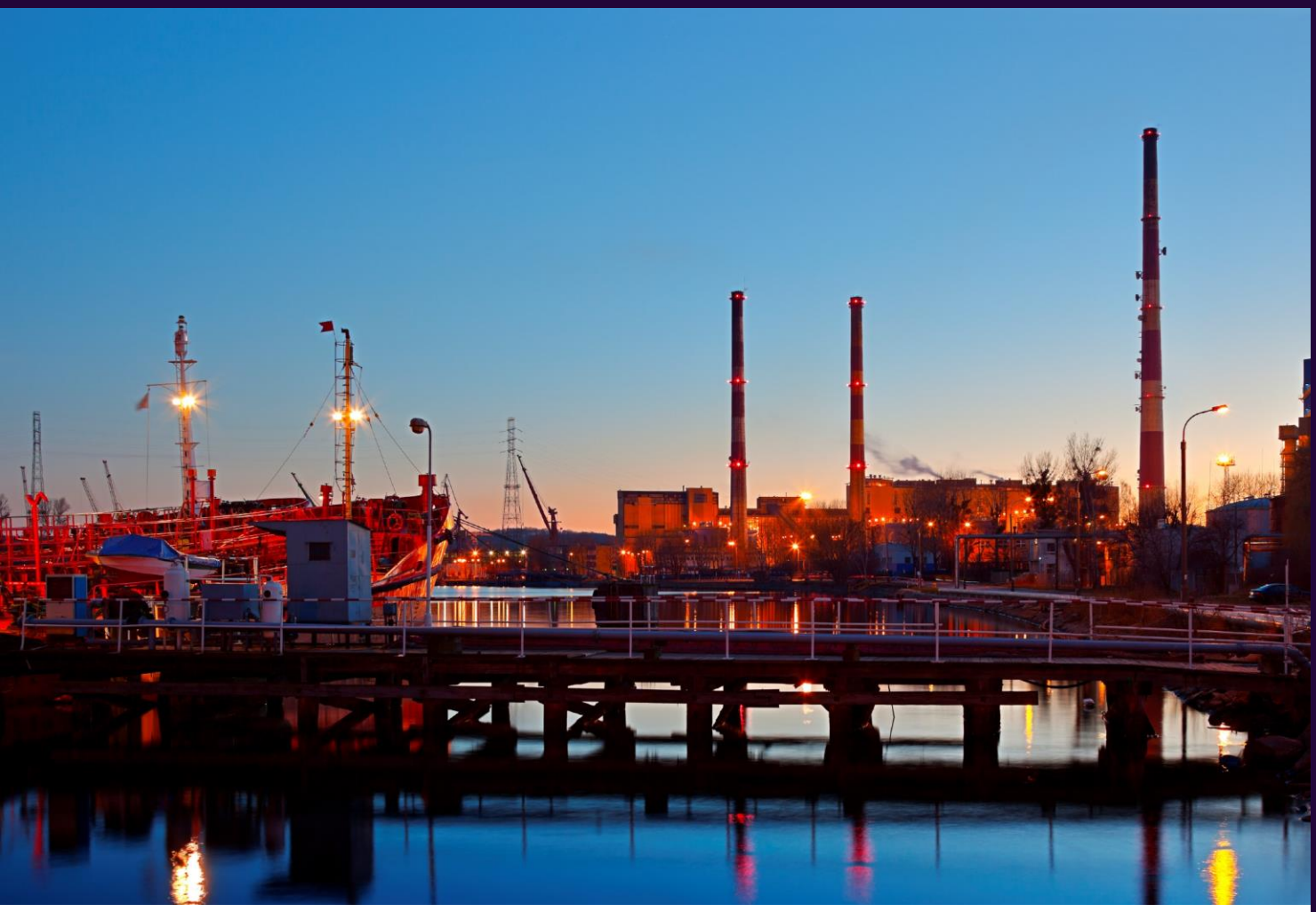

REPORT

Customer Guidance Document: Use of Internal Partial Discharge Sensors

4026-REPRT-S001-V01.00.00

June 2024

technology

Summary

This document is intended for customers wishing to install partial discharge sensors within HV switchgear. It provides guidance to ensure Health and Safety risks have been considered and appropriate mitigation is recommended.

