scope and PD pattern graphs.
Coding	Unipolar / Bipolar	PD pulses can be separated by their polarity. 'Bipolar' shows positive and negative pulses separated, whereas 'Unipolar' does not consider the polarity.
Gating	On / Off	If gating is enabled (On) it is possible to eliminate external noise pulses. This function is available with all instruments offering an external 'Gate In' connector on the acquisition box. The noise signal is taken directly on the HV line input on the HV filter. A special high frequency current transformer has to be built-in.
Gate Level	0–100%	This trigger level determines the sensitivity on the gate input of the acquisition system. As higher this level is set as less external pulses will be triggered.
Sync Mode	Normal, VLF 0.1 Hz, VLF 0.05 Hz, VLF 0.02 Hz	Normal: The frequency of the applied voltage is calculated automatically in a range between 20 Hz and 510 Hz. VLF: The frequency is set manually according to the frequency setting on the VLF power supply.
Set Time	0..100000 s	Preset set time for a PD pattern acquisition. The pattern (map) is stopped automatically after expiration of this time.

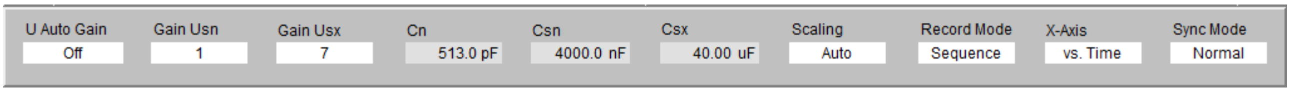
V.5.2 Settings for PD Fault Location



Setting	**Values / Range**	**Explanation**
DSO Auto Gain	On / Off	The automatic gain adjustment can help to find the best gain setting for the LOC or DSO graph. If the PD signal rises 95% of the Y-scale, the software automatically decreases the level. If the level drops down below 10%, the gain level will be incremented. An automatic voltage adjustment is recommended for the normal sync mode only.
DSO Gain	1,2,4,8,10,20,40,80, 100,200,400,800	Amplification factor for the PD signal in time domain.
Trg. level	0–100%	Trigger level for high resolution PD pulses in the time domain graph.
Trg. Mode	Auto Normal Single Shot	Auto: This mode displays continuously a signal on the DSO graph (triggered or non-triggered signals). Normal: This mode displays continuously triggered signals only. Single Shot: This mode displays a single triggered PD event and stops the refresh subsequently.

Pre Trigger	1–10 µs	Time on the DSO graph from zero position to the first trigger.
Scan time	2–320 µs	Total measurement time for PD signals versus time (DSO graph).
Zoom	2–320 µs	Zoomed area within the DSO graph. Zooming allows a more precise positioning of the cursors.
Zoom Pos	2–320 µs	Zero position of the zoomed area.
Cable Len.	10–25000 m	Length of the cable under test. This length can be calculated during calibration or can be preset if the exact value is known.
vc [m/µs] vc/2 [m/µs]	100–200 m/µs 50–100 m/µs	Pulse velocity for PD signals on the MV cable.

V.5.3 Settings for the Record Mode



Setting	Values / Range	Explanation
U Auto Gain	On / Off	The automatic gain adjustment can help to find the best gain setting for the voltage measurement path. If the voltage signal rises 95% of the Y-scale, the software automatically decreases the level. If the level drops down below 10%, the gain level will be incremented. An automatic voltage adjustment is recommended for the normal sync mode only.
Gain Usn	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	Amplification factor for the voltage signal from the shunt capacitor on the reference path; U_{max} = 20 V_{peak}
Gain Usx	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	Amplification factor for the voltage signal from the shunt capacitor on the test pat;. U_{max} = 200 V_{peak}
Cn	Stored into device via configuration file **firmware version >= 1.26**	Capacitance value of the reference capacitor. Please check the data sheet of your system or read the value as written on the gray acquisition box.
Csn	Stored into device via configuration file **firmware version >= 1.26**	Capacitance value of the shunt capacitor of the reference path. Please check the data sheet of your system or read the value as written on the gray acquisition box.
Csx (see remark below)	No limit; to be calculated before high voltage is applied	Capacitance value of the shunt capacitor of the test path. Please check the data sheet of your system or read the value as written on the gray acquisition box. With most systems this value is switchable (ext. jumper) between two ranges, e. g. 40 µF/400 µF
Scaling	Auto / Full Range	Y-axis scaling mode for the voltage graph (left upper corner). The voltage shape is scaled up to a maximum in 'Auto' mode, the 'Full Range' mode sets the maximum of the Y-axis to the maximum value according the gain chosen.

Record Mode	Manual / Sequence	This mode is important for the record function. In 'Manual' mode the values in the record table are filled with each manual trigger event. The Sequence mode fills data into the table if a preset voltage level is reached. These voltage levels must be predefined in advance.
X-Axis	vs. Time / vs. Voltage	The record graph in the left lower corner can show the recorded values versus time or versus voltage.
Sync Mode	Normal, VLF 0.1 Hz, VLF 0.05 Hz, VLF 0.02 Hz	Normal: The frequency of the applied voltage is calculated automatically in a range between 20 Hz and 510 Hz. VLF: The frequency is set manually according to the frequency setting on the VLF power supply

Remark:

The setting of the shunt capacitance value for the test circuit C_{sx} depends on the maximum voltage under test. The highest voltage at the shunt capacitor C_{sx} must not exceed 200 V_{peak} or 140 V_{rms}.

$U_{x\,(max)} = U_{max} \cdot C_{x,(max)} / C_{sx} < 140\ V$ (!)

Please select the values for C_{sx} according to the test specimen capacitance and the required maximum test voltage (U_{max}). The shunt capacitor values are stored into the device settings via the configuration file provided by Power Diagnostix. The actual values of voltage levels given by both dividers U_n and U_x can be represented in the voltage display via selecting U_{acq}. Wrong selection of the shunt capacitor will result into clipping of the sine wave. Please be aware that $U_{n,max}$ may not exceed 20 V_{peak} (14 V_{rms}) and $U_{x,max}$ may not exceed 200 V_{peak} (140 V_{rms}).

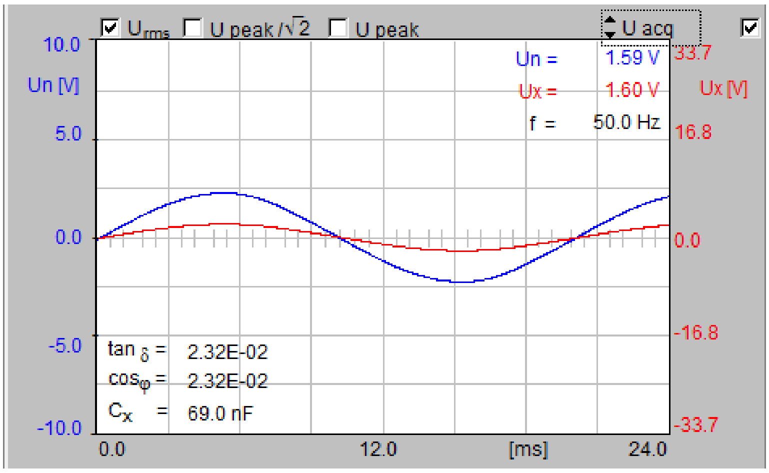


Fig. 35: Voltage measurement chart

V.6 Functions and Menus

The ICM*flex* software offers multiple functions directly from the front panel or via the menu bar on top. These functions can vary, depending on the display mode chosen, or depending on the hardware options available with the instrument.

V.6.1 Menu Items

V.6.1.1 File

Standard file functions, such as loading and saving of files and setting the default directory, can be selected directly from the 'File' menu. Further, waveform and/or record exports to an .xls, .xlsx or .html file can be selected here as well. After loading the .flx file from hard disc the export will be made automatically.

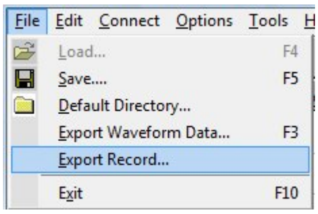


Fig. 36: File menu

V.6.1.2 Edit

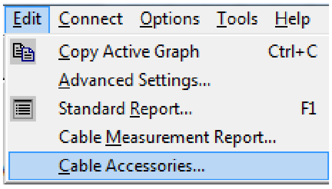


Fig. 37: Edit menu

The 'Edit' menu contains the options for copying the active graph into the Windows clipboard. Furthermore, it offers access to advanced settings for the device (see figure 37), to report functions, and to options for cable accessories (see figure 38).

If the cable is equipped with accessories at a fixed position that is known, such as joints, terminations, and cross link boxes, for instance, these can be shown as a symbol in the summarizing LOC graph. The exact position along the cable length and the desired symbol and color can be set in the 'Cable Acessories' option.

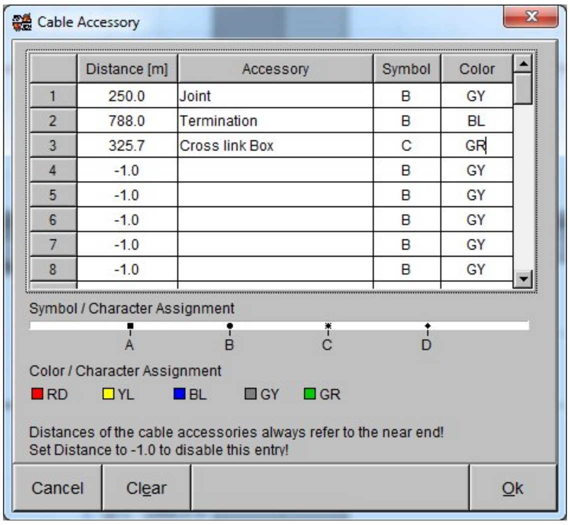
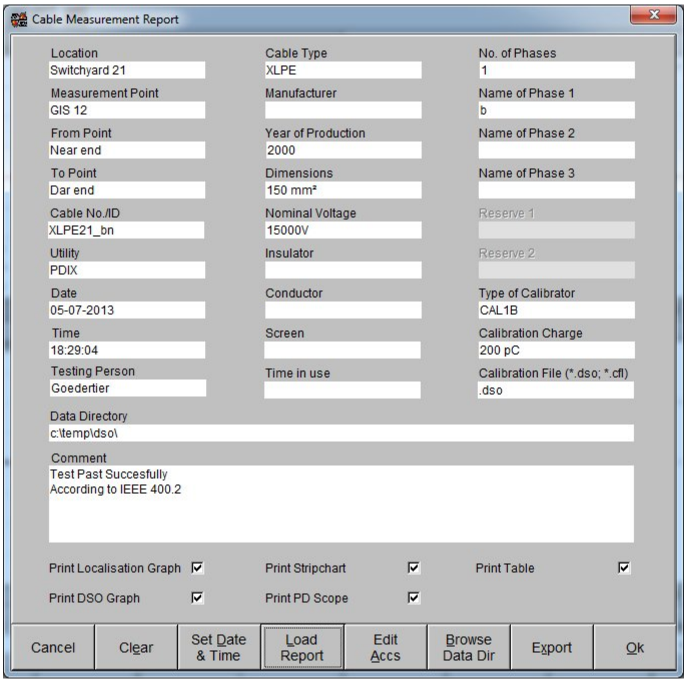


Fig. 38: Cable accessory window



The software can generate a standard report as explained in section V.6.2.1 and/or a detailed cable measurement report. In general, the represented measured data are comparable. The differences are mainly the various details concerning the specimen under test, which can be entered, and the cable accessories for known positions along the cable length.

Fig. 39: Cable measurement report window

V.6.1.3 Connect

A connection of the software to the ICM*flex* can be establish via the function key F6 or by pressing the 'Search' button in the key bar.

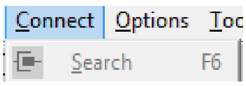


Fig. 40: Connect menu

V.6.1.4 Options

The 'Options' menu largely offers settings for the various charts. Besides this, the language, display resolution, and the interface settings, as explained in section V.1, can be selected

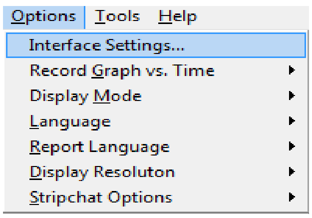


Fig. 41: Options menu

V.6.1.5 Tools

With the 'Tools' menu the device information can be seen as shown with figure 27.

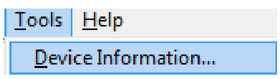


Fig. 42: Tools menu

V.6.1.6 Help

The 'About' item of the 'Help' menu gives information about the installed software release. In case of any further questions regarding the device Power Diagnostix's contact details are given as well.

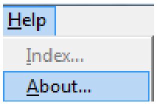


Fig. 43: Help menu

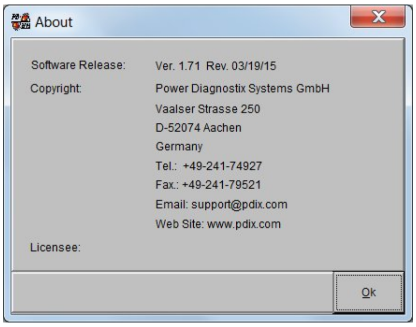


Fig. 44: 'About' window

V.6.2 Function Keys

All main functions are shown on the bottom of the window. Some buttons cover multiple functions depending on the display mode of the software.

V.6.2.1 Report [F1]

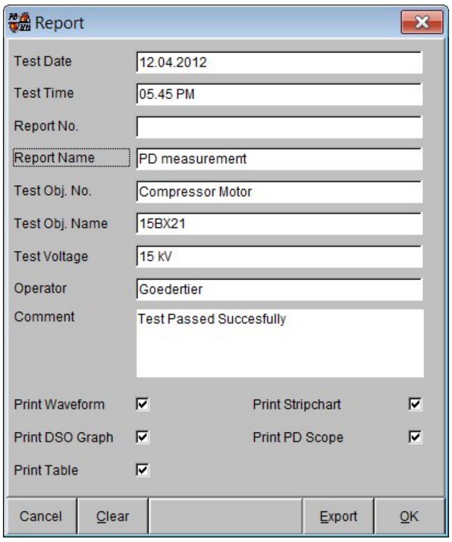


Fig. 45: Standard report

Pressing this button will open a pop-up window. Here, it is possible to fill out a standard report with brief information regarding the measurements taken. This set of information will be saved with each ICM*flex* file (*.flx) and will be available after loading files from hard disc. It will appear on most printouts and with all exported data, like .html or .xls(x) files. The required live charts for the report can be selected with the corresponding checkmarks at the bottom of the panel. Please be aware that the charts taken into the report are always the current charts.

V.6.2.2 Calibrate [F2]:

The 'Calibrate' function can be used to calibrate either the PD amplitude or the cable length of an MV cable under test. To calibrate the PD amplitude it is necessary to activate the PD scope display (graph on the upper right-hand side) or the PD pattern display (graph on the lower right-hand side). Pressing this button in this mode will open a pop-up window where the exact PD calibration value has to be filled in. This value is equal to the value displayed on the PD calibrator (CAL1A or CAL1B). Please check the correct connection of the PD calibrator, the correct gain setting, and the PD pulse on the PD scope display before calibrating. Further explanations are given with the applications notes in sections VI.1.2 and VI.2.2. The length of an MV cable can be calibrated by activating the DSO display first (lower left graph). Check the reflections of PD pulses on the graph and set cursor R and cursor 2 to the first and the second pulse. After pressing the button 'Calibrate' the software automatically calculates the pulse velocity of the PD pulses. Further explanations are given with the application notes in section V.8.

V.6.2.3 Copy [F3]:

This helpful tool allows copying each graph to the Windows clipboard. Pressing this button will place a copy of the activated graph (panel with dark gray background) into the clipboard, which can be pasted afterwards into all documents of other applications.

V.6.2.4 Load [F4]:

This function is available when being offline, means not connected to an instrument. It allows loading old measurements from hard disc or any other memory. Files saved with the ICM*flex* software come with the file suffix *.flx. This file consists of all measurement data, settings, and reports. To restore typical settings it is helpful to save some default files for standard set-ups for cables or rotating machines.

V.6.2.5 Save [F5]:

It is possible to save the *.flx files in all different modes. Old files can be loaded, modified, and saved again. Running measurements can be saved at any time. The saved file consists of all measurement data, settings, and reports.

V.6.2.6 Search / Offline [F6]:

To connect the ICM*flex* software with an instrument, press the 'Search' button. If the COM port settings and the cabling are correct and the instrument is turned on, a pop-up window will show the message 'ICM*flex* found at COM xy'. It will disappear automatically after a few seconds. To disconnect the communication line, press the same button once again. While being online this button is labeled 'Offline', while being offline this button is labeled with 'Search'.

V.6.2.7 Start Rec / Stop Rec [F7]:

This function can be used to start a record of values vs. time. Switch to the TD display mode to see all values recorded in the corresponding graph and in the table. This function has to be started manually and can be stopped by pressing the same button.

V.6.2.8 Start Map / Stop Map [F8]:

Use this function to start a PD pattern acquisition. The pattern is shown in the graph on the lower right-hand side. The measurement is stopped automatically after expiration of the preset 'Set Time' or after pressing this button once again.

V.6.2.9 Print [F9]:

This function sends the active graph to the default printer.

V.6.2.10 Exit

Close the program by pressing this button.

V.7 ICM*flex* and PD Calibration

V.7.1 Calibrators

There is a broad range of impulse generators offered by Power Diagnostix for different purposes. The table below gives an overview of these calibrators. All of them allow the calibration of PD measurements according to IEC 60270/2000, except the CAL2B/C/D. Since these calibrator models are not equipped with an injection capacitor to enable calibration on GIS. For the ICM*flex*'s applications, the most common calibrators used are the CAL1B for on-site testing and CAL1A for laboratory purposes.

Calibrator	Range	Output	Frequency
CAL1A	1, 2, 5, 10, 20, 50, 100 pC	Injection capacitor <1 pF	50 Hz (60 Hz)
CAL1B	100, 200, 500pC, 1, 2, 5, 10 nC	Injection capacitor <100 pF	50 Hz (60 Hz)
CAL1C	1, 2, 5, 10, 20, 50, 100pC* at 100 pF	Voltage output (50 Ω)	50 Hz (60 Hz)
CAL1D	10, 20, 50, 100, 200, 500, 1000 pC	Injection capacitor <10 pF	50 Hz (60 Hz)
CAL1E	0.5, 1, 2, 5, 10, 20, 50 nC	Injection capacitor <500 pF	50 Hz (60 Hz)
CAL1F	0.2, 0.5, 1, 2, 5, 10, 20 nC	Injection capacitor <200 pF	50 Hz (60 Hz)
CAL1G	0.02, 0.05, 0.1, 0.2, 0.5, 1, 2 nC	Injection capacitor <20 pF	50 Hz (60 Hz)
CAL1H	0.5, 1, 2, 5, 10, 20, 50pC* at **pF	Voltage output (50 Ω)	50 Hz (60 Hz)
CAL1J	10, 20, 50, 100, 200, 500, 1000pC* at 100 pF 100, 200, 500, 1000, 2000, 5000, 10000pC* at 1 nF	Voltage output (50 Ω)	50 Hz (60 Hz)
CAL2A	0.5, 1, 2, 5, 10, 20, 50 pC	Injection capacitor <1 pF	50 Hz (60 Hz)
CAL2B	2, 5, 10, 20, 30, 40, 50 V (into R_L=50 Ω)	Voltage output (50 Ω)	50 Hz (60 Hz)
CAL2C	1, 2, 5, 7, 10, 12, 15, 17, 20 V (into R_L=50 Ω)	Voltage output (50 Ω)	50 Hz (60 Hz)
CAL2D	5, 7.5, 10, 15, 20, 30, 40 V(into R_L=50 Ω)	Voltage output (50 Ω)	50 Hz (60 Hz)

*with external high voltage capacitor, ** value to be specified by customer

Table 1: Calibrator overview

Fig. 46: CAL1A

All calibrators are switched on with the pushbutton On/Off. Both amplitude (Range) and polarity (Pos/Neg) of the single charge pulse per cycle are displayed and can be adjusted by pressing the two buttons. The instrument is synchronized to line frequency by a photo diode. In case of insufficient pick-up of power frequency light, it will select automatically the internal quartz oscillator (50 Hz and 60 Hz versions available). The button On/Off must be pressed for more than one second to switch the pulse generator off, while automatic switch-off occurs after approximately 15 min. Operation time of up to 200 hours are obtainable with the 9 V lithium battery due to an average supply current of approx. 5 mA (quiescent current is negligible). An alkaline battery resulting in approx. 90 hours of continuous operation may replace the lithium battery. A weak battery is indicated by the LO BAT sign of the LC display.

Warning: While changing the battery, be aware of internal parts carrying up to 125 V of DC potential!

Power Diagnostix delivers its standard calibrators with a fully traceable DAkkS calibration (D-K-15068-01-00). This calibration certificate documents the traceability according to national standards, which fulfill the units of measurement according to the International System of Units (SI). The DAkkS (**D**eutsche **Akk**reditierungs**s**telle) is signatory to the multilateral agreement of the European co-operation for Accreditation (EA) for the mutual recognition of calibration certificates.

Before attaching the calibrator please make sure that the object under test is de-energized. The inner conductor of the BNC/Banana adapter must be terminated to the test specimen's conductor. The outer ground connector has to be connected with the solid grounding of the test object. Ensure ground links between the calibrator and the ground shield that are as short as possible. Care must be taken, that the calibrator is isolated from the HV part of the ICM*flex*.

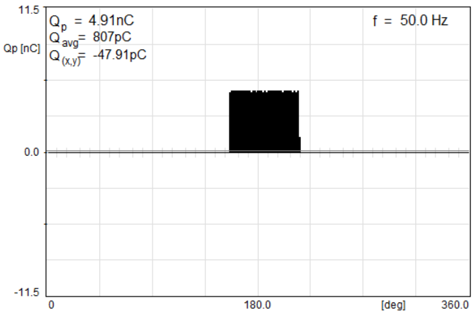


Fig. 47: Calibration pulse scope display

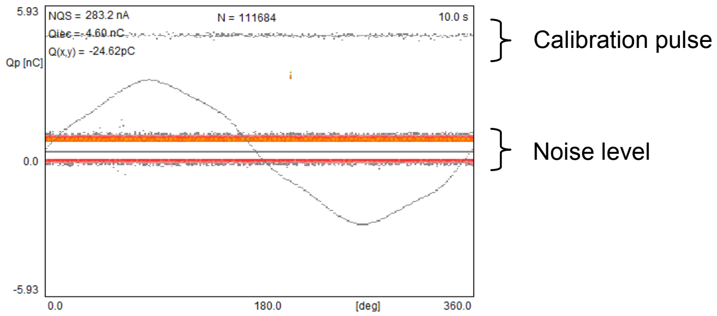


Fig. 48: Calibration pulse PD pattern

The selection of the relevant charge level to be injected into the measurement circuit can vary, depending on the cable length, stator winding's or bar's capacitance (attenuation), and background noise conditions. It's important to have a good signal to noise ratio in order to have a sufficient sensitivity. Chose a value approx. 5 to 10 times higher than the present background noise. Typical values used for on-site testing are varying from 200 pC to 5 nC, even 10 nC in case of very long cable lengths or large turbo generators.

Once the injected value is selected, the calibration pulse can be observed in the ICM*flex* software. The relevant screens supporting the calibration of the apparent charge are the two charts on the right-hand side of the PD display mode. The upper chart represents the calibration pulse as scope like pulse pattern (2-dimensional) while the lower one plots the pulse into an Φ-q-n related pattern (3-dimensional). Please adjust PD gain in a way the calibration pulse fills 60–90% of the maximum current amplitude. Also select the proper SYNC setting during calibration, CAL50Hz or CAL60Hz, even if VLF is used. Using the same settings also for VLF, only speeds up the screen refresh. Select the value for the low level discriminator high or low enough, so that the background noise can still be observed. Don't forget to switch off the gating function during calibration.

Calibration can be performed by a double click on the highest pulse shown in the scope like display or by a double click on the corresponding upper line in the phase resolved PD pattern. Thereafter, the calibration pop-up will ask for the value of calibration charge. Once entered, the compensation of the attenuation of the complete circuit will be done automatically. Please have in mind that the calibration is valid for one band-bandwidth and one specific test set-up only. Hardware and/or software changes require a new calibration. Don't forget to save the calibration file.

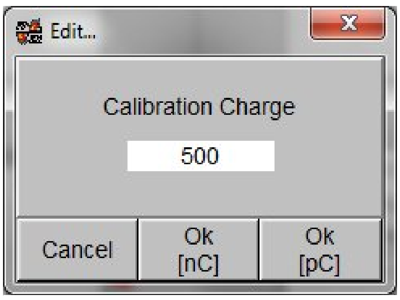


Fig. 49: Calibration charge pop-up

Please ensure that the selected unit [pC/nC] and amplitude fit with the injected charge. For further information about calibration, please check sections VI.1.2 and VI.2.2.

! **Warning:**

- Always provide solid grounding of the instrument and the filter units.
- Make sure that the cable/machine is de-energized before calibration.

V.8 Gating

V.8.1 Principle of Operation

Caution: The analog gating input of the ICMflex is solely for connecting to an HV filter! Never connect another instrument to this input, because this will result in serious damage of the equipment

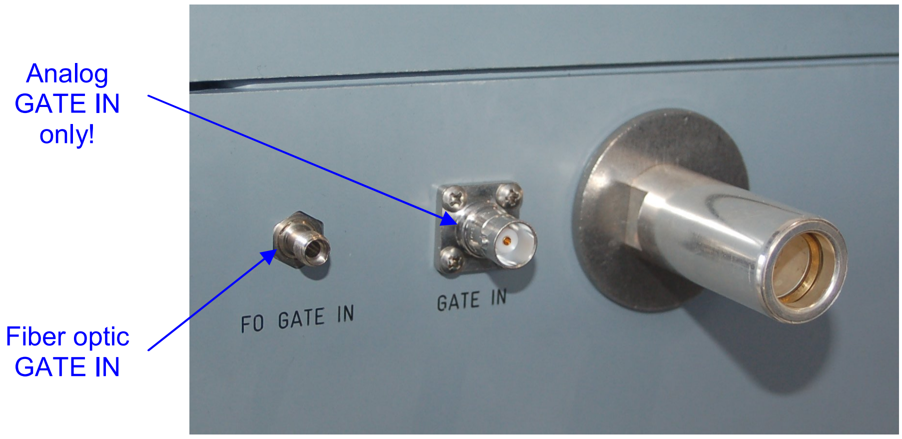


Fig. 50: Gating Inputs

When using the gating function in the ICM*flex*, disturbance signals coming over the HV-line are captured by the HFCT that is embedded into the high voltage filter (T50/05 or equivalent). The output of the HFCT should be connected the GATE IN BNC terminal of the ICM*flex* or ICM*flex* GRC. Internally in the instrument, a built in preamplifier takes care of the signal conditioning. The bandwidth for the gating signal is internally set from 2 to 20 MHz. Analog gating can be activated in the software in the PD Mode (gating on) and the gating threshold in % (gating sensitivity) must be set according to the level of the measured disturbance pulses. The gate level in percent is referring to the maximum scale of the PD pattern or PD scope view at the particular gain. In order to adjust the gate level to blind out the switching pulses of the VLF for instance, the general background noise must be investigated; the LLD level shall be set to the top of the overall ambient noise. As soon the LLD level (top of the ambient noise) is known, the gate level can be selected at a level above the LLD level in order to prevent excessive gating times. As soon as the instrument is effectively gating, the corresponding gating time is shown in the PD scope graph (right upper one in the PD mode). The gate time in percent is referring to the time the instrument is gating during one full cycle.

Example:

With 0.1 Hz, one cycle is 10 s, if the gate time is 30%, gating has been active for 3 s.

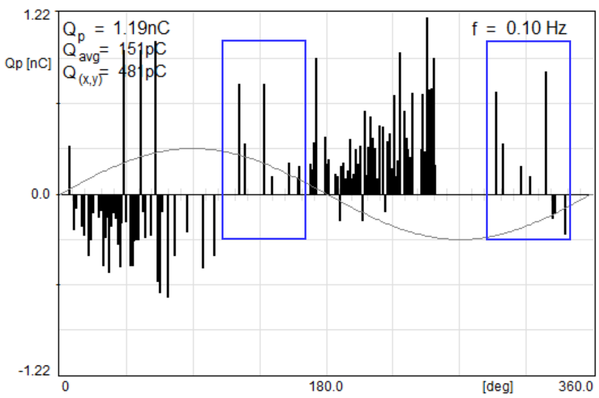


Fig. 51: PD and VLF switching pulses

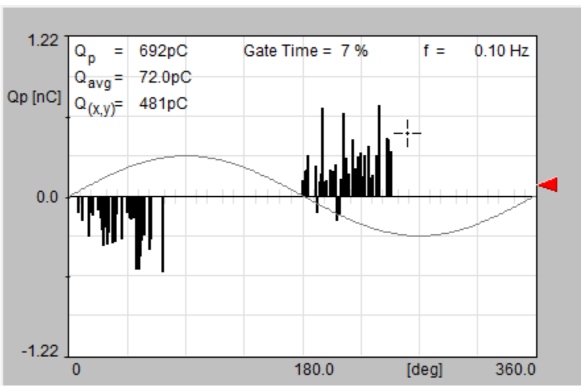


Fig. 52: Switching pulses effectively gated

In the example mentioned above the LLD level was 5%, the gating threshold was set to 8% causing a gating time of 7%, i. e. 0.7 s with a sine wave of respectively 0.1 Hz.

Try to reduce the gate time below 30% in order not to lose significant PD pulses. Hence, don't set the gating sensitivity too low, so that the corresponding gate time is exceeding 30 to 50%. Any remaining ambient noise beside the switching pulses of the VLF, transformer, or RTS are not blocked using analog gating. For such sort of disturbances fiber optic gating using the GST1 and a CT is available.

V.8.2 Gating via Fiber Optic Link (FO Gating)

An ICM*flex* with a gating function comes with an additional terminal for a fiber optic (FO) cable, which takes over a signal on HV potential provided by a gating signal transmitter (GST1). The transmitter is included in the delivery range if FO gating is ordered. An external signal sensor (e. g. CT1) is connected via a BNC cable to the 'GATE IN' terminal of the GST1.

If disturbances like switching of a relay or thyristor firing have a known source, it might be possible to create a TTL signal prior to the disturbance. This signal can be used to blind out the PD measurement path. If a TTL signal is available, it can be provided to the GST1 via a BNC cable that is connected to the ''TTL IN' terminal.

Caution: Never connect the GST1's BNC TTL output to the analog gating input of the ICM*flex*. This will result in serious damage of the instruments!

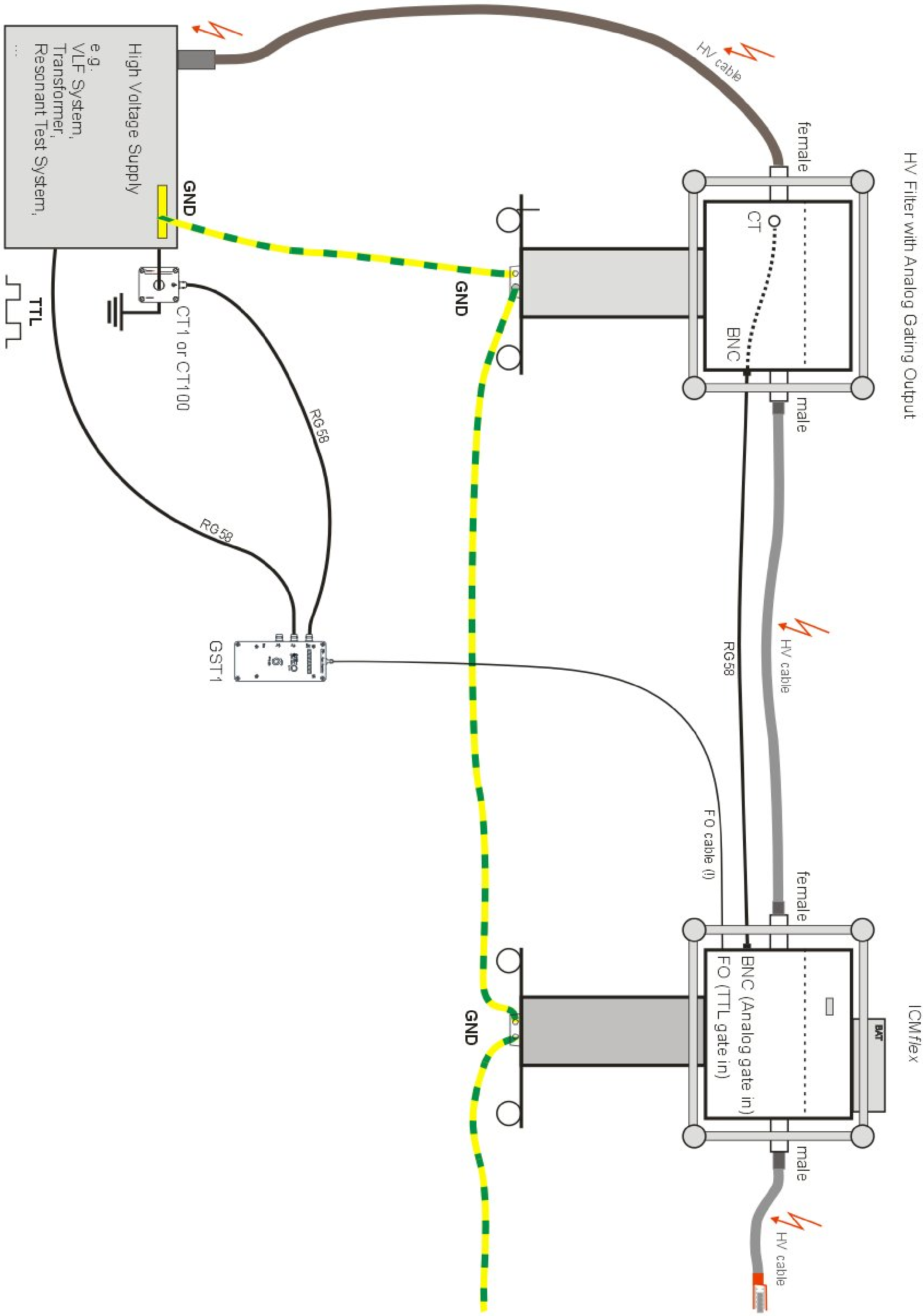


Fig. 53: Gating connection diagram

The gating signal transmitter GST1 has a logarithmic amplification and can be set to three different frequency ranges (40–800 kHz, 2–20 MHz, or 200–600 MHz), which can be selected with a push button. The active bandwidth mode is marked by a lit green LED. The gate level can be adjusted with the rotary switch of the GST1 and is indicated by the orange LED. The level of the analog signal incoming via 'GATE IN' is indicated by the green LED bar. If it exceeds the selected gate level, the bar changes to red. The gate level should be set to the maximum when using a TTL gating signal as signal source, only.

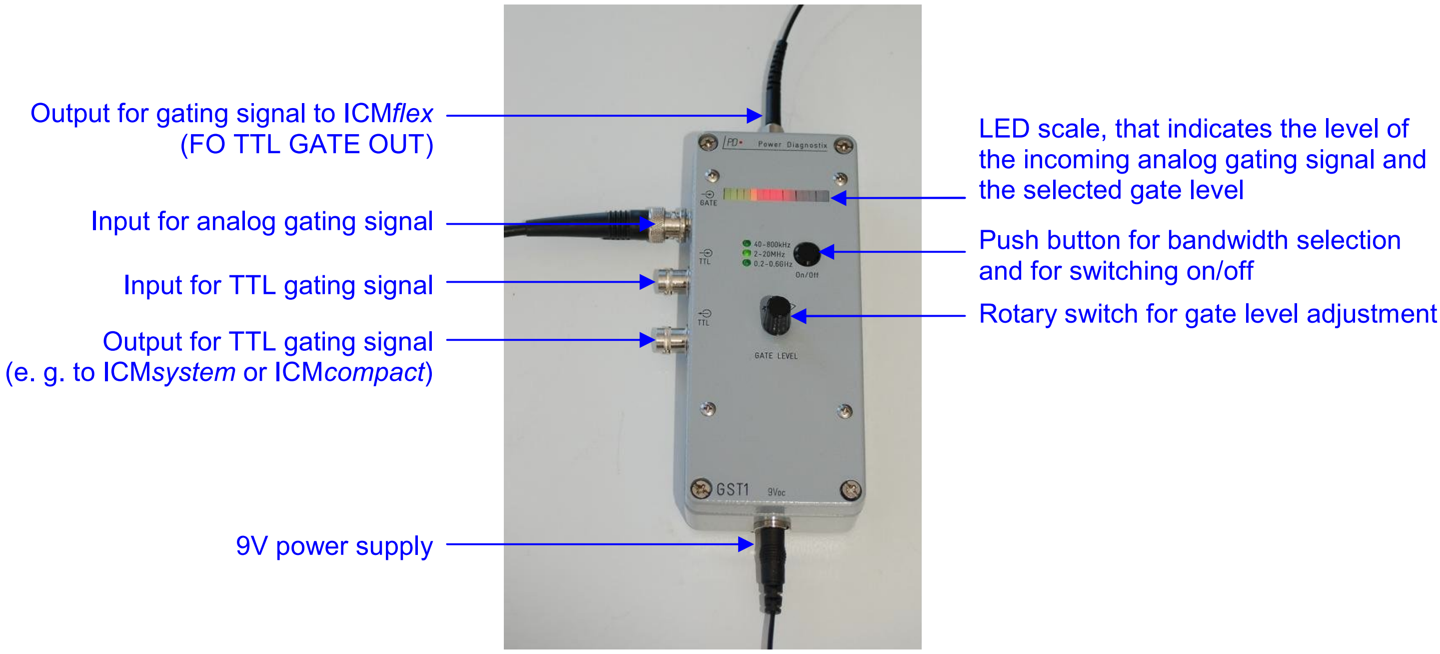


Fig. 54: Gating signal transmitter (GST1)

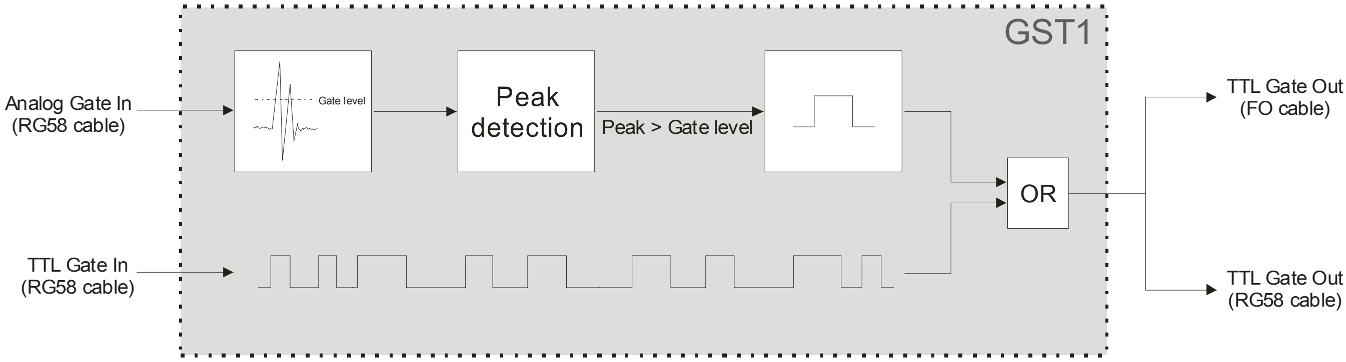


Fig. 55: Disjunction of gating signals when simultaneously using analog and TTL gating

VI Application Notes

The application notes for medium and high voltage cables, rotating machines, and single stator bars, describe the specific measurement set-up, calibration, step by step procedure for performing the measurement, software usage, and evaluation criteria according to the relevant standards.

VI.1 Medium and High Voltage Cables

VI.1.1 Measurement Set-up

A general description of the measurement set-up is given with section III. In this case, the focus lies on the medium and HV voltage cable application. Most important is the interconnection between the main grounding of the high voltage supply and the cable ground shield. The final link from the grounded baseplate of the ICM*flex* to the ground shield must be as short as possible. The high voltage output cable of the ICM*flex* has to be connected to the inner conductor or termination. The order of connecting the various links is shown in figure 56.

VI.1.2 Calibration

Performing high voltage tests including partial discharge measurements and PD fault location on cables requires calibration of both the apparent charge and the cable length. When the safety procedure as mentioned in section I.3 is accomplished and when the set-up is built-up as described above, the calibration can be performed. General procedures are described in the Power Diagnostix's user manual for calibration impulse generators. However, the detailed calibration procedure for cable fault location is explained below.

Since a test specimen has a capacitance against the ground shield, for medium and high voltage cables varying from 200 pF/m to 425 pF/m, the cable capacitance will cause strong attenuation of the injected pulse. The difference between the injected and measured Q_p level is the k-factor, the overall attenuation factor of the complete test circuit. The k factor has to be compensated by the calibration.