This document sets forth the recommended minimum requirements for safe installation of partial discharge sensors. This document does not replace nor supersede local or national safety laws, rules and regulations nor your company safety practices, all of which must be observed during installation. In the event of any conflict with those requirements, the safer practice is to be applied. EA Technology provides these requirements as an aid to the customer. EA Technology expressly disclaims any and all liability for the safety of the installation, which remains the sole responsibility of the qualified safety personnel of the customer staff and any Authority having jurisdiction.

Version History

Date	Version	Author(s)	Notes
June 2024	01.00.00	Will Platts	First version, adapted from "Customer Guidance Document: Installation of RFCTs Issue 1"

Final Approval

Date	Version	Name	Signature
26/06/2024	01.00.00	Robert Burns	

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Appendices

1. Background

This document is intended for customers wishing to install partial discharge sensors within HV switchgear. It provides guidance to ensure Health and Safety risks have been considered and appropriate mitigation is recommended.

2. Pre-installation audit

It is recommended the customers complete a site and switchgear assessment to ensure a suitable technical and safe installation is viable and assess the potential risk associated with specific sites and switchgear. The audit should be completed by a competent person in accordance with the customer's Safety Rules. The audit should include:

2.1 Assessment of substation condition

- Cleanliness
- Humidity
- Temperature
- Environmental control
- Building type (Brick, concrete, GRP, Metal, etc.) and the condition and integrity of the substation

2.2 Assessment of switchgear condition

- SF6 gas pressure gauge indicating healthy gas pressure (where applicable)
- Perform a quick PD survey prior to operation of the switchgear
- Ensure all covers are fitted correctly before operation
- Visually check for signs of electrical or mechanical stress to the equipment
- Listen for any audible signs of stress within the switchgear

2.3 Isolation and earthing

1. The customer shall isolate and earth the switchgear and prove dead at the point of working in accordance with their safety rules.

2.4 Earthing of the sensors

For any internal sensors, the outer screen conductor of the sensor cable must be attached to earth to improve safety and reduce induced currents. The EA Technology equipment does not provide a solid connection to earth. There are many ways the screen of the sensor cable can be connected to earth, two of which are described below. Typically, the size of the earth should be equal to or greater than the total cross-sectional area of all other cores within the sensor cable.

Grounded bulkhead connector

A feed through coaxial bulkhead can be permanently mounted to the metal work of the compartment. The bulkhead can then be separately tied to earth using a suitable separate earth cable to a dedicated Earth point within the switchgear. The following, Figure 1 is an example of a test box with such a bulkhead adaptor where the black metal plate is earthed on the rear side through the back of the box to the main earth bar in the switchgear. The feed through coaxial connectors used on the bulkhead must be fitted in such a way that a good connection is made between the connector shell and the earthed chassis plate.

Figure 1: Feed through bulkhead

Modified sensor cable

Where the mounting of bulkheads is not feasible the sensor can be connected with a modified cable that has a separate earth lead attached to the outer screen. This can then be connected directly to a local earth point within the switchgear.

2.5 Voltage surge mitigation for HFCTs

HFCTs are typically installed around HV earth straps. It is possible for large transient currents to be present during power system fault conditions, local switching activity or electrical storms. When HFCTs are left unterminated, it is possible for large transient voltages to be induced on sensor connectors. The magnitude and risk of transient voltages are detailed in report 3386-REPRT-S015[1].

Based on this report, all installations should take steps to limit access to unterminated HFCTs. This should include the use of dust caps or suitable test connector enclosures, warning labels, and specifying a safe connection sequence within local operating procedures.