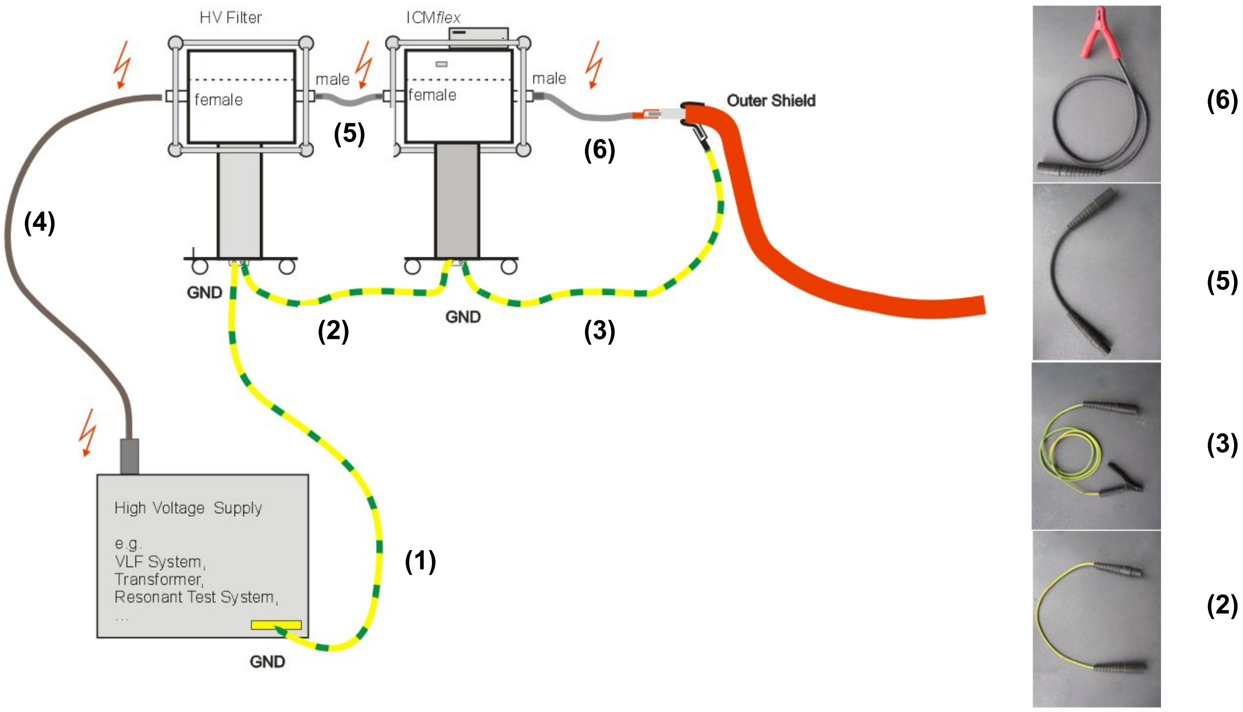


Fig. 56: MV cable measurement set-up

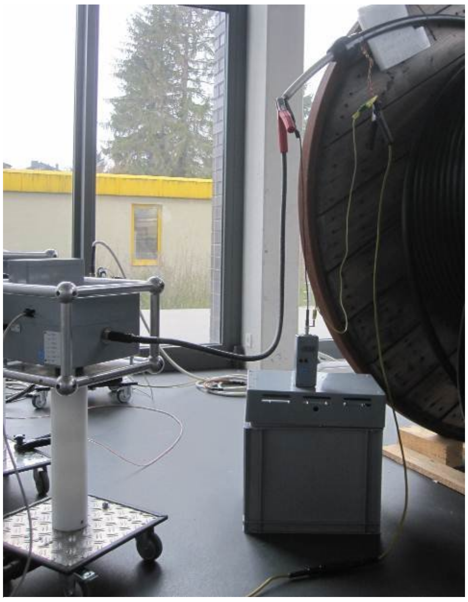


Fig. 57: CAL1B connected to MV cable (lab)

Fig. 58: CAL1B connected to MV cable (on-site)

Common calibration levels for laboratory acceptance tests are in range of 2 to10 pC (CAL1A). However, for on-site testing the set-up sensitivity often does not allow such a sensitive calibration as in the laboratory. Due to this, calibrations are often made with injection levels from 100 pC to 2 nC (CAL1B).

Except the calibration of the apparent charge in accordance with IEC 60270 the cable length or pulse velocity has to be calibrated for performing PD fault location (TDR). At least one of the two values must be known in advance. Table 2 lists some typical values for the velocity of propagation in relation to the cable insulation type. Please note that these values can vary, depending on the nominal voltage and dielectric strength. Usually, the cable supplier provides the exact values with the cable data.

Insulation Type	**Vc (m/µs)**	**Vc/2 (m/µs)**
XLPE	147–168	73–84
PILC	147	73
EPR	165	82
Vacuum	300	150

Table 2: Pulse velocity factors

The injection principle is the same as with the calibration of the apparent charge. Maybe a higher charge level is required to see the necessary reflections for the TDR. Often a pulse magnitude of 5 or even 10 nC is required. If the injected calibration pulse is not visible in the DSO screen, it's necessary to increase the value of 'DSO Gain', until the pulse becomes visible. It's also important to choose a trigger value that is high enough. Do not trigger on disturbance levels. Besides the DSO gain and trigger level, ensure that the reflections are visible by adjusting the time base (X-axis).

For the calibration of the cable length, the cable terminations must be opened on both sides so that they have infinite impedance. Please check the cable set-up carefully before calibrating.

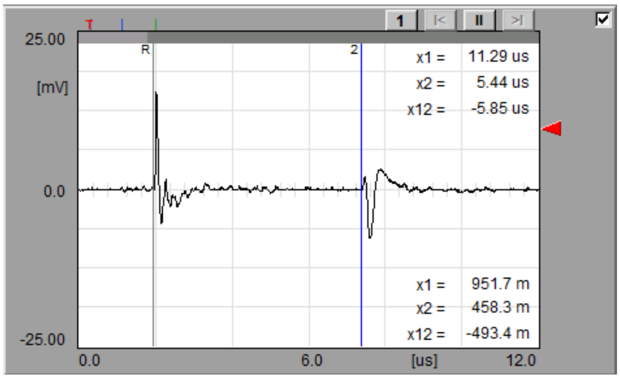


Fig. 59: Cable with shorted end

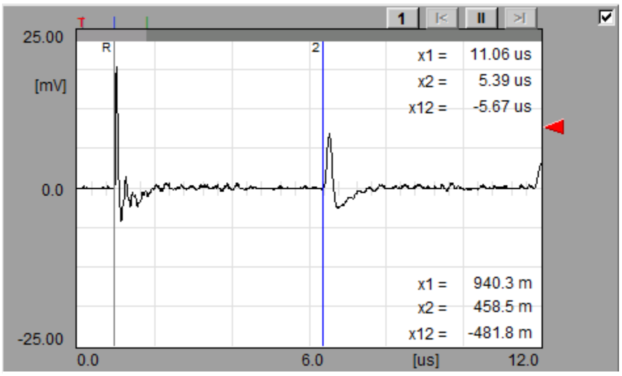


Fig. 60: Cable with open end

The DSO screen on the right-hand side shows the first two reflections arriving at the measuring impendance. Since the cable has an open end, we know that the time difference between the reference pulse and its first reflection represents twice the cable length. The factor of 2 is automatically computed and must not be considered. The DSO screen on the left-hand side shows the result of a shorted cable. Here, the second reflection shows a polarity change due to the negative reflection factor. Please check both ends in such a case.

For the calibration of the cable length its important to consider the following parameters:

- DSO gain : The reference pulse must fill 60–90% of the max. actual scale
- Trigger level : Must be selected sufficiently high not to trigger on disturbance pulses
- Scan time : To be set according to the cable length for having the best sensitivity (0–320 µs)
- Zoom : Use the zoom function to position the cursors more accurate
- Zoom position : The start position of the zoom function with reference to the X-axis

The black cursor (R) must be placed at the beginning of the reference pulse; the blue cursor (2) must be placed at the beginning of the first reflection. If the cable length is given, the 'Calibrate' button at the bottom of the window can be pressed. The software will ask to edit the cable length accordingly. In case the pulse velocity is given, this value must be entered in for V_c. When the pulse velocity is known and both cursors are set correctly, X2 will show the cable length. The more accurate the cursor positions are, the more accurate the distances will be calculated. We recommend saving the file.

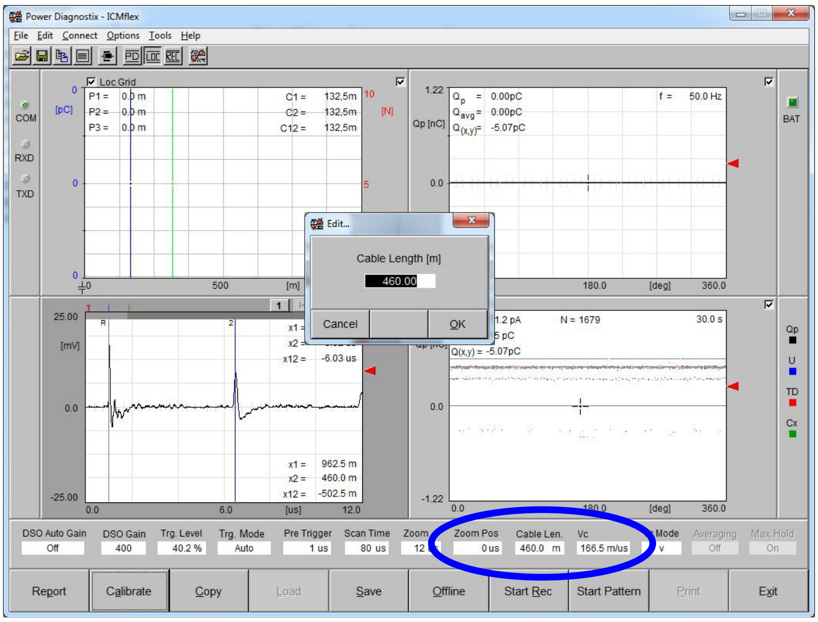


Fig. 61: Cable length calibration

VI.1.3 Standard PD Measurement

Once the calibration procedure is completed and the calibrator has been removed from the test specimen, the voltage may be switched on. Please pay attention to the correct settings of the shunt capacitor C_{sx} (low or high) as mentioned in section V.5.3.

Before switching on the voltage, it's important to observe the present background noise level. Adjust the PD gain and LLD level so that the maximum of the background noise is still visible. Do not set the LLD level completely to 0% in order to prevent occupying the A/D converter with converting background noise pulses. Masking the background noise up to 80% of its maximum amplitude is an acceptable level.

After switching on the voltage, maybe additional noise cancellation is required to get rid of disturbances caused by the power supply itself or by external sources. This can be done by using the gating option, either with analog gating or gating via a fiber optic gating transmitter. Please consult section V.8 for more information.

The next step is finding the partial discharge inception voltage level. It stands to reason that before reaching the partial discharge inception voltage (PDIV), no root cause analysis or PD location investigation using time domain reflectometry can be performed. According to IEEE 400-3, for instance, a healthy cable will not show any sign of partial discharge activity before reaching a voltage level lower than 2 U_n.

Once the inception voltage is reached, the PD pattern can be mapped and compared with typical phase resolved pattern from known PD origins (see section VI.1.7). Besides the pattern, the related discharge levels (Q_p, Q_{IEC}) and the average discharge current (NQS) are given. Please pay attention to the correct settings of PD gain and LLD level. Choose a gain value in such a way, that the PD pulse amplitude is between 50–90% of the maximum scale. The first line analysis concerning the nature cause or PD origin can be made using the pattern. The location along the cable length must be traced via time domain reflectometry. Typical times for mapping the phase resolved pattern are 30 to 60 seconds for power frequency and about 500 to 1000 seconds for VLF at 0.1 Hz.

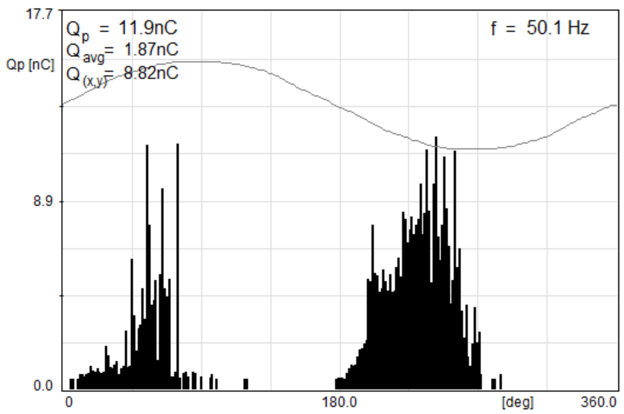


Fig. 62: Surface discharge (PD pattern)

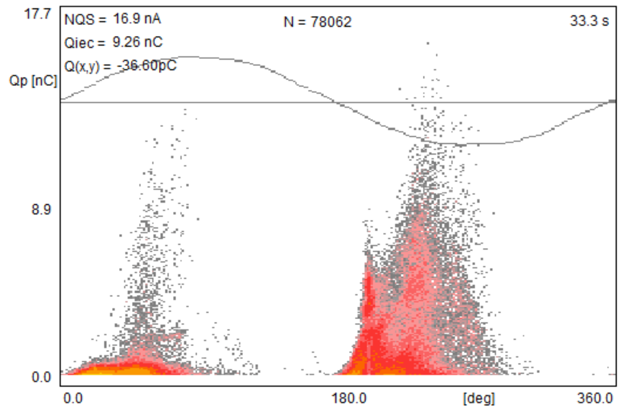


Fig. 63: Surface discharge (scope mode)

VI.1.4 PD Measurements on Cables with High Capacitance

For PD measurements on specimen with high capacitances Power Diagnostix provides the extension box CSX900 that extends the C_{sx} value of the ICM*flex* to 900 µF. The box is mounted onto an isolator of predefined height according to the maximum voltage level of the VLF source.

The following figure shows the set-up when using the CSX900 box.

Fig. 64: Extension box CSX900

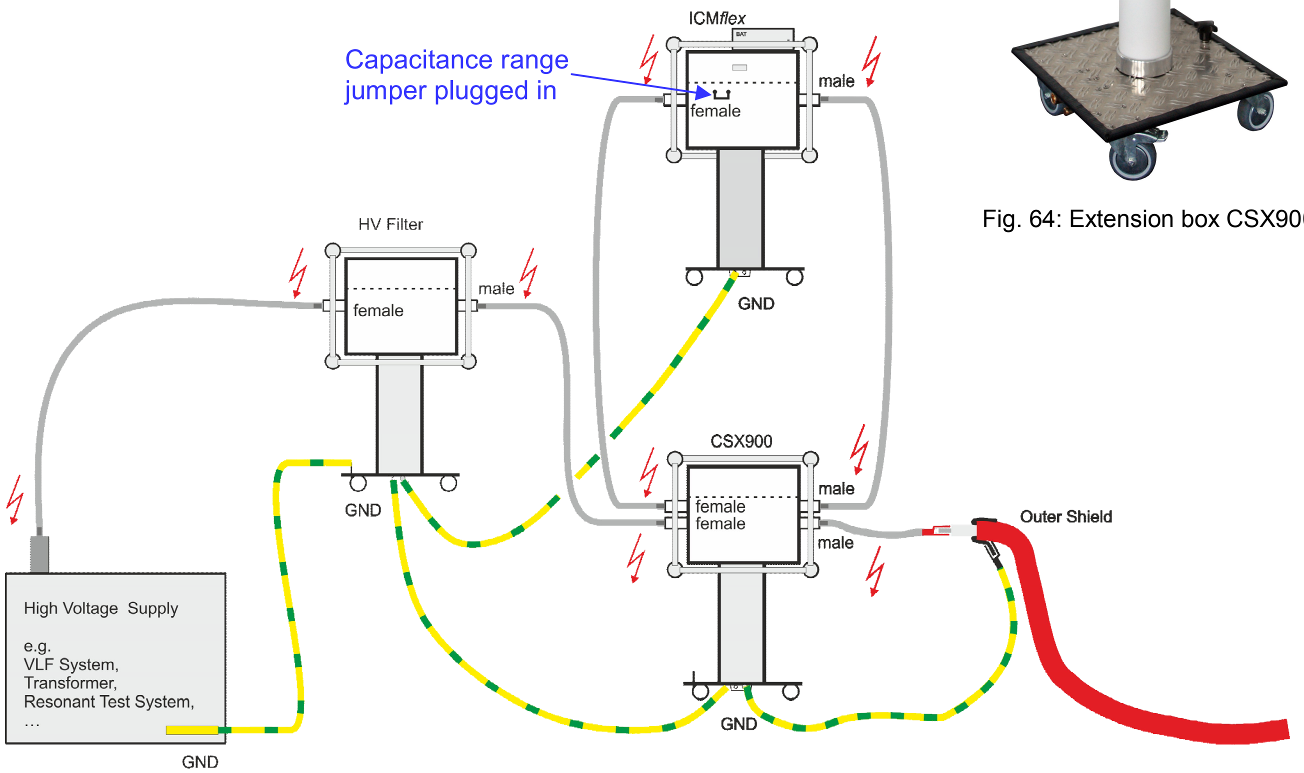


Fig. 65: Measurement set-up with extension box CSX900 for specimen with high capacitances

VI.1.5 PD Fault Location

When the PD pattern is mapped and saved and required notes are made; focus should be laid on the digital storage oscilloscope. Here, each partial discharge pulse is represented on a time based curve. First of all, the settings must be modified so that the reference pulse and the two first reflections arriving at the coupling unit are visible in the screen as explained in section V.4.2.

Once the partial discharge activity has initiated, the digital storage oscilloscope can be used for estimating the PD location. To find the PD location, some good TDR shots must be taken. Accurate DSO settings before starting the scan procedure will result in shorter measuring and analysis time. Moreover, fewer scan files are required to find the PD location.

When the DSO settings (such as the DSO gain, trigger level, scan time, zoom, and zoom position) are optimized so that the reference pulse and the first as well as the second reflection are clearly visible in the DSO screen, the scan procedure may be started. While scanning, snapshots will be taken from pulses exceeding the trigger level. It's important to select a reasonable trigger level that prevents triggering on disturbance signals. After pressing of the 'Scan' button in the DSO menu, the pop-up screen for scan settings will appear.

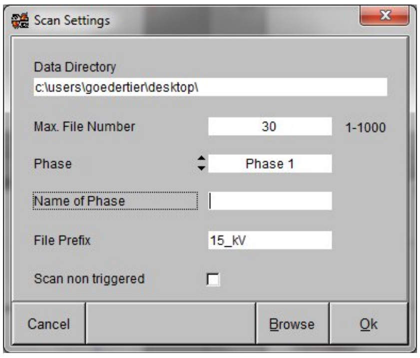


Fig. 66: Scan settings pop-up

- Select the required data directory for saving of scan files
- Enter the maximum number of scan files (up to 1000)
- Phase selection (1, 2, or 3)
- Name of phase under test
- Enter the file prefix, useful for later analysis
- If non-triggered snapshots are also needed, select the corresponding option
- To start the scan, press 'OK'

After the scan procedure is finished, the PD location can be pinpointed. Therefore, you have to go offline with the software and run the 'Start Replay' function from the function keys at the bottom of the window. Here, you can evaluate the scan files manually. First, the software requests you to select the folder were the scan files are stored.

Once you have chosen the relevant folder, you can select the .tdr files to be evaluated. By selecting the files and pressing the 'Add' button, the selection of .tdr files will be shown in the selection box (see figure 67). To confirm the selected files, simply click 'OK'. The software will automatically open the replay function.

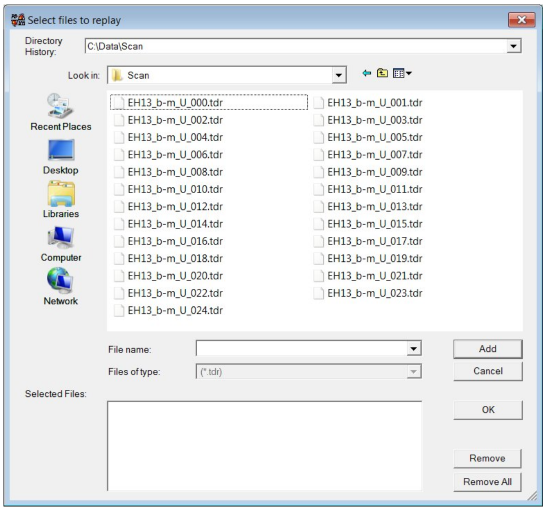


Fig. 67: Scan files selection

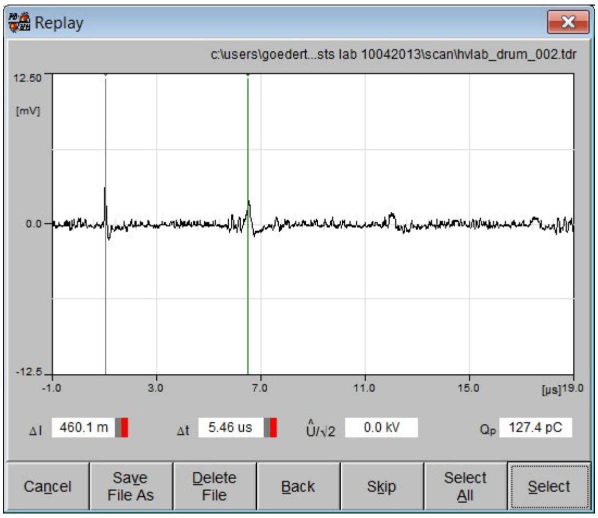


Fig. 68: Replay screen

The main task of the replay function is the correct positioning of the cursor for the reference pulse (grey cursor) and the cursor for the first reflection arriving at the coupling capacitor (green cursor). The file name of the current .tdr file is displayed above the diagram.

Below the diagram are text fields indicating the distance between the cursors, the time delay between the two pulses, the voltage level at which the files were recorded, and the related Qp level for the file.

In the bottom part of the replay screen, you can choose between the following buttons:

- Cancel: For stopping the current replay
- Save File As: For storing the current file
- Delete File: For removing the file from the selection
- Back: For returning to the previous file
- Skip: For switching to the next file
- Select All: For adding all files into the LOC screen
- Select: For adding the current file into the LOC screen

After having positioned the cursors for the reference pulse and first reflection, you can press 'Select' to add the related position of the PD activity along the cable in the summarizing LOC diagram. When scan files are validated and resulting in the identical position along the cable, the result of each single event will be added and shown as the total amplitude in the red bar. The PD amplitude refers to the peak discharge level at the time of scanning and does not indicate the PD amplitude at the position of occurrence.

With the check box 'Loc Grid' it's possible to switch on grid lines within the LOC chart. With the option 'Projections' you can enable cursors in the LOC chart. The mapping reference, i. e. near or far end, is indicated by the coupler symbol on the X-axis. Depending on the precision of the settings during the scan, you may require fewer scan files for finding the PD fault location and thereby shorten the evaluation time during replay.

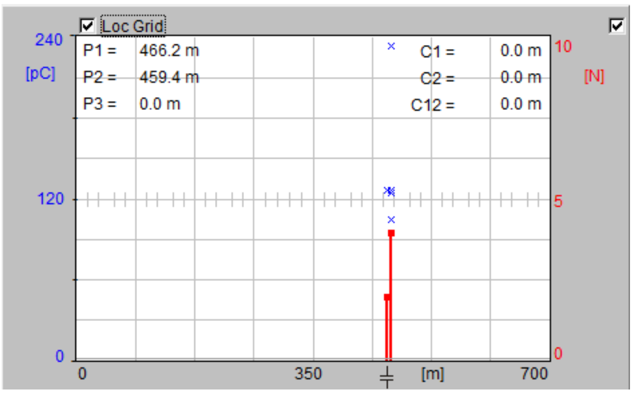


Fig. 69: LOC chart

VI.1.6 Test Voltage Recommendations and Criteria

According to the relevant standards for medium and high voltage cable testing, test voltages, sequences, and PD evaluation criteria are described in relation to the cable's voltage class. Please select the test type to be performed i. e. acceptance testing or on-site testing. On-site testing is mostly performed after installation tests. Such testing is recommended in order to verify the performance of the cable accessories such as joints and end terminations, which are often mounted on-site. Table 3 describes the recommendations given by the relevant IEC standards.

	Acceptance Testing			On-site Testing		
Standard	Frequency	Voltage	PD Criteria	Frequency	Voltage	PD Criteria
1 kV < U < 40 kV						
IEC 60502	49–61 Hz	3.5 U_0/5 min	1.73 U_0 < 10 pC	49–61 Hz 49–61 Hz DC	1.73 U_0/5 min U_0/24h 4 U_0/15 min	None
40 kV < U < 150 kV						
IEC 60840	49–61 Hz	2.5 U_0/30 min	No PD up to 1.5 U_0	20–300 Hz 49–61 Hz	1.73–2 U_0/1 h U_0/24 h	None
150 kV < U < 500 kV						
IEC 62067	49–61 Hz	2.5 U_0/30 min 2.5 U_0/60 min	1.5 U_0 < 10 pC	20–300 Hz 49–61 Hz	1.1–1.73 U_0/1 h U_0/24 h	None

Table 3: MV cable test voltages

As you can see, no PD criteria are given for on-site testing. Shielded test room conditions cannot be compared with on-site conditions. The main reason is the set-up sensitivity which is often critical because of the background noise. In shielded test rooms background noise levels from less than 2 pC can be obtained and for those cases, specifying criteria makes sense. With on-site testing a background noise from few tens up to hundred pC is not unusual. In this case, it’s important to build up a well-considered partial discharge free test set-up and to perform sufficient sensitivity checks at all available positions in order to have a better understanding of the partial discharge's high frequency signal transfer within a certain bandwidth.

Besides the IEC standards, there are applicable IEEE publications as well. The general procedures and criteria are not too different from IEC. However, interesting in the IEEE standards are the test voltage criteria for testing at very low frequency (VLF). IEEE splits cable testing into three different groups, i. e. installation test, acceptance test and maintenance test, each with its related test voltages.

VLF Output Waveform	Cable Rating Phase-to-Phase	**Installation Test** Phase-to-Ground – U_0		**Acceptance Test** Phase-to-Ground – U_0		**Maintenance Test** Phase-to-Ground – U_0	
Sinusoidal	kV rms	kV rms	kV peak	kV rms	kV peak	kV rms	kV peak
	5	9	13	10	14	7	10
	8	11	16	13	18	10	14
	15	19	27	21	30	16	22
	20	24	34	26	37	20	28
	25	29	41	32	45	24	34
	28	32	45	36	51	27	38
	30	34	48	38	54	29	41
	35	29	55	44	62	33	47
	46	51	72	57	81	43	61
	69	75	106	84	119	63	89

Table 4: MV cable VLF test voltage recommendations

In general, the recommended testing time according to IEEE 400.2 varies between 15 and 60 minutes. Suggested are 30 minutes. For maintenance testing a period of 15 minutes is recommended.

VI.1.7 Typical PD Patterns and Tan Delta Levels

MV class cables are tested in the factory according to common IEC standards. The acceptance level for new cable systems is < 2 pC or even less. Therefore, all PD detected on MV cables under applied voltage up to 1.5 rated voltage should be considered as a problem within the cable or its accessories. Further analysis should clarify the cause of such internal PD activity.

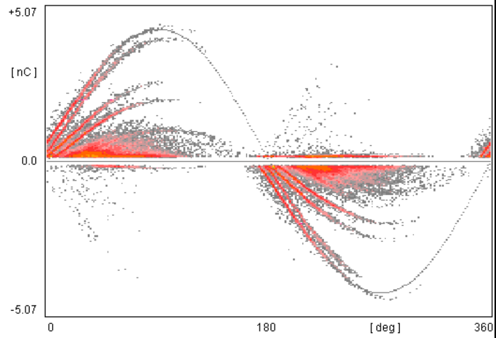
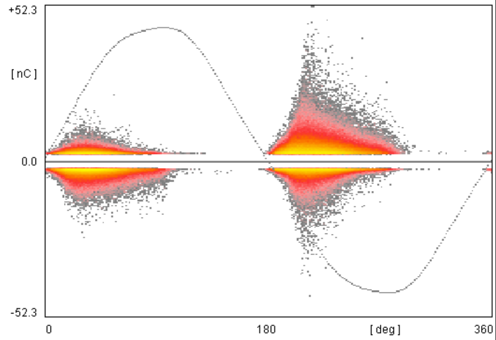
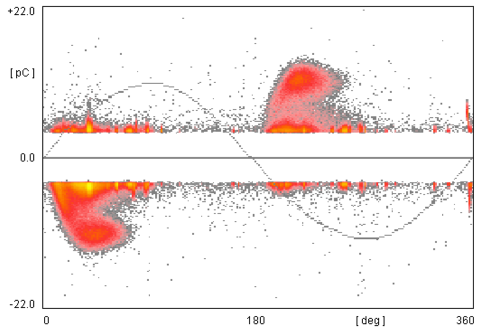
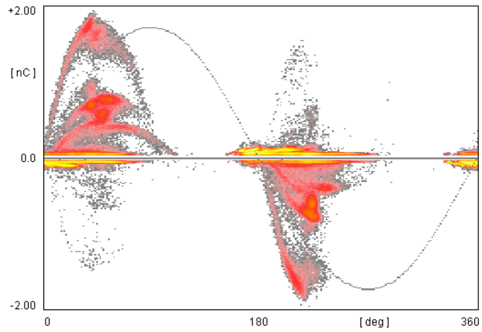
PD Phenomena	Typical Range	Further Analysis recommended	PD Pattern Example
Void discharge with low availability of starting electrons	<2 pC	>20 pC	
Surface discharge	<2 pC	>20 pC	
Internal discharges in a prefabricated EPR cable joint	<2 pC	>20 pC	
Several flat cavities in silicon fat due to improper mounting procedure	<2 pC	>20 pC	

Table 5: Typical PD patterns for MV cables

The loss factor values measured on MV cables are usually specified according to the cable insulation system and voltage level U_0, $2U_0$ or the tip-up between $2U_0$ and U_0. Please pay attention to the environmental conditions as they strongly influence the loss factor and capacitance measurements. Indicative TD values are listed with table 6.

Type of Cable System	**New**	**Service Aged**	**Critical Levels**
PE	< 0.1×10^{-3}	> 2.2×10^{-3}	> 2×10^{-3}
VPE-S	< 1×10^{-4}	> 1×10^{-4}	> 1×10^{-3}
VPE-C	< 1×10^{-3}	> 1×10^{-3}	> 1×10^{-3}
VPE-WTR	< 1×10^{-3}	> 1×10^{-3}	> 1×10^{-3}
EPR	< 3.5×10^{-3}	> 3.5×10^{-3}	–
PVC	< 6×10^{-2} (50 Hz) < 8×10^{-2} (0.1 Hz)	> 6×10^{-2} (50 Hz) > 8×10^{-2} (0.1 Hz)	–
XLPE	0.1×10^{-3}	> 2.2×10^{-3}	–
HDPE	0.1×10^{-3}	> 2.2×10^{-3}	–

Table 6: Tan delta levels versus insulation system

VI.1.8 Normative References

IEC 60502: Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV)

IEC 60840: Power cables with extruded insulation and their accessories for rated voltages above 30 kV (U_m = 36 kV) up to 150 kV (U_m = 170 kV) – Test methods and requirements

IEC 62067: Power cables with extruded insulation and their accessories for rated voltages above 150 kV (U_m = 170 kV) up to 500 kV (U_m = 550 kV) – Test methods and requirements

IEEE 400: IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above

IEEE 400.2: IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

IEEE 400.3: IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment

VI.2 Rotating Machines

VI.2.1 Test Set-up

A general description of the measurement set-up is given in section III. In this case, the focus is set on the rotating machines application. Of main importance is the interconnection between the main grounding of the high voltage power supply, i. e. a transformer or resonance test set, and the main grounding of the machine frame. The final link from the grounded baseplate of the ICM*flex* to the ground shield must be as short as possible. The high voltage output cable of the ICM*flex* has to be connected to the phase terminals of the motor or generator housing. An installation scheme showing the connections is given with figure 70.

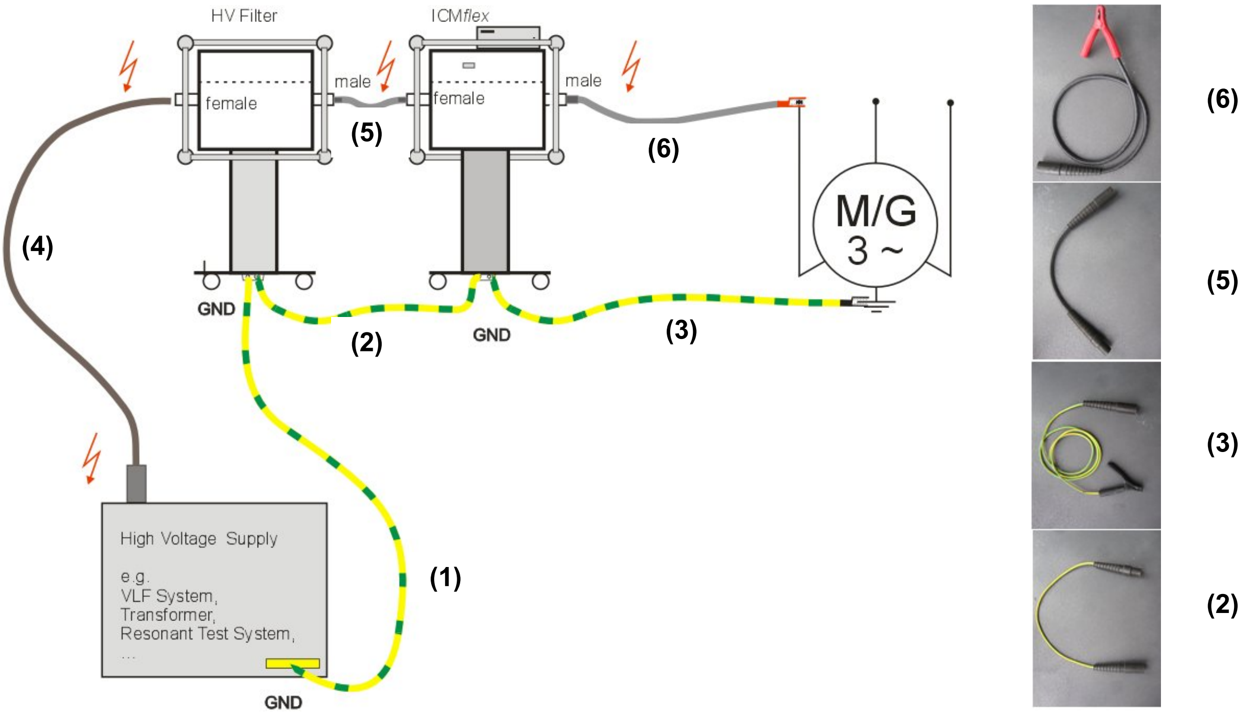


Fig. 70: Rotating machines measurement set-up

VI.2.2 Calibration

Performing high voltage tests, including partial discharge measurements on rotating machines insulation systems according to IEC 60270, requires a calibration of the apparent charge. When the complete safety procedure as mentioned in section I.3 is accomplished and when the set-up is built-up as described above, the calibration can be performed. General procedures are described in the Power Diagnostix's user manual for calibration impulse generators. However, the detailed calibration procedure for generators and motors is explained below.

The selection of the relevant charge level to be injected into the measurement circuit is mainly depending on the machine's ratings. The main parameter influencing the required charge is the stator windings capacitance. In general, the capacitance is depending on the nominal voltage, number of poles, and the core length. It’s important to have a reasonable signal to noise ratio in order to ensure sufficient sensitivity. Select a value that is approximately 5 to 10 times higher than the present background noise. Typical values used for on-site testing are varying from 1 nC to 5 nC, even 10 nC in case of hydro or turbo generators.

It is recommended to make a calibration using the PD attenuator as well. Due to the properties of the insulation materials and the winding manufacturing techniques of an epoxy mica insulation system, it is known that the related partial discharge pulses can produces strong amplitudes. It might happen that the amplifier in regular mode cannot handle extraordinary high pulses. Therefore, the ICM*flex* has an on-board 10 dB attenuator to be activated in the advanced settings. In this case, you can activate the attenuator and upload the relevant calibration file without interrupting the measurement session. The PD attenuator can be switched on with the menu item 'Edit->Advanced Settings' of the ICM*flex* software.

If access to the neutral connection (star point) is possible, testing of the separate phases can be performed as well. In this case, it’s necessary to have an additional calibration as the capacitance to ground will be different. On the other hand, injecting a pulse at the neutral terminal and measuring the response at the line terminal gives a good idea of the measurement sensitivity.

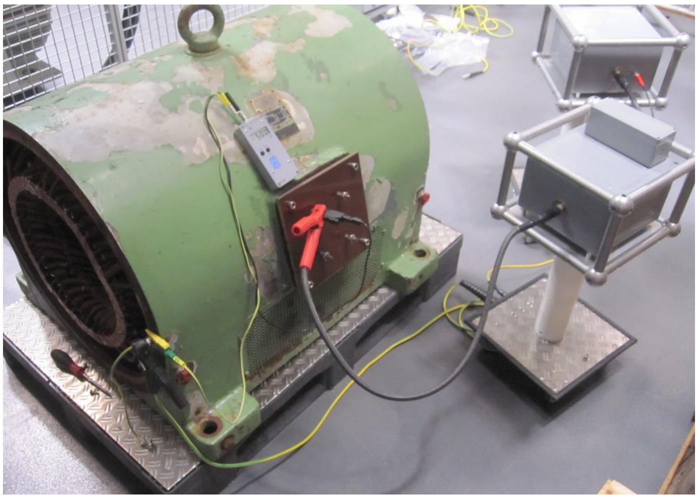


Fig. 71: Calibration on a small asynchronous motor

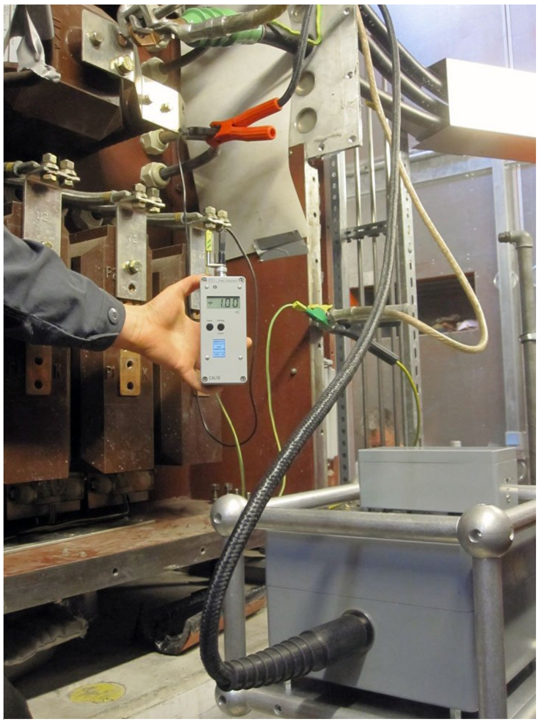


Fig. 72: Calibration on a synchronous generator

VI.2.3 PD Measurements

Once the calibration procedure is completed and the calibrator (CAL1) has been removed from the test specimen, the voltage may be switched on. Please pay attention to the correct settings of the shunt capacitor C_{sx} (low or high) as mentioned in section V.5.3.

Before switching on the voltage, it’s important to observe the level of the present background noise. Adjust the PD gain and LLD level in such a way that the value of the PD amplitude is 50–90% of the maximum scale and that the maximum of the background noise is still visible. Do not set the LLD level to 0% in order to prevent occupying the A/D converter with converting background noise pulses. Masking the background noise up to 80% of its maximum is an acceptable level.

After switching on the voltage, maybe an additional noise cancellation is required to get rid of disturbances caused by the power supply itself or by external sources. Use the gating option for this purpose. Analog gating and gating via a fiber optic gating transmitter are possible. Please check section V.8 for more information.

The next step of the measurement process is searching for the level of the partial discharge inception voltage (PDIV). Important for finding the PDIV is a sensitive and slight ramp-up of the test voltage. A typical test sequence used for partial discharge measurements is, for instance, the one for tan delta measuring. In this case, the test voltage must be increased in five equal steps of 20% of U_{MAX} up to U_{MAX}. The maximum voltage level (U_{MAX}) applied to ground is the operating line-to-line voltage as mentioned on the machines rating plate. Testing up to the line-to-line voltage does not only cover the insulation to ground but also the performance of the inter phases insulation and is strongly recommended for acceptance testing of new stator windings. Other common U_{MAX} levels are up to the operating line-to-ground voltage (U_{MAX} / √3) or up to 120% of the operating line-to-ground voltage (1.2 U_{MAX}/√3). The maximum test voltage is often agreed between the owner and service group and is chosen in respect to the kind of test, e. g. a periodical test or test after repair.

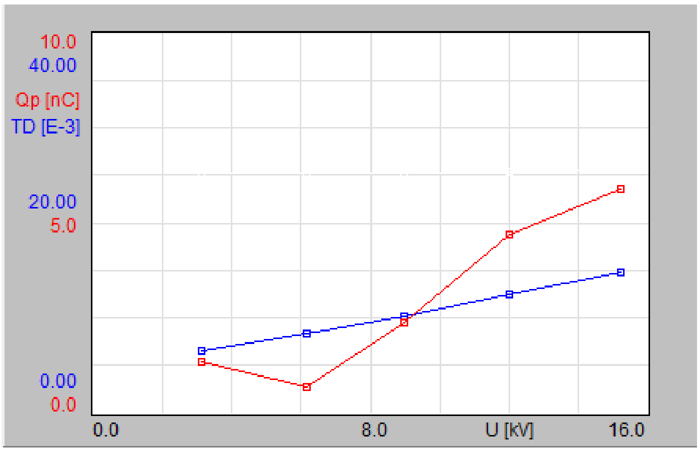


Fig. 73: Test sequence of a 15 kV winding, PD and TD vs. voltage

After the inception voltage is found, phase resolved patterns can be mapped and compared with typical phase resolved pattern from known PD origins (see section VI.2.5). The recommended value for the PD pattern set time is between 30 s and 60 s when working at power frequency (50 Hz–60 Hz) and about 1000 s to 1500 s when using very low frequency (VLF) power supplies.

Together with the pattern the related discharge levels (Q_p, Q_{IEC}) and the average discharge current (NQS) are given. Relevant data for the measurement reports concerning rotating machines are as follows: Summary table of all test results versus voltage, partial discharge inception and extinction voltage, and the phase resolved patterns at each voltage step. The ICM*flex* software offers an export of those data as a file for MS Excel.

VI.2.4 Step by Step Guide

In order to simplify the measurements, a step by step option was implemented into the ICM*flex* standard software, which guides users through the required steps that must be fulfilled prior and during the measurement. To enable the step by step guidance, the option must be activated via Edit->Edit Preferences in the tab "Miscellaneous". The settings related to the step by step measurement can be found on the tab "Step by Step Guide".

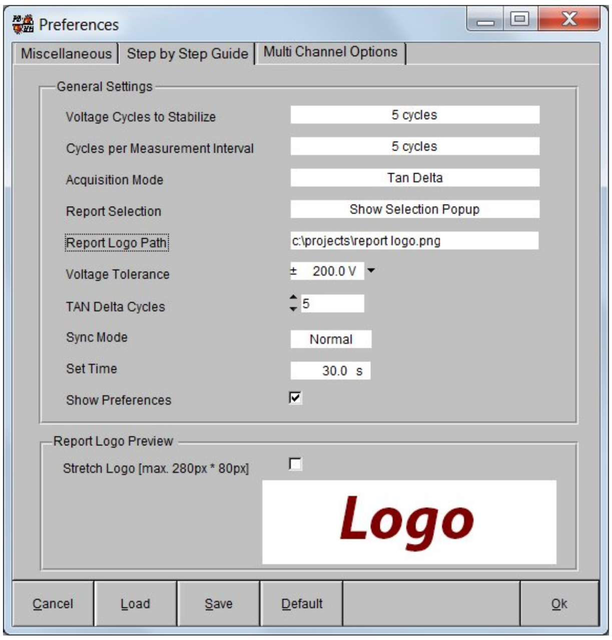


Fig. 74: Preferences window

1) Voltage cycles to stabilize: The system recognizes the applied voltage after having detected the selected number of stable cycles in between the fixed voltage tolerance levels.