2.6 Power system earthing arrangement within the HV cable boxes

To enable safe operation of any internal sensor within a HV cable box, it must be confirmed that the HV earth wire from the cable screen can withstand fault current until the protection operates. This should be determined in accordance the latest edition of relevant National Standard (for example in USA National Electrical Code NFPA 70, Appendix II). Visual verification and measurement of the earthing arrangement should be made to confirm it meets the requirements stated in relevant National Electrical Code.

If national standards are not readily available as a minimum recommendation all earth strands from a conductor should be brought out to a common point and crimped together. Any additional earth wire added from this point to the main Earth Bar of the HV compartment must be of at least the same cross-sectional area as the sum of all the strands brought out from the cable screen.

If the earthing arrangement is not compliant, then the use of internally installed sensors is not recommended until the issues have been rectified.

2.7 Minimum Acceptable Condition of the HV Compartment[2]

The HV compartments should be visually inspected to ensure they are in a suitable condition to enable safe and reliable installation of the sensors.

[1] Available on request.

[2] The term HV compartment will be used throughout this document and refers to HV enclosures, HV cable boxes, HV chambers, HV cable chambers, HV cubicles and other enclosed high voltage spaces within switchgear.

As a minimum the compartment should be dry, free from excessive contamination (although this is acceptable if it is adequately cleaned), all connections should be secure and free from significant mechanical damage. Evidence of normal age degradation or the on-set of partial discharge activity is acceptable if the condition meets the above stipulation.

If this is not the case, then the use of internally installed sensors is not recommended until the issues have been rectified.

2.8 Minimum Clearances

Internal sensors should only be fitted within HV switchgear if the required minimum clearances stated in Appendix I can be maintained.

If this is not the case, then the use of internally installed sensors is not recommended until the issues have been rectified.

2.9 Installation Verification

Photographic evidence of the switchgear condition and dimensions should be recorded for future use.

3. Installation Considerations

The purpose of this section is to assess the risk associated with an internally positioned sensor.

3.1 Sensor Location

If the pre-installation audit indicates that it is possible to permanently install sensors in an acceptable safe manner and a number of alternate safe positions exist then an assessment of the technical benefits of these sensor positions, should be completed. The use of internal sensors should be an improved technical solution compared to external sensors such as:

2. Improved accuracy of measurements
3. Additional protection from environmental factors
4. Additional mechanical protection
5. Additional components can be monitored.
6. Data can be more appropriately utilised and interpreted to provide improved outputs regarding asset condition and recommended asset management actions.
7. In addition, it is recognised customers' drivers and preferences should be considered.

3.2 Clearances

When installing sensors in an air insulated HV compartments clearance distances between HV components and the sensors should be maximised. As a minimum, clearances outlined in local/national laws or Appendix I (whichever is more stringent) must be maintained.

HFCTs - fully screened separable type connectors

Where fully screened separable type connectors are used within a cable compartment, HFCTs should be mounted as far as practicable from the connector boot around the earth screen wires. Note on these types of systems the sensor must be placed around the cable earth screen wires and not the drain earthing lead associated with the connector system, see Figure 2.