2) Cycles per measurement interval: Determines the number of averages taken for the tan delta measurement at a certain voltage level after detection of a stable voltage level in between the fixed voltage tolerances

3) Voltage measurement tolerance: Tolerance free to select in volts [V] of percentage [%]. Based on the accepted difference between the theoretical value calculated for each voltage step according to the machines phase-to-phase voltage entered in the machine information

Step 1: The user has to enter the general information such as:

- Work number
- Machine type
- Serial number
- Nominal voltage
- Phase to be tested
- Maximum voltage
- Measured by
- Approved by

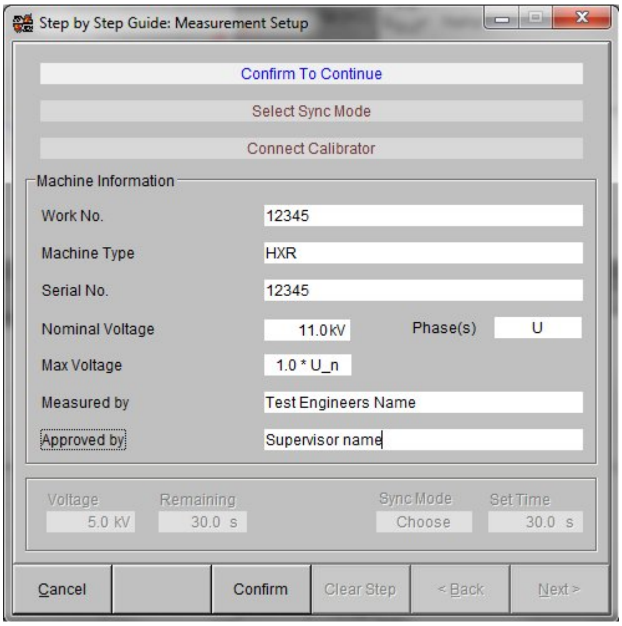


Fig. 75: Measurement Setup Guide screen

After filling out each field, the background color of the relevant item to be filled changes from red into black after confirming by pressing the enter button. The nominal voltage to be entered is the operating phase to phase voltage of the stator winding. The user can make a selection to record date for each phase separately or all three phases together (star point connected). The maximum voltage of the record file is adjustable, varying from 0.8 x U_N to 1.4 x U_N. Once, all the required fields are filled out, the upper guide bar will indicate “Confirm to Continue”. The settings are saved by pressing the “Confirm" button below in the guidance screen. Pressing the “Cancel” button stops the step by step procedure.

If the user confirms the entered data, the upper guidance bar will indicate “Completed” in green font color and the software continues to the next step. If a failure is detected, the forgoing step can be fully deleted by pushing the “Clear step” button.

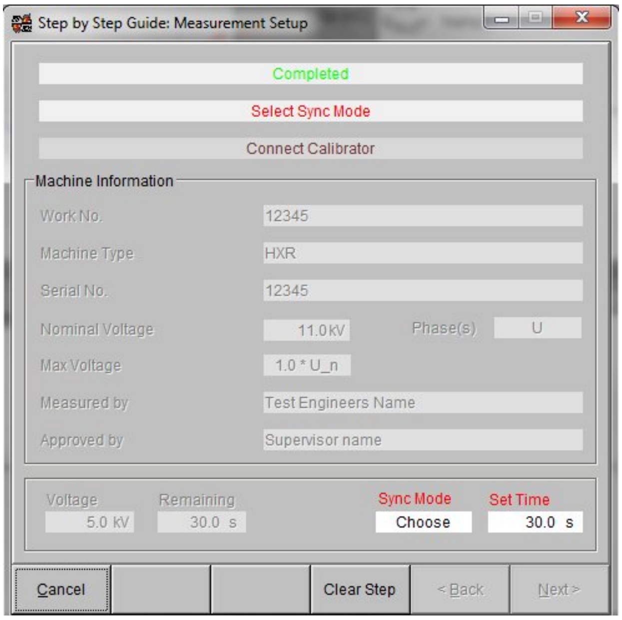


Fig. 76: Completed first step

Step 2: Selection of synchronization frequency

In step 2 the user has to select the synchronization frequency for the measurement within the dropdown list “Sync Mode”. Available values are:

- Normal: 50–60 Hz, power frequency
- VLF 0.1 Hz
- VLF 0.05 Hz
- VLF 0.02 Hz

According to the synchronization frequency, the set time must be chosen accordingly. Power Diagnostix has entered recommended set times for each frequency. The user can chose between selecting the proposed set time or entering a random set time based on his own test procedure. Proposed set timees are:

- Normal: 60 seconds
- VLF 0.1 Hz : 1500 seconds
- VLF 0.05 Hz : 1500 seconds
- VLF 0.02 Hz: 3000 seconds

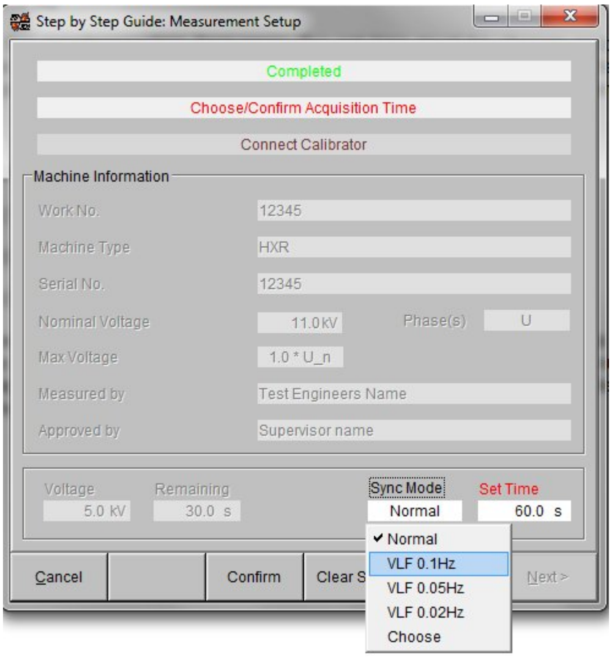


Fig. 77: Synchronization frequency selection

After entering and confirming the set time, the user is asekd to enter the filename. He can do this by pushing the button “Filename” in the bottom guidance menu. All measured data at each voltage interval will be stored under the entered filename into in the relevant folder at a fixed location at the computer’s hard drive.

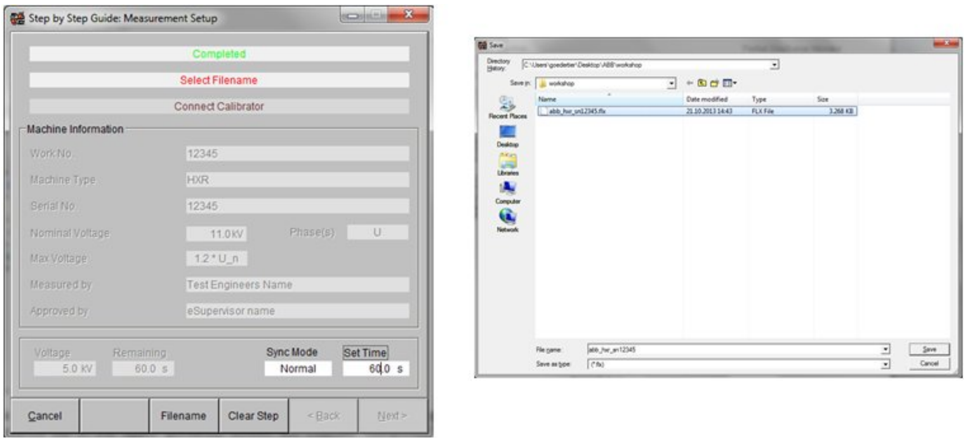
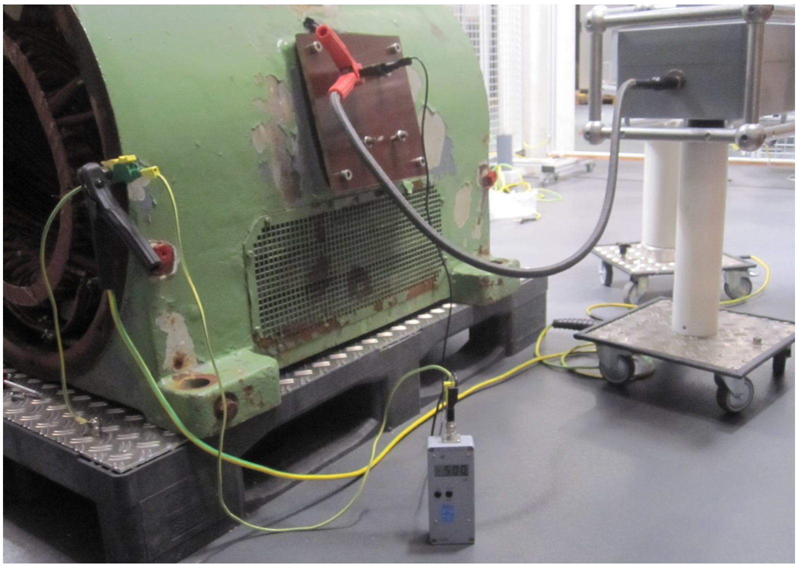


Fig. 78: File name selection

After having selected the filename and desired location at the computer’s hard drive, the second guidance bar in the upper guidance screen will indicate “Completed” in green font color and will request the operator the continue with step 3.In case a failure is detected, the forgoing step can be deleted by pushing the “Clear step” button and the forgoing step can be repeated.

Step 3: Partial Discharge Calibration (IEC 60270)

The third step of the measurement guidance will request the user to perform the calibration of the apparent charge for the partial discharge measurement. Therefore, he has to connect the calibrator to the winding that is going to be measured. The calibrator must be connected according to the example in figure **Fehler! Verweisquelle konnte nicht gefunden werden.**.



It is important to consider the signal to noise ratio (STN). According to the present background noise level, the user has to inject a sufficiently strong calibration pulse. It must be possible to clearly distinguish the calibration pulse and the present background noise level. Common charge levels injected for rotating machines are 500 pC, 1 nC, 2 nC, and 5 nC. In general, the charge to be injected will be determined by the overall capacitance of the stator winding and measurement setup. By performing the calibration this overall attenuation gets compensated so that the ICM*flex* recognizes the same pulse amplitude of the apparent charge level that arrives at the phase terminal under test. By double clicking on the upper calibrator line, the injected value can be entered in dialog box which will appear on the screen.

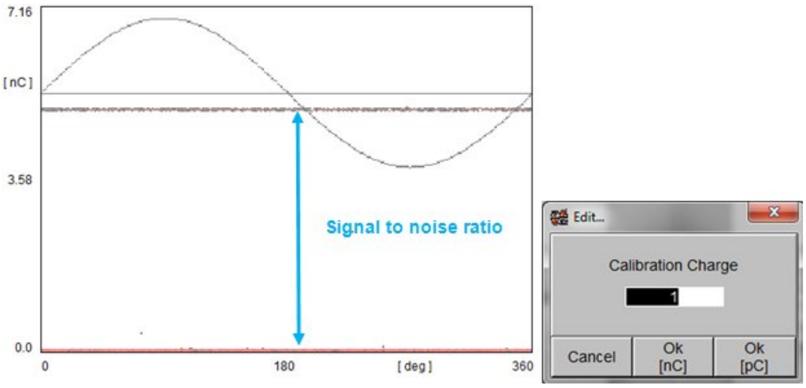


Fig. 79: PD calibration

Each step that has to be performed to complete the calibration process will be asked by the step by step guide.

1) Connect the calibrator
2) Start pattern: wait for 10 s (standard acquisition time for calibration)
3) Double click on the calibrator pulse

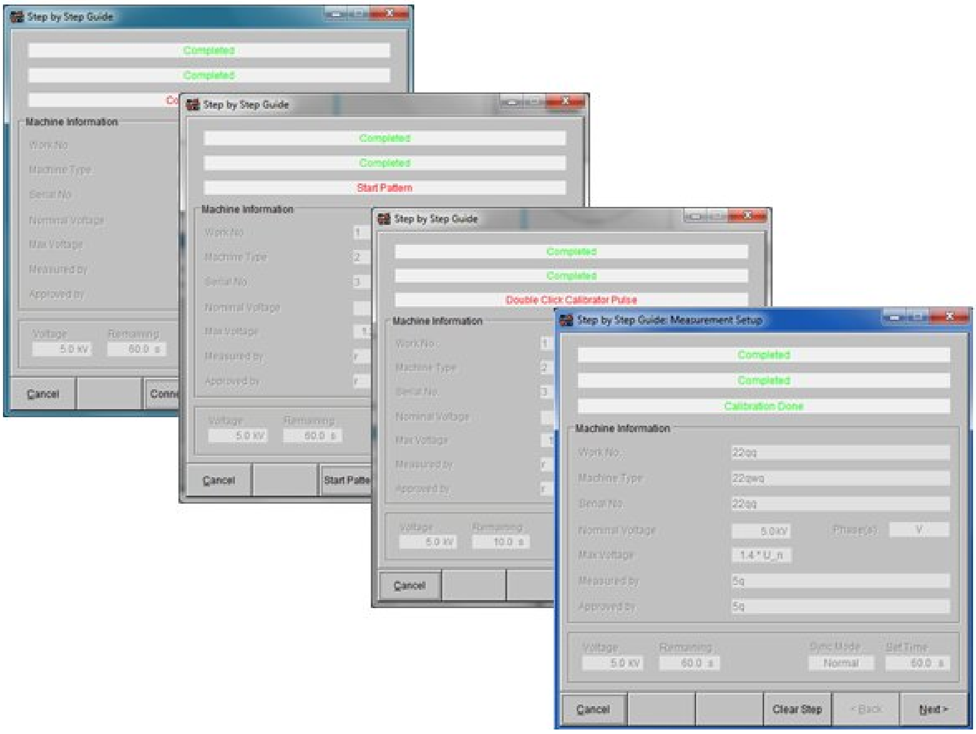


Fig. 80: Calibration sequence

After the injected calibration pulse was entered, the calibration file will be stored into the .flx file with the chosen filename in the selected location on the computer. The third guidance bar in the upper guidance screen will now indicate “Calibration done” in green font color and request the user to continue with the next step by pressing the “Next >” button in lower right corner of the guidance screen.

Step 4: Switch on the voltage

The next step in the measurement process is to switch on the voltage. In the upper guidance bar, the required voltage level will be indicated. It is represented as a phase to ground of phase to phase level.

From this point in the sequence, the user can turn back to the forgoing step by pushing the button “< Back” or go to the next step by pushing “> Next”, at any time. Please note that "> Next" becomes available after having completed the forgoing step, only.

The instrument will recognize the voltage level automatically. The voltage tolerance, number of cycles to stabilize, and the interval time, i. e. the number of averages per voltage step by means of number of cycles per interval, can be selected in the tab "Step by Step Guide" of the preferences panel shown with figure 74.

Until the desired voltage within the fixed tolerance is reached, the second guidance bar will indicate “Waiting”. Once the required voltage level is reached, the first guidance bar will change into “Voltage reached” in green font color and the second guidance bar will show now “Acquire Tan Delta Values”.

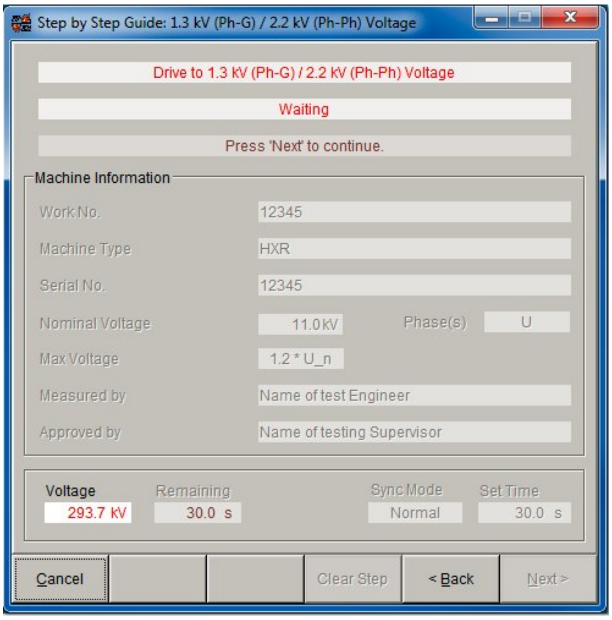


Fig. 81: Guidance screen while wainting for the voltage level to be reached

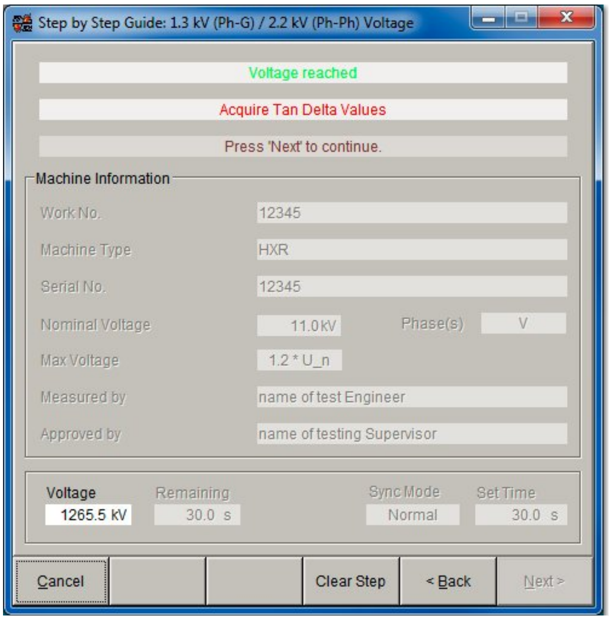


Fig. 82: Guidance screen after reaching the test voltage

The tan delta measurement will now be performed automatically according to the fixed settings in the preferences. When the number of averages is reached and values are stored for a certain voltage step, the second guidance bar will indicate “Start Pattern Acquisition” for performing the partial discharge measurement. The voltage level and remaining acquisition time will always be shown at the left-hand side in the lower part of the guidance window.

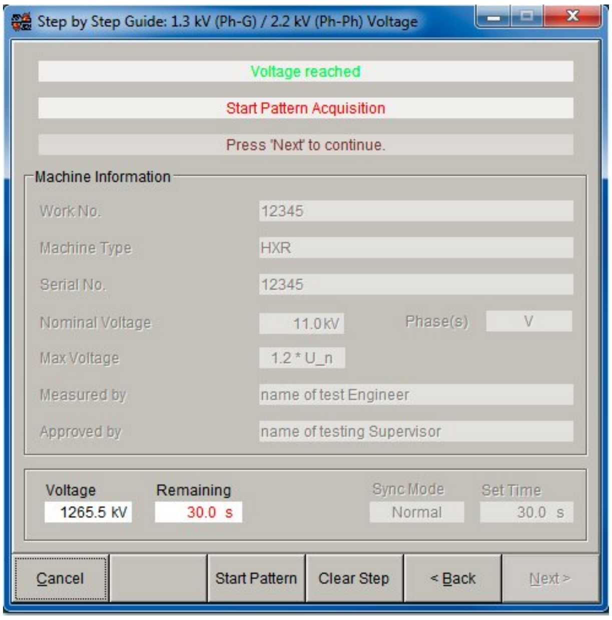


Fig. 83: Guidance screen for starting the PD pattern

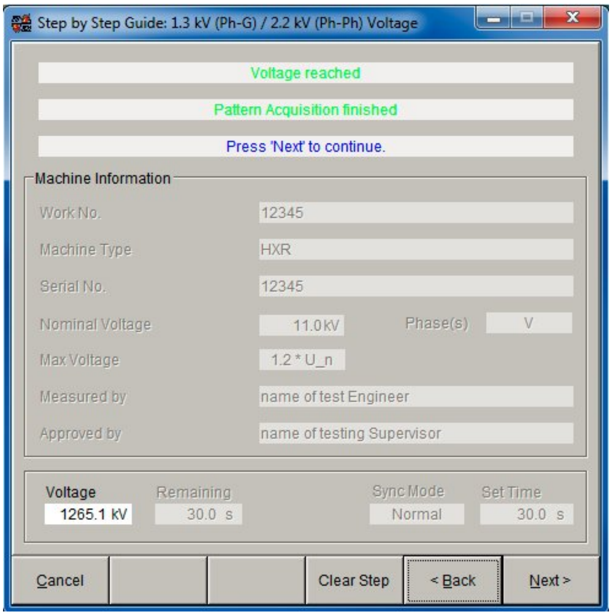


Fig. 84: Guidance screen after completing pattern acquisition

The pattern acqusition will be started by pressing the “Start Pattern” button at the bottom of the guidance screen (see figure 84). The pattern will be collected according to the fixed set time. Once the pattern is acquired, the second guidance bar will indicate “Pattern Acquisition finished” in green font color. The user has to confirm this message by pressing the “Next >” button. The pattern will then be stored under the selected filename, per voltage step into one .flx files. If necessary, the pattern can be mapped again in case some of the settings have to be adjusted. The pattern stored before will be over-saved by the latest one acquired. To map a new pattern, select the “< Back” button first.

After having confirmed by pressing “Next >”, the guide will indicate the next voltage step to be reached. When ramping-up the voltage, the user has cross check the gain settings for U_N and U_x at any time in order to not over-range the capacitive voltage dividers. When this is the case, a warning will be generated in the second guidance bar “U_sn or sx Over-range-Decrease U_sn Gain”. The corrective action by means of changing the Usn or Usx gain will be indicated as well. The maximum voltage level for Usn = 14 V_{RMS}, for U_{SX}=140V_{RMS}. The actual voltage drops over the capacitive dividers can be observed in the upper left chart by selecting U_{ACQ}, located in the upper right corner of the chart. After adjusting the gain settings properly and detecting the applied voltage within the fixed tolerance, the message “Voltage Reached” will appear in green font color into the first guidance bar. The tan delta records will be made and afterwards, the pattern can be acquired again. This procedure must be repeated until reaching the last voltage step.

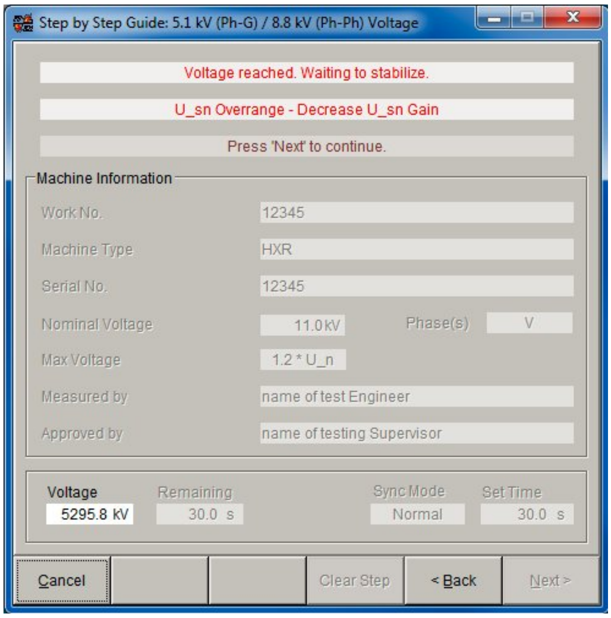


Fig. 85: Voltage over-ranging

Besides the gain settings for both voltage dividers, the gain for the partial discharge measurement must be guarded as well. After reaching a voltage step, please check if the present PD activity is within the maximum scale of the pattern. If not, increase or decrease the PD gain accordingly.

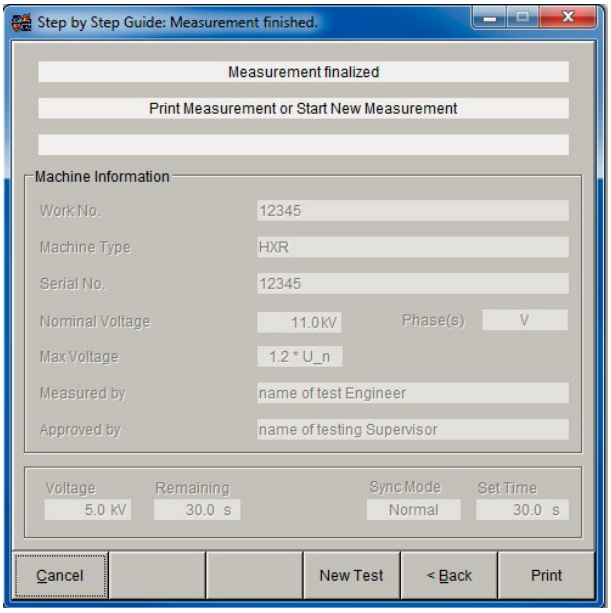


Fig. 86: Printing/new test guidance screen

Once the pattern acquisition for the last voltage step is finished, the entire table has been filled out by the software automatically. The upper guidance bar will show then the message “Measurement finalized” and the second guidance bar will ask the operator “Print measurement or start new measurement” (see figure 86). The test report can by printed by pressing the “Print” button located in the lower right-hand corner of the guidance screen. The report will be printed and shown on the computer’s screen.

After having printed or started a new test, the button "Keep Infos" appears in the lower area of the guidance screen. This option is implemented in order to keep the machine details etc. for a consecutive measurement on the same machine. For instance, phase V after finishing phase U. So, in case, you only have to re-select the phase name, filename and re-do the PD calibration for the relevant phase. For performing the consecutive measurements for the next phase or all tree phases together, for instance, the principle of measuring stays the same, i. e. the operator will be guided through the complete sequence again, step by step. When pressing the "Clear all" button, all the machine information will be deleted.

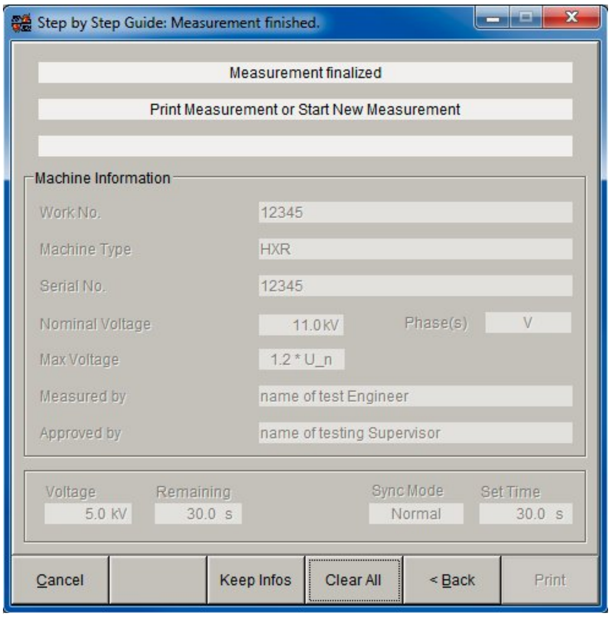


Fig. 87: Final guidance screen

VI.2.5 Typical PD Patterns and Tan Delta Levels

To simplify the evaluation of all measurement results you can find here some common partial discharge patterns versus PD origin and tan delta evaluation criteria as known from rotating machines standards and other related literature. Power Diagnostix has experience in PD diagnostic on rotating machines for more than 20 years. The following table gives an overview regarding regular PD levels and miscellaneous PD phenomena.

In general, partial discharge activity is inherent to epoxy-mica insulation systems. Compared to other insulation systems were the PD level criteria are specified in the lower pC ranges, such as XLPE for medium and high voltage cables or oil-paper insulation system for power transformers, the common PD levels for stator winding insulation systems are higher. Epoxy-mica insulation systems also widely tolerate partial discharge activity since these systems are developed to be partial discharge resistant for many years. Performing PD tests on new machines offers a finger print for further trending over time and will indicate the presence of essential design faults, if present. Basically, every significant deviation from regular internal PD can be considered as a deviation. In this case, the root cause must be investigated.

As the measured apparent charge levels are depending on many different parameters such as the measurement set-up, measurement frequency, location of the coupler, test voltage, insulation system, and origin of the PD location within the winding, there are currently no specific no-go criteria specified. The levels given below are indicative values.

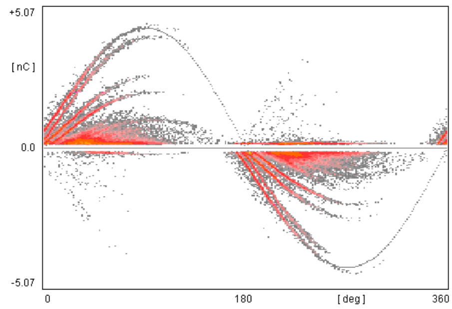
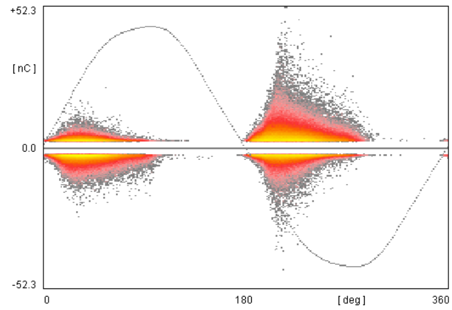
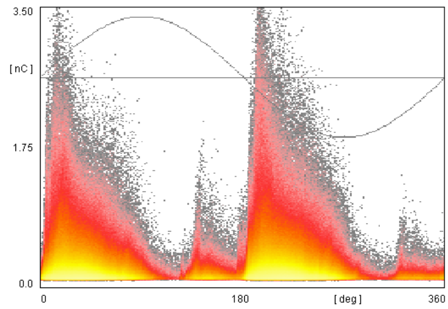
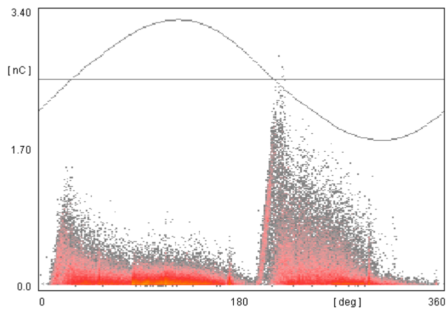
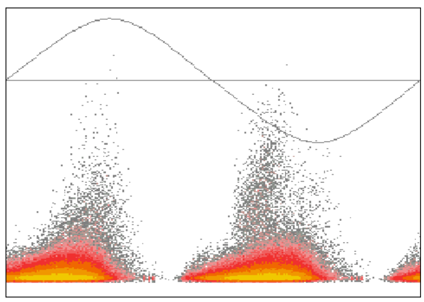
PD Phenomena	**Typical Range**	**Further Analysis Recommended**	**PD Pattern Example**
Spherical void discharge with low availability of starting electrons	0 nC	>500 pC	
Surface discharge at the slot exit the first stage of field grading problem	0–2 nC	>2 nC	
Thermally aged main insulation symmetrical in both half-cyles	<5 nC	>5 nC	
Slot discharges with machine bars non-symmetrical predominantly in the negative half-cycle	0 nC	>5 nC	
Surface discharges at the end winding	0-2 nC	>20 nC	

Table 7: Typical rotating machine patterns

Specimen	Voltage level	New	Service Aged	Comments
Stator winding	$0.2\ U_N$ U_N Tip-up per $0.2\ U_N$	$< 30 \times 10^{-3}$ $< 60 \times 10^{-3}$ $< 5 \times 10^{-3}$ @ 50 Hz	$> 30 \times 10^{-3}$ $> 80 \times 10^{-3}$ $> 5 \times 10^{-3}$ @ 50 Hz	Relevant standard: IEC 60894 Often, different tan delta levels are found between various insulation types such as global VPI and resin rich.
Single bar	$0.2\ U_N$ U_N Tip-up per $0.2\ U_N$	$< 30 \times 10^{-3}$ $< 60 \times 10^{-3}$ $2–7 \times 10^{-3}$ @ 50 Hz		Relevant standard: IEEE 286-2000 Please be aware that is only reasonable to test fully cured coils 10% of the complete set needs to be examined.

Table 8: Common TD evaluation criteria for rotating machines

VI.2.6 Normative References

TS IEC 600034-27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines

IEC 600034-27-3: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines

IEC 60894: Guide for test procedure for the measurement of loss tangent of coils and bars for machine windings

IEEE 286-2000: Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation

VI.3 Stator Bars

VI.3.1 General

The test principle for PD and Tan delta testing on separate stator bars using the ICM*flex* is very similar to testing of complete assembled stator windings. In this case, the coils are not assembled into the magnetic stator core, and, hence, an artificial core simulation should be provided in order to ground the straight part of the coils. Common materials used for applying grounding electrodes (simulated slot) are conductive adhesive tapes or copper/aluminum bars. It is important that the ground electrode has a similar the length as the real stator core. And, it is even more important to achieve and optimal contact of ground electrode material used to the slot´s semi-conductive outer layer. In case of copper/aluminum bars are used, pincers can be used to ensure the good contact. Coils can be tested completely by bridging the grounded straight parts of both coil ends, or tested partly by grounding the straight part of one coil end only. The main purpose of tan delta and tan delta tip-up testing is determining the general condition of the coil´s ground wall insulation (see section XI.1). The test results mainly show the performance of the slot's conductive outer layer, acting as the ground electrode to the magnetic core.

Generally, stator bars with rated voltage of 6 kV and more are provided of a field grading junction, consisting of a semi-conductive material, e. g. silicon carbide, at the slot-exit area. The function of grading junction is controlling the surface field at the coils slot exit proportionally to the distance remote from the core. Depending on the rated voltage, this high resistance material with non-linear resistive voltage characteristic shall have a certain length and makes an overlap with the slot's linear resistive outer layer. Mostly, the overlap between these two layers is made outside the magnetic core.

With regard to tan delta measurements, these semi conductive materials can influence the overall tan delta level, as they show a resistive loss under influence of high voltage potential. Therefore, standards such as the IEEE 286-2000 and the new upcoming IEC 60034-27-3 are defining the appliance of guard rings during the tan delta test, in order to neglect these resistive losses. Thus, when using guard rings, the aim of the tan delta measurement, i.e. checking the performance of the slot corona prevention layer, can be achieved without any influence of the results by the semi conductive materials used for the field grading. Therefore, Power Diagnostix designed the ICM*flex* GRC*,* with guard ring control. For complete windings the contribution of the resistive losses produced by the semi-conductive material in the overall tan delta level cannot be ignored, and, hence, the standard ICM*flex* can still be used.

VI.3.2 Test Setup with Standard ICM*flex*

The PD and tan delta measurement setup using standard ICM*flex* is very similar to testing of complete windings (see section VI.2.1). Instead of connecting the grounding to the motor or generators frame, it is connected to the simulated slot applied on the straight part. In case the entire coil need to be tested, both straight parts are interconnected. The high voltage output of the ICMflex must be connected to the coil´s HV-conductor circuit.

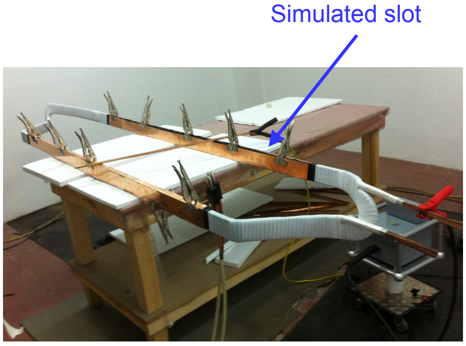


Fig. 88: PD and TD testing of resin rich bar for a small hydro generator

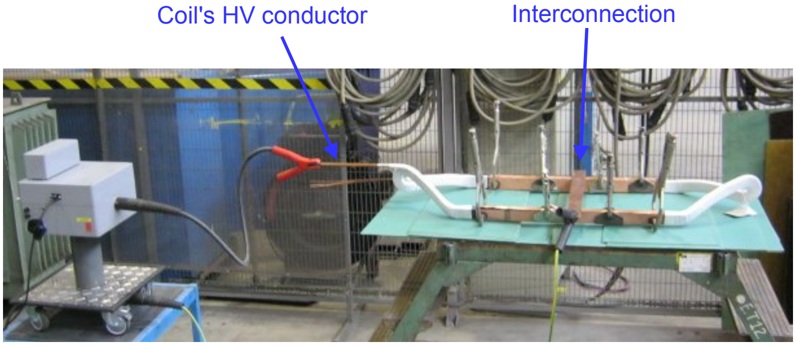


Fig. 89: Testing of resin rich bar for an asynchronous motor

VI.3.3 Test Setup with ICM*flex* GRC

Connecting the ICM*flex* GRC is slightly different from the setup as mentioned in section VI.3.2. First of all, the principle of the standard ICM*flex* is now reverted. The acquisition unit is not under high voltage potential, but on ground potential. This modification had to be done in order to be able to provide the instrument with the driven guard inputs. The HV electrode on top the of the coupling capacitor needs to be connected to the coils high voltage conductor, the simulated slot to the C_{SX} input, and, finally, the main ground of the HV transformer to main grounding point of the ICM*flex* GRC.

Caution: The test specimen may not touch the floor! To avoid damage of the ICM*flex* GRC, the specimen shall be placed on an isolation mat or must be in hanging position during test.

Secondly, the guard rings need to be applied to the coils. As preferred material for the guard rings, we recommend using copper or aluminum conductive adhesive tape. The guard rings need to be applied fully on the semi-conductive tape (grey tape or paint) and may not overlap with the slot´s conductive outer layer (black tape or paint). The ideal position for the guard ring is between 5 mm and 1 cm remote from the beginning of the field grading junction, viewed from the straight part. The contact resistance from to guard ring to coil surface of straight part is here very low, and, hence, the guard ring shall successfully intercept currents flowing from the semi-conductive layer into the direction of the straight part.

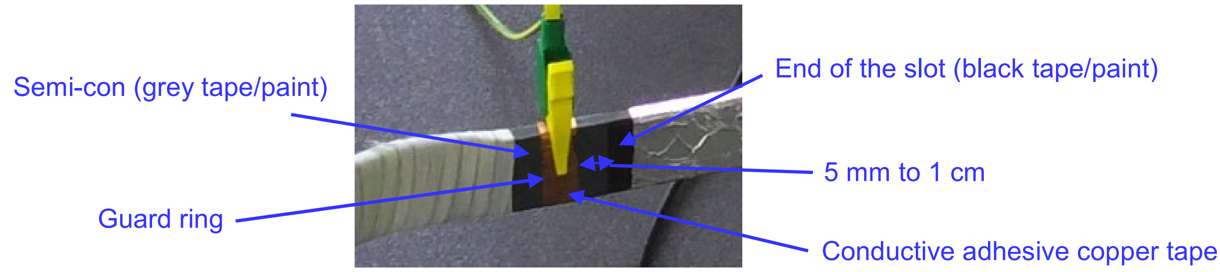


Fig. 90: Guard ring application

Once the guard rings are applied, alligator clamps can be used to connect both guard rings to the guard inputs of the ICM*flex* GRC. In case the complete bar should be tested, the guard rings opposite to each other can be interconnected.

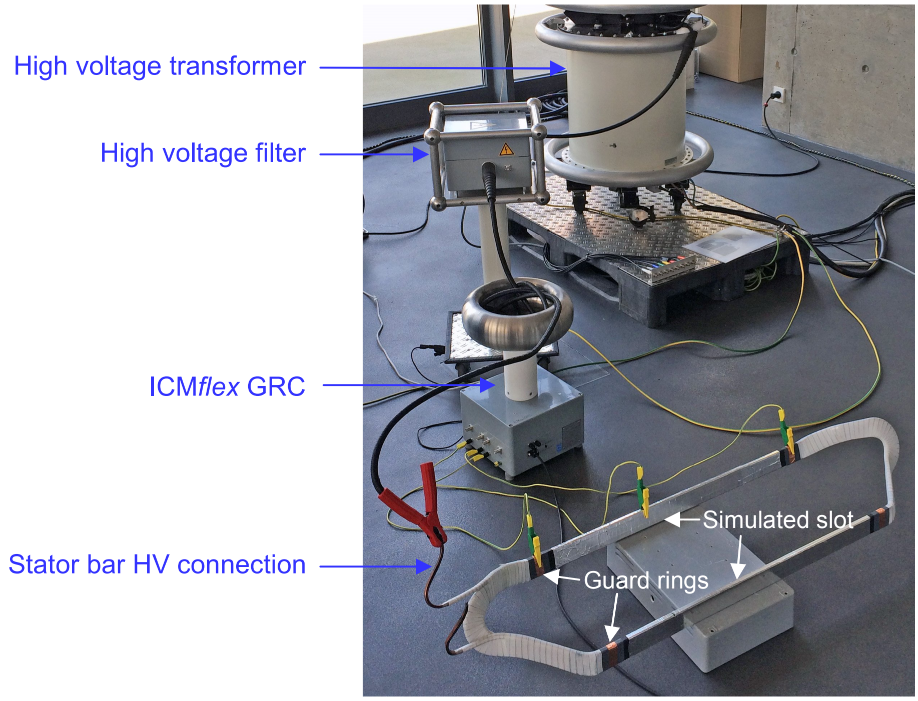


Fig. 91: Test setup with ICM*flex* GRC

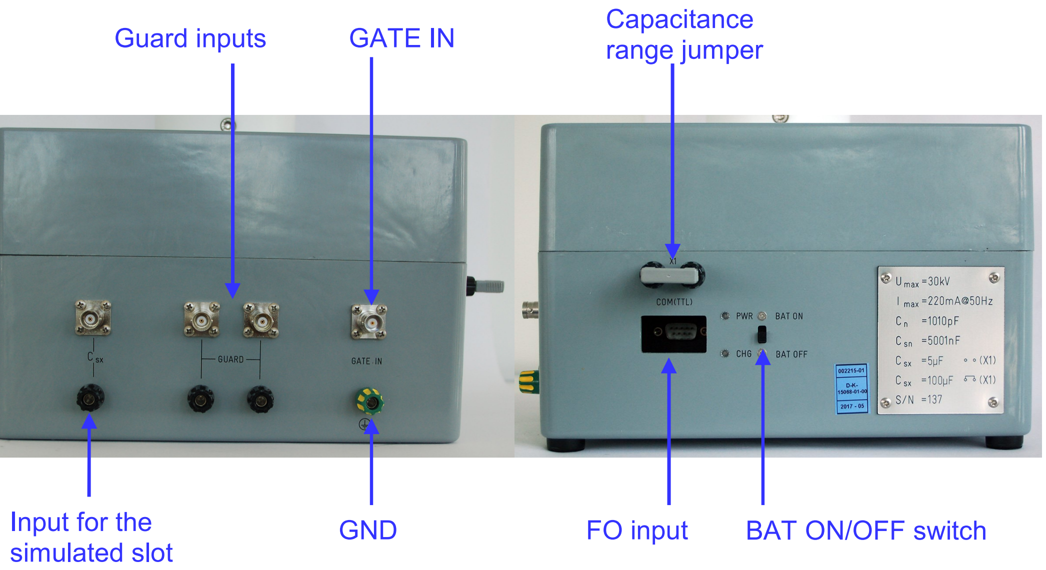


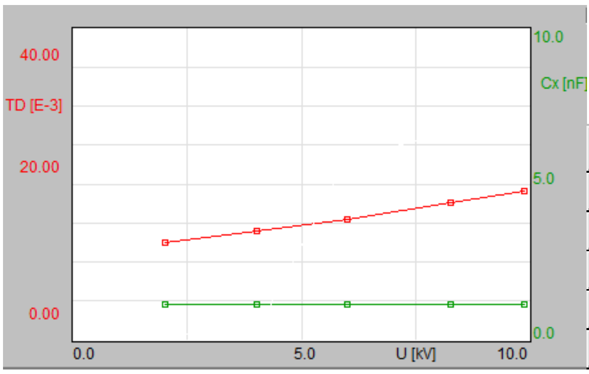
Fig. 92: Connectors of the ICM*flex* GRC

VI.3.4 PD Calibration

In general, the calibration procedure for the PD measurement is similar to what is described in section VI.2.2. Since the test circuit of a single bar has a fairly low capacitance, the required calibration charge can be selected to a lower magnitude compared to fully assembled stator windings. Common charge levels are in the range of 100 pC to 500 pC. The PD calibrator should be connected between the HV conductor circuit of the coil and the simulated slot (GND clamp).