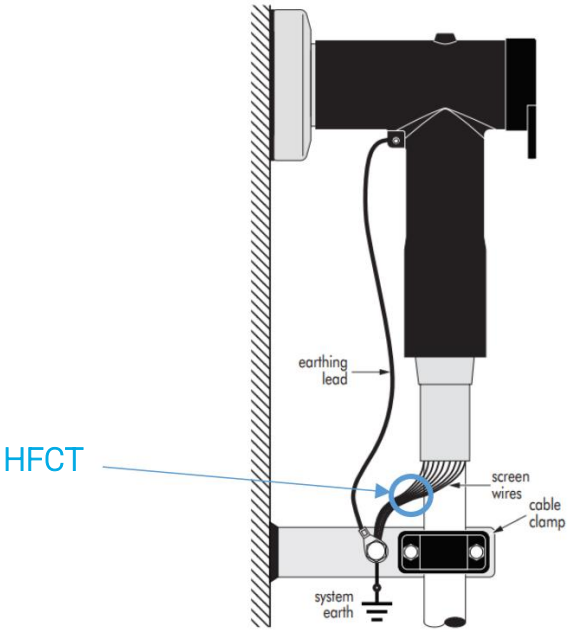


Figure 2: Separable connector system

3.3 Fixing the Sensors

1. The risk of components / debris falling onto the sensors should be considered, wherever possible the sensors should be positioned such that contamination, or a single mechanical failure of a fixing does not impinge on the sensors.
2. Use permanent fixings for sensors and cables. Self-adhesive (or similar) fixings are not suitable as they may fail over time.
3. Ideally, ensure that existing earthed metalwork is closer to the HV conductors than the sensors or cabling being installed.
4. Where possible the sensors shall be secured in place to prevent additional mechanical loading on the installed cabling.
5. All drilling debris shall be removed from the switchgear.
6. Given the above considerations the sensors should be positioned to achieve the maximum PD detection of the various components.

3.4 Routing of the Sensor Cables

1. Sensor cable routes needs to be considered, it should not impinge on other components or be an excessive length – the external node position should be considered. Any cabling installed needs to meet the relevant local/national cabling standards.
2. All sensor cabling must be kept as far from the HV terminations as practicably possible maintaining minimum clearance distances detailed in Appendix I.
3. All sensor cabling should be routed in a way that it is not possible for the cabling to fall upon any live HV components. Where possible route the cabling away from live exposed components and along edges of the switchgear compartments. If sensor cables can be routed below HV components this minimises the risk of them falling on HV components.
4. Where cabling is to be routed around the hinge of the door it should be mechanically supported on both sides of the hinge and sufficient slack provided to enable the door to fully open. If possible, additional sleeving should be placed around the cables.
5. Consult the manufacturers documentation to confirm if there is a preferred method of routing sensor cables within the HV compartments and utilise this method where possible.

6. On modern switchgear there is often a dedicated trunking route behind a metallic cover for the routing of CT, VT, and ancillary component wiring within the HV compartments. Where this is available, and space permits it should be used.
7. The cable length shall be secured to ensure no load is present on cables and excessive lengths of cabling shall be secured within the trunking.
8. Determine if the switchgear HV compartments are internally Arc Rated. If this is the case, then any additional drilling of these compartments to facilitate the routing of the sensors cables needs to be confirmed by the switchgear manufacturer.
9. All drilling debris shall be removed from the switchgear.

3.5 PC/Laptop galvanic isolation

The guidance provided in this report reduces the risks associated with internal PD sensors to a low level. However, when connecting a PC/Laptop to a measurement device (e.g., Astute Monitor, CableData Collector) for longer than a few minutes, it is possible to reduce the risk even further by employing galvanic isolation between the devices. For example, an Ethernet to Fibre converter or Wireless connection could be used. A risk assessment approach on a case-by-case basis should determine whether such isolation is necessary.

3.6 Function Test of Sensors

Once installed, but prior to energisation and closure of the panel a functional test of the sensor is recommended. A test signal of a known size will be coupled into the sensors and detection will be confirmed on the installed measurement system or a separate UltraTEV Plus[2]. The method of coupling the test signal will vary depending on the type of sensor installed. The purpose of this test is to confirm continuity of the wiring between the sensor and the measurement device and where appropriate to confirm correct phase identification.

3.7 Final HV Compartment Checks

A final visual examination of the completed installation should be made to ensure no physical damage has occurred, components are secure, minimum clearance distances have been adhered to and all contamination is removed.

3.8 Warning and Security Signs

External warning signs like those shown below in Figure 3 should be fitted on the exterior of the switchgear to communicate that the installation contains permanently installed sensors that are not to be tampered with. These shall be placed in a clearly visible position.

Figure 3: Example warning sign

3.9 Personnel and Installation Documentation

Installation work should be undertaken by appropriately authorised and competent personnel, in accordance with the customer's safety rules. For each asset installation the installer should complete appropriate installation documentation and hold on record; examples are given in Appendix III.