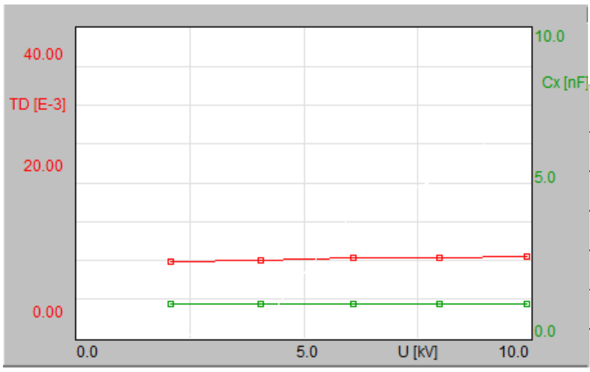
VI.3.5 PD and Tan Delta Measurement

The measurement procedure is similar as is described in section VI.2.3 for testing of complete windings. Depending on the applicable standard (see section VI.3.7), the procedure and levels for voltage application might be different. In the examples below, tan delta measurement results are shown of a 10 kV resin rich bar without guard rings and with guard rings applied. Besides the results in strip charts, the tendency of the tan delta graph versus voltage clearly shows the effect of the resistive losses of the semi-conductive layer.



	U [kV]	tanD	D(tanD)	Cx [nF]	Qp [pC]
1	2.02	1.25E-02	N/A	1.116	10.8
2	4.03	1.39E-02	1.38E-03	1.119	29.0
3	6.01	1.54E-02	1.49E-03	1.121	581
4	8.28	1.76E-02	2.20E-03	1.124	667
5	9.90	1.91E-02	1.48E-03	1.126	720

Fig. 93: Tan delta measurement without guard rings



	U [kV]	tanD	D(tanD)	Cx [nF]	Qp [pC]
1	2.07	9.86E-03	N/A	1.085	0.00
2	2.08	9.84E-03	-2.33E-05	1.085	0.00
3	4.05	1.00E-02	1.96E-04	1.086	38.7
4	6.08	1.02E-02	1.80E-04	1.085	403
5	7.98	1.04E-02	1.36E-04	1.085	516
6	9.90	1.05E-02	1.54E-04	1.085	731

Fig. 94: Tan delta measurement with guard rings

VI.3.6 Typical Patterns and Tan Delta Levels

The partial discharge patterns are very similar to the ones given for rotating machines in VI.2.5. However, for the tan delta measurement, different criteria are applicable. Common levels are specified in the table mentioned below. In contrast to testing of complete windings, both IEC and IEEE have specified evaluation criteria for the tan delta measurements on single stator bars.

Currently, these criteria are only valid for resin rich insulation systems and not yet for vacuum pressure impregnated systems. Once, the IEC 60034-27-3 is released, it is expected that generalized criteria shall be defined for both resin rich and VPI systems.

For the partial discharge measurement, no criteria are given. According to measurement experiences in the past, regular levels for internal PD in well performed new bars are varying from <100 pC up to 500 pC. When testing a batch of coils, it is specified that up to 10% of the complete set must be tested. The intention is to compare the results and check the conformity. This procedure allows defining average levels per coil type, and, hence, any deviations in the sample testing can point problems with the particular bar.

Specimen	Voltage level	New	Service Aged	Comments
Single bar	$0.2\ U_N$ U_N Tip-up per $0.2\ U_N$	$< 30 \times 10^{-3}$ $< 60 \times 10^{-3}$ $2–7 \times 10^{-3}$ @ 50 Hz		Relevant standard: IEEE 286-2000 Please be aware that is only reasonable to test fully cured coils 10% of the complete set needs to be examined.

Table 9: Common TD evaluation criteria for stator bars

VI.3.7 Normative References

IEEE 286-2000: IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation

IEC 600034-27-3*: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines

IEC 60894: Guide for test procedure for the measurement of loss tangent of coils and bars for machine windings

* *Under preparation*

VII Options

VII.1 Guard Ring Control (GRC)

Fig. 95: IMC*flex* GRC

In order to meet with the requirements of the existing IEEE 286-2000 and the new upcoming IEC 60034 27 3 standard for dielectric dissipation factor testing (also known as tan testing) on rotating machine stator bars, Power Diagnostix made a re-design of the existing ICM*flex*, i. e. the ICM*flex* GRC "Guard Ring Control". Both standards mentioned above define that tan delta testing on stator bars should be performed using guard rings in order to neglect the resistive losses of the semi-conductive layer.

The guard ring control option provides two driven guard inputs on the ICM*flex'*s acquisition unit. The internal voltage follower circuit keeps the surface potential of the semi-conductive layer equal to the surface potential of the simulated slot. As a consequence, leakage currents created by resistive losses in the semi-conductive layer flowing from the semi conductive layer into the direction of the straight part shall be intercepted, and, thus not contribute to the measurement results.

The ICM*flex* GRC is optimized for the capacitance range of stator bars and for smaller asynchronous induction motors up to Roebel bars for larger synchronous turbo generators. Furthermore, the embedded voltage divider for up to 30 kV_{RMS} comes with a DAkkS (former DKD) calibration certificate.

The general principle of operation is similar to that of the regular ICM*flex*. It still combines both the PD and Tan delta measurement simultaneously, and, hence, the operational software for the ICM*flex* GRC is the same. The main difference with the standard unit is, that the acquisition unit is on low voltage potential allowing embedding guard rings. Additionally, the battery is now embedded. Beside operating on the battery voltage, the instrument can now be operated using line supply as well.

VII.2 Additional PD Input for Noise Cancellation (ICM*flex*2)

An ICMflex2 offers the possibility to separate pulses coming from the test object and pulses coming from the test voltage source by their polarity. The instrument has a second PD input for PD pulses coming from a quadrupole that is built into the HV filter. Another quadrupole is in the path of the coupling capacitor, the same position as in the standard ICM*flex*. With this configuration pulses that are coming from the test object have similar polarity, while pulses coming from the test voltage source have opposite polarity (see figure 98). The acquisition unit analyses the polarity of each pulse and sorts it either in a PD pattern or in a disturbance pattern.

Fig. 96: Additional input for noise cancellation 'PD2 IN'

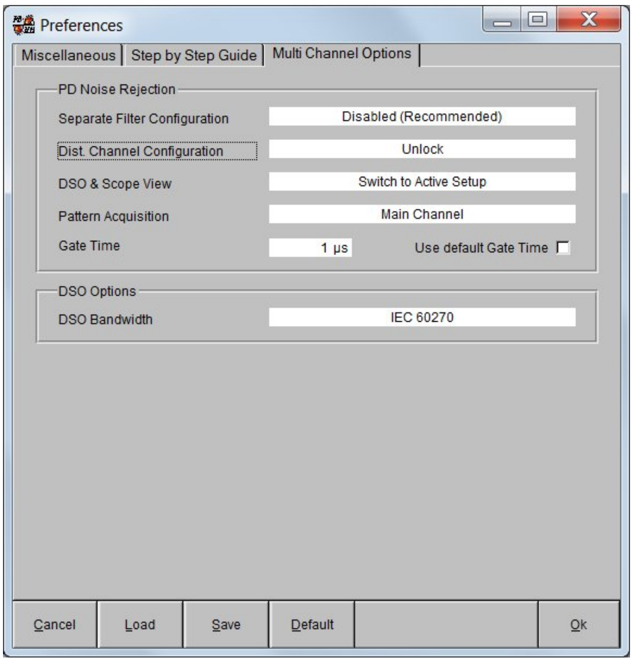


Fig. 97: Multi-channel options

With an additional PD input there are some more options selectable within the preferences panel of the ICM*flex* software. The user can determine if different filter configurations should be used for the main and the auxiliary channel (not recommended) and if these two channels should use the same configuration or not. 'DSO & Scope View' determines the behavior of the software when changing the channel during acquisition, while 'Pattern Acquisition' shows, which channel is used for the acquisition of a PD pattern. Furthermore, it's possible to change the gating time or to set it to the default value of 10 µs.

The 'DSO Bandwidth' can be switched to 'IEC 60270'. To have a good time resolution for fault location DSO usually works with an extended bandwidth of 20 MHz.

To analyze the polarity each pulse must be acquired separately. The acquisition gets triggered when one of both channels exceeds the low level discriminator (LLD). At this moment the deadtime starts and at its end the positive and negative peak amplitudes of both channels get A/D converted. To get a good pulse separation both values must be set very carefully. It would be optimal to put the LLD higher than the noise flour, but in order to see the noise flour in the acquisition pattern the LLD can also be set that kind, that it triggers only the highest noise pulses. If the LLD is set too low, the acquisition triggers too often and not by the PD pulses. The deadtime must be set to the length of the pulse oscillation. If it is set too short, the pulse is not finished and can trigger double. If it is set too long, it's most likely, that a second pulse come within the deadtime, and the lower one gets discriminated.

Depending on the ICM*flex*2 installation the two quadrupoles might have different sensitivity. In this case the PD gain must be set separately for the two channels. To compare the sensitivity the user can switch to the auxiliary channel during calibration and set the gain to a value that the calibrator pulse amplitude is similar to that of the main channel. The LLD can also be set individually for each channel. To get equal pulse properties on both channels, their highpass and lowpass settings should be equal. For that purpose, the separate filter configuration can be disabled in the multi-channel options of the preferences (see figure 97).

The ICM*flex*2 functions can be used with the two right-hand side screens in the PD and LOC display of the ICM*flex* software. Three additional settings are available with these displays:

Channel: For toggling between the main and the auxiliary channel in the screen on the upper right-hand side.

Rejection: Offers three different modes of noise cancellation ('First Pol.', 'Peak Pol.', and 'F&P Pol.')

Dead Time: Time during which a signal is converted and which is reserved to a single pulse. The A/D converter does not convert or accept another signal during that time, so that another pulse occurring within the dead time is lost.

In general, there are two different methods of pulse polarity detection. The first method is to decide at what polarity the LLD is exceeded first (First Pol.). The second method is to compare the peak amplitude of both polarities at the end of the deadtime (Peak Pol.). Additionally, the ICM*flex*2 offers an AND combination of both methods (F&P Pol.). The effectivity of these methods is depending on the repetition rate and the amplitude ratio of the two pulse sources. If there is a high repetition rate, the 'First Pol.' method has a problem if a large disturbance pulse follows a smaller PD pulse. If the amplitude of both pulse sources is very different, the 'Peak Pol.' method has a problem, if one pulse is overranged in both polarities because the peak amplitudes cannot be compared. Several examples of pulse polarity detection cases are shown with figures 100 to 103.

The calibration and PD measurement is usually done with the main channel. If 'Switch to Active Setup' is selected for 'DSO & Scope View' within the preferences (see figure 97), the corresponding screens of the PD and LOC display can also show the auxiliary channel. But there is no calibration possible, the amplitude is shown in percent. For the upper right-hand screen it is possible to choose, if the scope view displays the acquisition pattern or the disturbance pattern. The lower right-hand screen always shows the acquisition pattern.

To view the shape of the pulses used for the pattern choose 'IEC 60270' for 'DSO Bandwidth' in the multi-channel options of the preferences (see figure 97). In IEC 60270 mode the DSO shows the filtered signal used for the pattern and the polarity decision. In this mode only the PD gain is relevant.

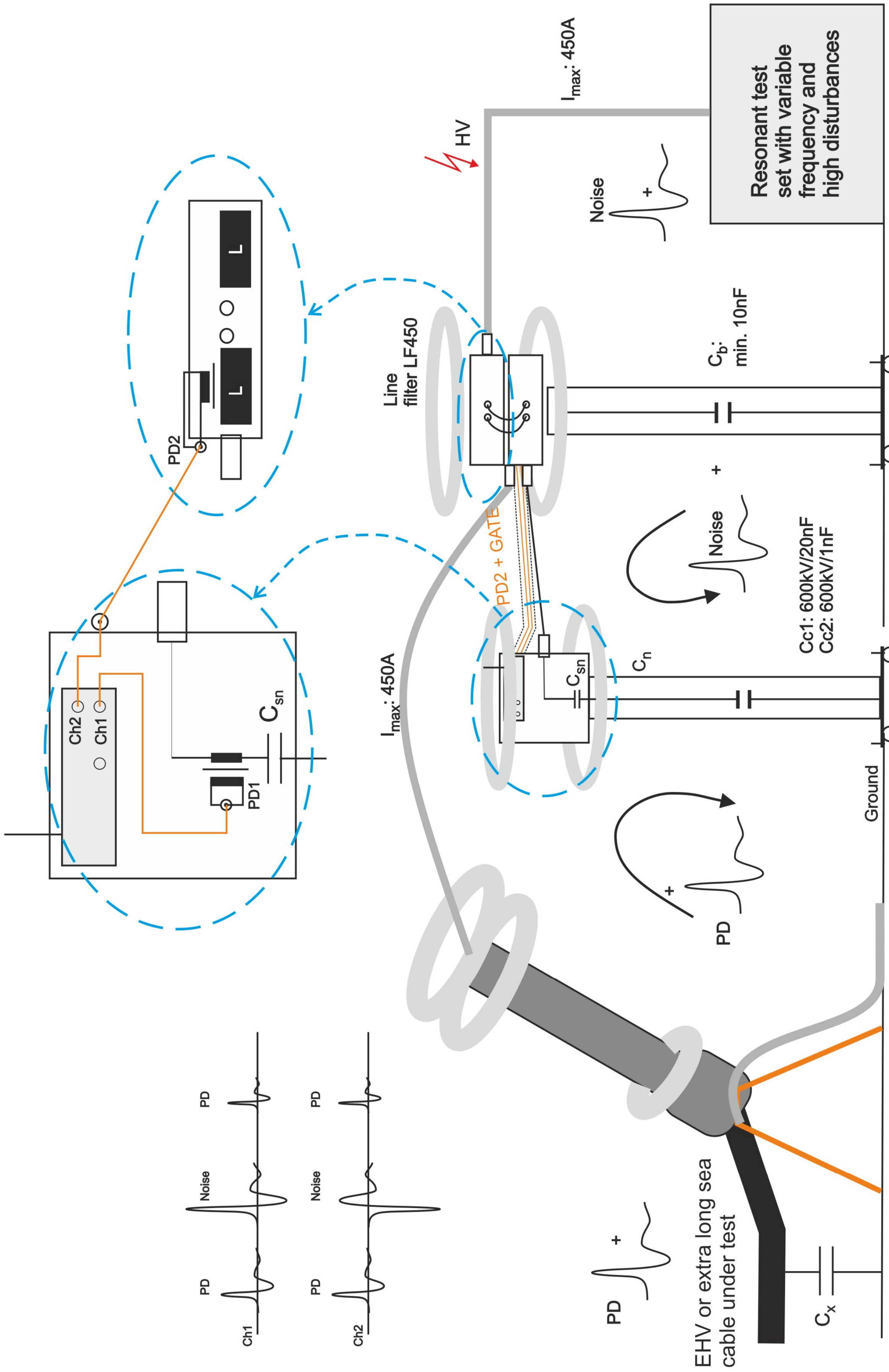


Fig. 98: General connection diagram for ICM*flex*2

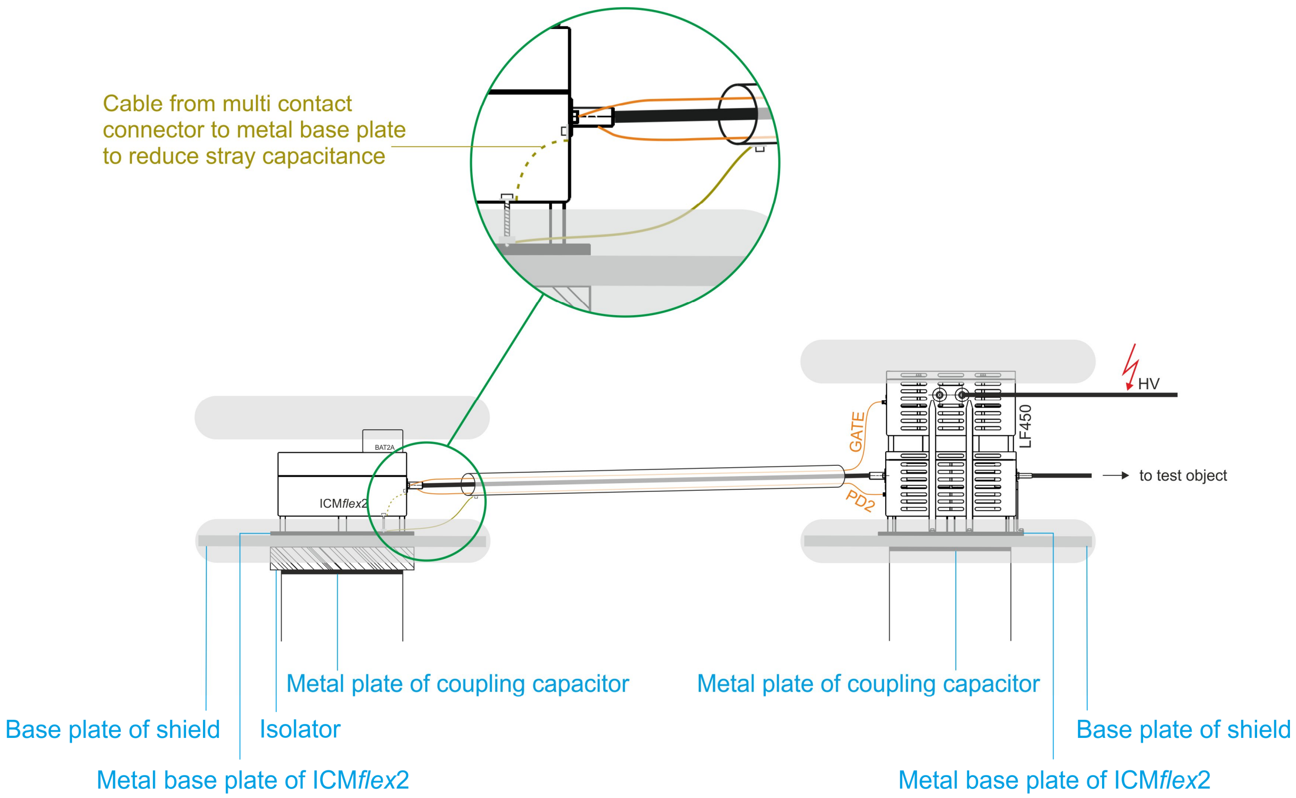


Fig. 99: ICM*flex*2 and line filter LF450 installed on an external coupling capacitor

- Polarity of first exceeding the LLD
- Polarity of maximum pulse amplitude
- Sampled peak values
- Peak hold

Pulse from Test Object

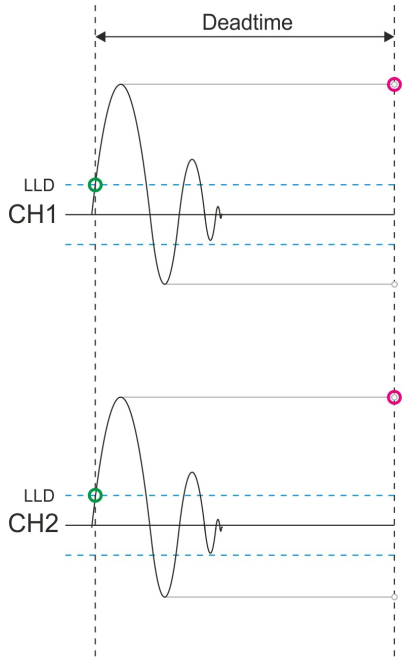


Fig. 100: and have positive polarity on both channels
=> 'First Pol.' and 'Peak Pol.' have the same result

Pulse from Test Voltage Source

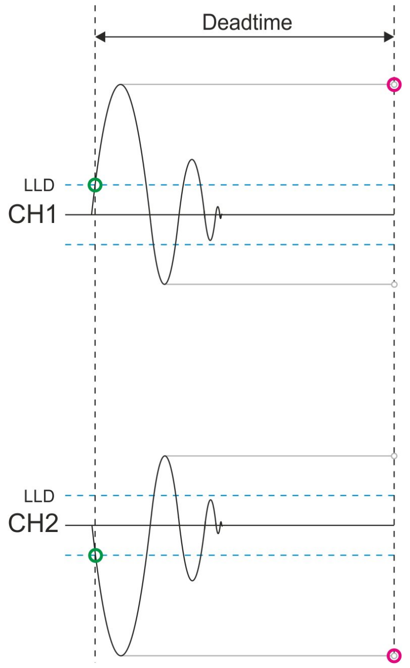


Fig. 101: positive polarity on channel 1, negative polarity on channel 2; positive polarity on channel 1, negative polarity on channel 2
=> 'First Pol.' and 'Peak Pol.' have the same result

Pulse from Test Object Followed by Larger Pulse from Test Voltage Source within Deadtime

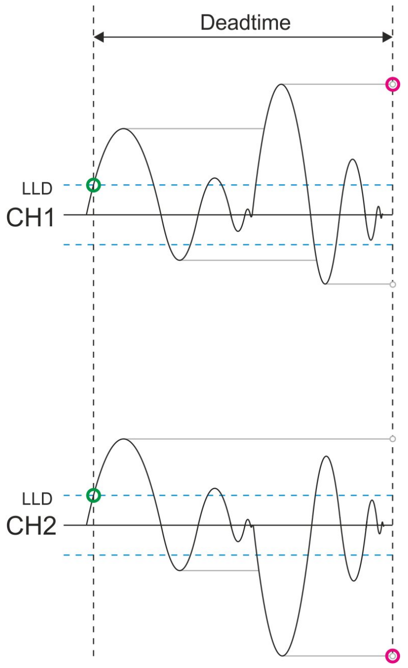


Fig. 102: positive polarity on both channels; positive polarity on channel 1, negative polarity on channel 2
=> Only 'Peak Pol.' result is correct: Pulse gets sorted to disturbance pattern

Pulse from Test Object with too high Amplitude (Clipping on both Polarities

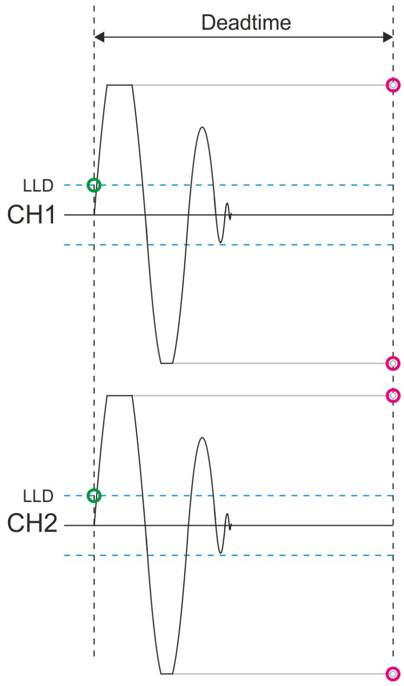


Fig. 103: positive polarity on both channels; no decision possible,
=> only 'First Pol.' result is correct: Pulse gets sorted into disturbance pattern

VII.3 Gating

An effective noise reduction is required in case that the ICM*flex* is used for measurements in an environment with high frequency (HF) disturbance. HF disturbances, which hamper partial discharge detection and which can be handled by the gating function, are, for instance, frequency converter switching pulses, corona discharge, or thyristor firing, whose signals are picked up by an antenna or another sensor. Using the analog gating function blinds out such impulse noise. With some applications a current transformer is used to acquire the disturbance signal from a ground conductor or from the screen of a signal cable. Electronic controlled resonant test sets provide a TTL signal for switching activities (see also section V.8).

The different signals and gating methods explained below can be used simultaneously.

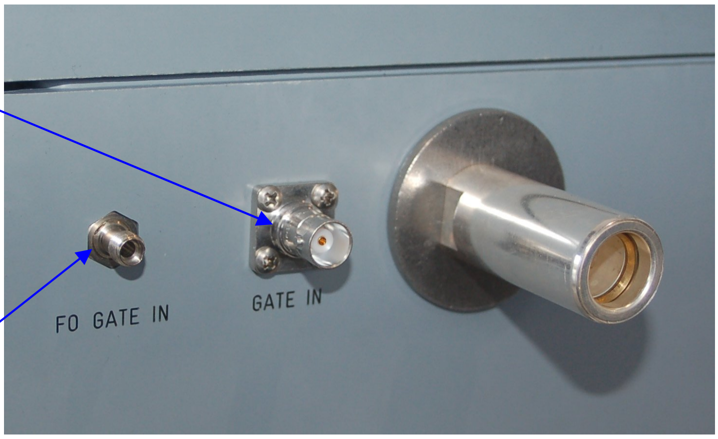


Fig. 104: Gating inputs

VII.3.1 Standard Analog Gating

An ICM*flex* with a standard gating function comes with a terminal for a BNC cable that transmits a gating signal from an HV filter with a built-in current transformer (CT). The gate level is set by using the ICM*flex* software (see section V.5.1). This option is mainly used for VLF cable testing.

VII.3.2 Gating via Fiber Optic Link (FO Gating)

An ICM*flex* with a gating function comes with an additional terminal for a fiber optic (FO) cable, which takes over a signal on HV potential provided by a gating signal transmitter (GST1). The transmitter is included in the delivery range if FO gating is ordered. An external signal sensor (e. g. CT1) is connected via a BNC cable to the 'GATE IN' terminal of the GST1.

If disturbances like switching of a relay or thyristor firing have a known source, it might be possible to create a TTL signal prior to the disturbance. This signal can be used to blind out the PD measurement path. If a TTL signal is available, it can be provided to the GST1 via a BNC cable that is connected to the "TTL IN' terminal.

VII.4 Bypass

If the test object's capacitance is too high, an ICM*flex* for tan δ measurements can be fitted with a C_x bypass to avoid overstressing of the shunt capacitor. With an active bypass loss factor measurements are disabled but PD diagnostic is still possible.

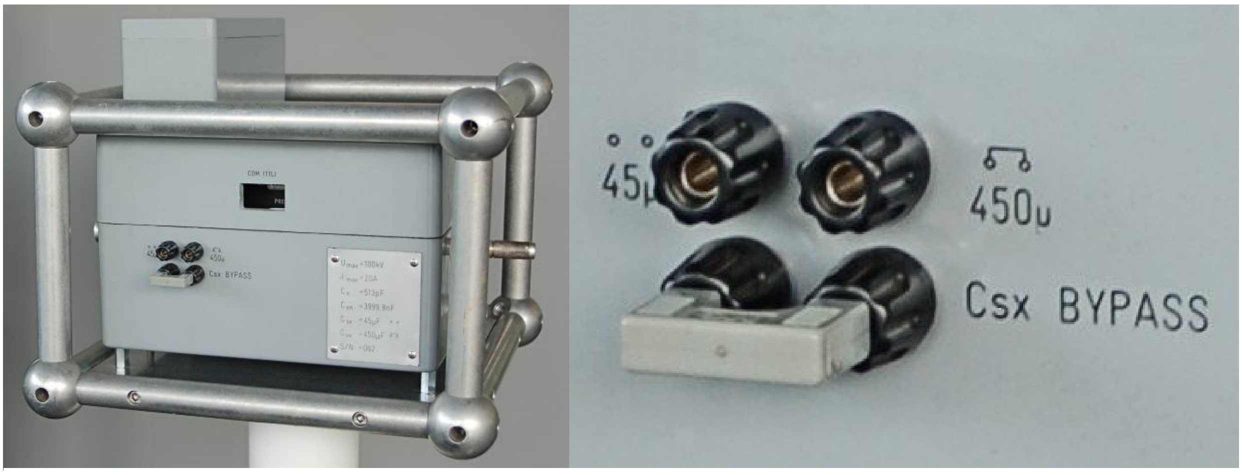


Fig. 105: Jumper in bypass mode

VII.5 Built-in RPA1L

For applications with high requirements in sensitivity the ICM*flex* can be equipped with a built-in preamplifier (RPA1L), which reduces the instruments input sensitivity to 15 µV. It has a switchable pre-gain of 1, 10 and 100. The ICM*flex* with preamplifier has an extended gain list (4 to 80000). From 4 to 100 the pre-gain is 1, from 200 to 1000 the pre-gain is 10, and from 2000 to 80000 the pre-gain is 100. The range of the DSO gain is also influenced by the pre-gain, the total DSO gain can't be lower than the pre-gain.

If there is no correct connection or a short circuit in the cable from the ICM*flex* to the RPA1L, the software shows a warning by filling the background of the 'PD Gain' setting with a red color.

If an ICM*flex*2 is equipped with a built-in preamplifier, a second RPA1L is needed to be installed as close as possible to the quadrupole in the HV filter.

Fig. 106: Extended gain list

VII.6 External Battery Adapter

Power Diagnostix offers an external battery adapter for connecting larger batteries to the instrument, instead of using the standard ICM*flex* battery BAT2A.

VIII Miscellaneous

VIII.1 Maintenance

The ICM*flex* does not require any maintenance on a regular basis. There is no fine adjustment on a regular basis required, as the partial discharge measurement is a relative measurement that is calibrated with a reference source (charge calibrator, CAL series) prior to a measurement. The instrument receives high frequency PD signals and quotes them with a certain pC level based on the calibration made prior to the testing. In case of daily usage, it is recommended to calibrate the impulse generator on an annual basis to ensure that its output signal remains within the recommended boundaries. The only part of the instrument that requires calibration is voltage measurement. The voltage calibration is also recommended to be calibrated on yearly base, unless the calibration policy of the customer defines a different time interval.

Care should be taken that the instrument stays clean. Any conductive contamination on the corona cage, and mainly on the connection of the reference capacitor to the corona cage might result into leakage current, which can influence the tan delta measurement results.

VIII.2 Transporting and Shipment Instructions

Generally, we recommend transporting the high voltage filter and the ICM*flex* in vertical direction in order to prevent problems with the HV and GND connections of the reference capacitor of the ICM*flex* and the damping capacitor of the T-filter.

In case a unit needs to be returned to the factory, make sure the acquisition unit is packed safely. Please use the provided boxes for the shipment. As the units are relatively large, shipment by a forwarding agent is the recommended mode of transportation. If possible, declare the instrument as 'used instruments for evaluation' at a relative low value. Consult Power Diagnostix for further details. Additionally, Power Diagnostix may provide you with a temporary replacement unit, in case of urgent needs.

VIII.3 Declaration of Conformity

Power Diagnostix Systems GmbH
Vaalser Strasse 250
52074 Aachen
Germany

declares, that the instrument as specified below, meets the requirements of the standards and/or normative documents as listed below.

Subsequently the instrument complies with the requirements of the EMC directive 2004/108/EC.

Product:	ICM*flex*	
Description:	Partial discharge detector for use in high voltage test areas	
Standards:	EN 61000-6-1,	EN 61000-6-2
	EN 61000-6-3,	EN 61000-6-4
	EN 61010-1,	2006/95/EC
Date:		

Markus Söller (Managing Director)

Remark: Since the measurement of partial discharge pulses is done in frequency bands partly occupied by radio transmission, and since further test leads may act as antennas, disturbance free measurements may require well shielded environments and/or additional filter techniques.

IX Technical Data (Standard Version)

Mains supply:	Battery operated	
Power requirements:	Approx. 20 VA	
Operation:	Remote controlled via ICM*flex* software	
PD input impedance:	10 kΩ // 50 pF	
PD input sensitivity: (without test object)	< 150 µV, corresponds to 0.2 pC < 15 µV, corresponds to 0.02 pC	(without built-in preamplifier) (with built-in preamplifier)
PD lower cut-off (-6 dB):	40, 80 or 100 kHz	(software controlled)
PD upper cut-off (-6 dB):	250, 600 or 800 kHz	(software controlled)
PD A/D converter:	8 bit (±7 bit)	
PD location (TDR):	8 bit, 100 MS	
Specimen cable length:	10 to 25000 m, for a sample rate of 320 µs & v_c = 160 m/µs	
Localization precision:	1 m + 0.1% of the cable length	
Voltage measurement:	16 bit, 100 MS	
Voltage values displayed:	U_{RMS} value, Û/√2 value, crest factor	
Tan delta resolution:	5×10^{-5}	
Tan delta precision:	1×10^{-4}	
Synchronization:	External on reference voltage	
Synchronization range:	20 Hz–510 Hz 0.1 Hz, 0.05 Hz, 0.02 Hz	(normal mode) (VLF)
Operation temperature:	0–55°C	(non-condensing)
Interfaces:	Bluetooth Fiber optic serial link	(921 kBit/s) (921 kBit/s)

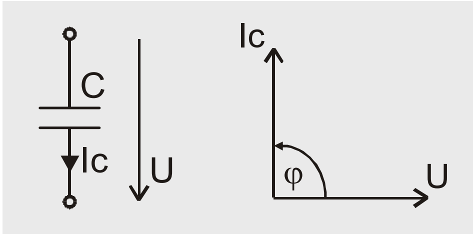
X Weight and Dimensions

Type	Rated Voltage Ur (RMS)	Max. Weight kg	Height mm	Width mm	Length mm	Comment
Measurement System						
ICM*flex*	30 kV	15	600	350	350	
ICM*flex*	50 kV	40	800	350	350	
ICM*flex*	100 kV	45	910	350	350	
ICM*flex*	150 kV	50	1440	350	350	
ICM*flex*	>200 kV		-	-	-	To be installed on separate HV reference capacitor of min. 1 nF.
ICM*flex*2	>200 kV		220	365	350	To be installed on separate HV reference capacitor of min. 1 nF.
Filter Unit						
T30	30 kV	33	610	350	350	
T50	50 kV	40	800	350	350	
T100	100 kV	53	985	350	350	
T150	150 kV	65	1200	350	350	
LF450	-	130	512	450	450	To be installed on separate HV blocking capacitors of min. 10 nF.

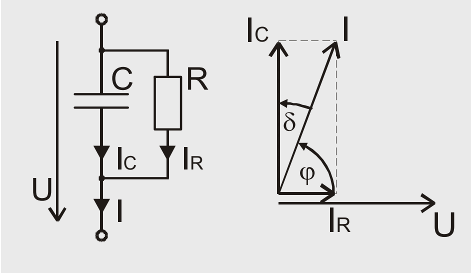
XI Appendix

XI.1 What is the Loss Factor (or Dissipation Factor) tan δ?

Building high voltage equipment requires using insulation material. Commonly used insulation materials show losses due to resistive currents or polarization currents of dipoles. Often, the magnitude of these losses can be used as an indicator for the quality of the insulation. Especially, in case of assessing the quality of aged insulation, increased dissipation indicates oil or paper decomposition (transformers), humidity, electro-chemical processes (water-trees in polymeric cables), or, for instance, heavy partial discharge.



With an ideal capacitor (C), the resistance of the insulation material (dielectric) is infinitely large. When an AC voltage (U) is applied, the current (I_C) leads the voltage by exactly φ = 90°. A component close to this ideal capacitor with a negligible resistance should be used as standard (or reference) capacitor for the reference branch of a dielectric loss analyzer.



Technical insulation systems are usually built of less perfect insulation material resulting in a small current (IR) in phase to the supplied voltage (U). This current can be described by a parallel resistor (R) to an ideal capacitor (C). The phase difference between the real current (I) and the ideal current (IC) can be described as phase angle: 'δ'.

Because P = Q · tan δ, the losses which are proportional to tan δ, will usually be given as a value of tan δ to express the quality of an insulation material. Therefore, the angle δ is described as loss angle and tan δ as loss factor.

<u>Loss factor (Dissipation factor)</u>

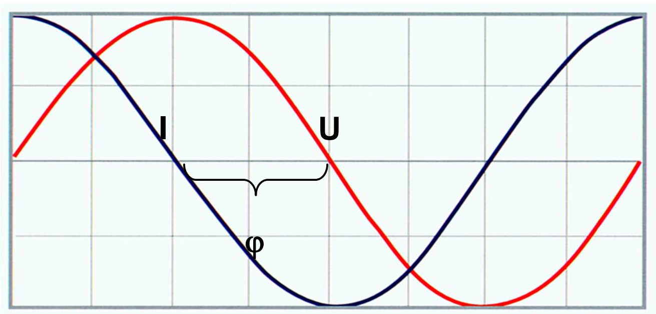
$$\tan\delta = \frac{I_R}{I_C} = \frac{P}{Q} = \frac{1}{\omega \cdot C \cdot R}$$

<u>Quality Factor</u>

$$QF = \frac{1}{\tan\delta} = \frac{I_C}{I_R} = \frac{Q}{P} = \omega \cdot C \cdot R$$

<u>Power Factor</u>

$$PF = \cos\varphi = \frac{I_R}{I}$$



With a good insulation of low-loss capacitors (δ ~ 0° and φ ~90°), the ideal current 'IC' is approximately equal to the real current 'I'; resulting in a negligible deviation of the values tan δ and cos φ. In Europe, the dissipation factor tan δ is mostly used to describe the dielectric losses, while in North America the Power factor (PF = cos φ) is commonly used. The software of the ICM*flex* displays both values together with the calculated capacitance, the voltages, and the frequency.

XI.2 Troubleshooting

The personal computer cannot find the ICM*flex*

If no communication between the ICM*flex* and the software can be established, please reboot the control computer and check

- if all necessary drivers are installed properly (see section IV.2 and IV.3)
- if the battery is charged.
  In order to do so, measure the DC voltage when trying to establish a connection to the ICM*flex*. Therefor, connect the battery to the ICM*flex* as shown with figure 107 (please check the polarity first). If the voltage is 10.5 Volts or even less, the battery has to be recharged. If the voltage drops down even after charging for at least six hours, the battery is faulty.

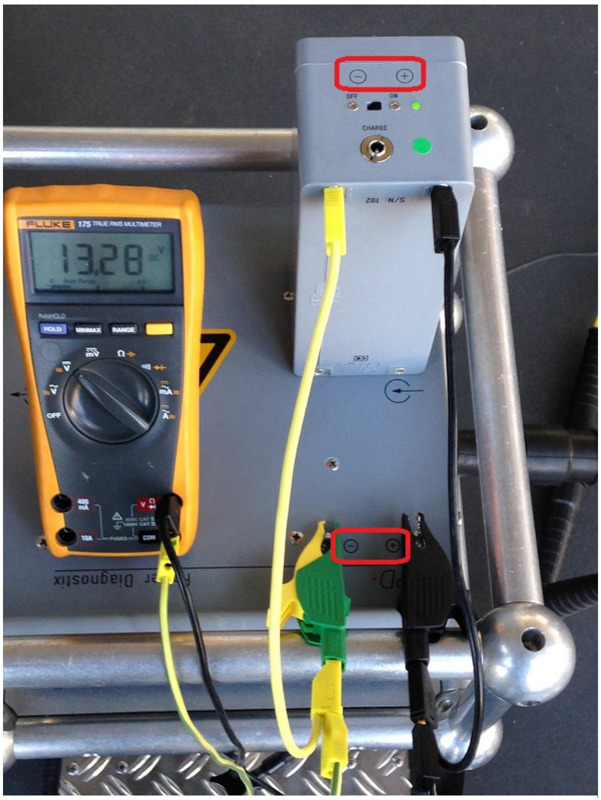


Fig. 107: Testing the voltage level of the battery

The ICM*flex* application window appears very small on high resolution monitors und Windows 10.

On PCs running Windows 10 with the Creator's Update of 2017 the ICM*flex* application window may appear very small on high resolution monitors. To enlarge the display size of the software, please take the following steps:

1. Right-click on the application short cut on the desktop.
2. Choose "Properties" from the context menu, which will open the Properties window.
3. Enable "Override high DPI scaling behaviour" and set "Scaling performed by" to "System" on the "Compatibility" tab.
4. If you have administrator rights, you can change the settings for all users by clicking the corresponding button.
5. Approve the change by clicking "OK".

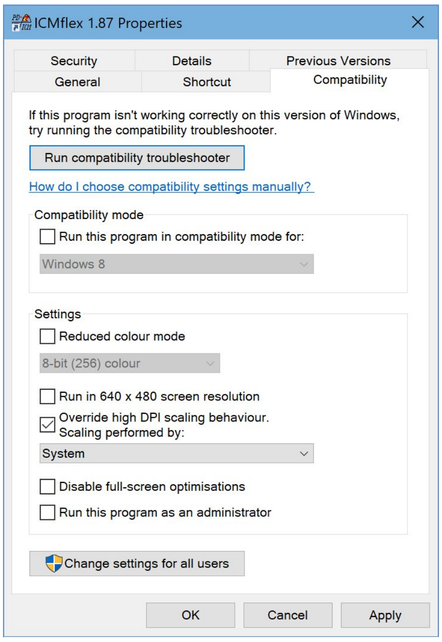


Fig. 108: Properties window

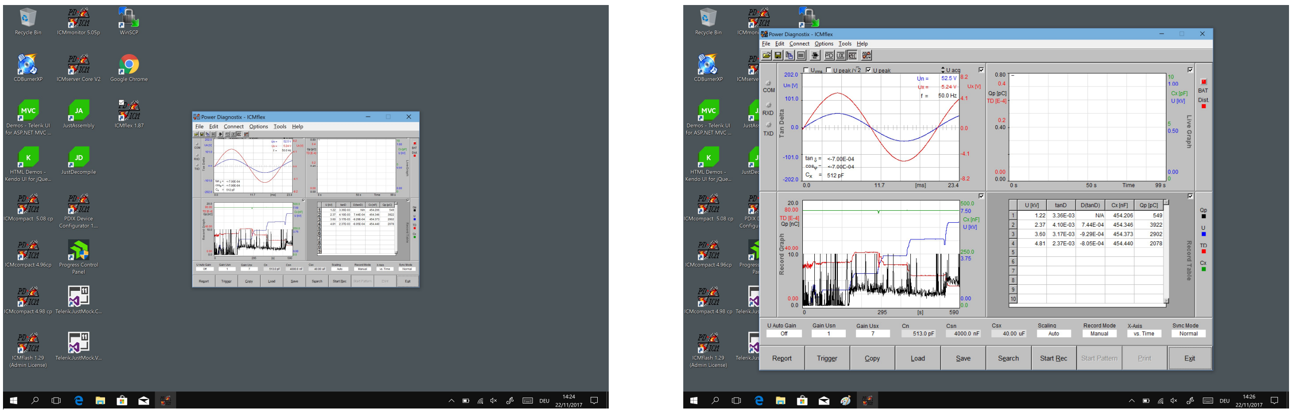


Fig. 109: Desktop before and after change of scaling behavior