3.10 Ongoing Management of Installations

The customer's documented maintenance procedure for the associated switchgear should be amended to recognise that internal sensors are fitted and the integrity of the sensors upheld. The customer should have adequate control measures in place to ensure the continued safe operation of the system including:

1. Appointment of competent persons to work on the system.
2. The customer's documented maintenance procedure for the associated switchgear should be amended to recognise the presence of internal sensors and that minimum clearances distances will be maintained, and the integrity of the sensors secured.
3. The customer should ensure that the warning and security notices are intact.
4. The customer should have a written procedure for the management of the installation.
5. The 'Installation Documentation' Part 1 (examples in Appendix III) should be completed for each installation. The installations should be in accordance with the approved procedure as outlined in this document.
6. During multiple panel installations, external connections to the sensors inside HV compartments should be the final activity.

3.11 Decommissioning

Should there be a need to remove the internal partial discharge sensors, the switchgear should be restored as much as possible to its original condition. In particular:

1. Sensors and their associated cabling should be removed in their entirety.
2. Any holes made in the switchgear should be suitably closed where possible, especially if they allow ingress into HV compartments.
3. Warning signs should be removed as appropriate.
4. Records should be updated to reflect the installation status.

4. Disclaimer

This document sets forth the recommended minimum requirements for safe installation of internal partial discharge sensors. This document does not replace nor supersede local or national safety laws, rules and regulations nor your company safety practices, all of which must be observed during installation. In the event of any conflict with those requirements, the safer practice is to be applied. EA Technology provides these requirements as an aid to the customer. EA Technology expressly disclaims any and all liability for the safety of the installation, which remains the sole responsibility of the qualified safety personnel of the customer staff and any Authority having jurisdiction.

Appendix I Minimum HV Clearance Guidelines

When installing partial discharge sensors within HV compartments, care must be taken to ensure that an installation meets the minimum HV clearances from the sensors to any HV component (the "sensor-to-HV") clearances.

The minimum recommended clearances are based on IEC 61936-1 POWER INSTALLATIONS EXCEEDING 1 kV AC –Part 1: Common rules (Table 1). EA Technology has used the most onerous condition (i.e. outdoor equipment and highest rated impulse withstand voltage) and applied a "safety factor" of x2 in recognition that the breakdown voltage can vary with humidity, airborne contamination, and the geometry of the components.

EA Technology's Recommended Minimum "Sensor-to-HV" High Voltage Clearances:

- 240 mm for 6.6 kV
- 320 mm for 11 kV
- 320 mm for 14.8 kV
- 520 mm for 20 kV
- 640 mm for 33 kV
- Refer to appropriate international standards for voltages in excess of 33 kV

Table 1: IEC 61936-1 standard - minimum clearances in air

Nominal voltage of system	Highest voltage for equipment	Rated short-duration power-frequency withstand voltage	Rated lightning impulse withstand voltage [a]	Minimum phase-to-earth and phase-to-phase clearance, *N* [c]	
U_n r.m.s.	U_n r.m.s.	r.m.s.	1,2/50 µs (peak value)	Indoor installations	Outdoor installations
kV	kV	kV	kV	mm	mm
3	3,6	10	20 40	60 60	120 120
6	7,2	20	40 60	60 90	120 120
10	12	28	60 75 95	90 120 160	150 150 160
15	17,5	38	75 95	120 160	160 160
20	24	50	95 125 145	160 220 270	
33	36	70	145 170	270 320	

Appendix II Earthing requirements

Example of Earthing Requirements (Extracts from NFPA 70 2017 (also known as National Equipment Code for the USA).

Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors[a] (AWG/kcmil)		Size of Grounding Electrode Conductor (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum[b]
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Notes:
1. If multiple sets of service-entrance conductors connect directly to a service drop, set of overhead service conductors, set of underground service conductors, or service lateral, the equivalent size of the largest service-entrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.
2. Where there are no service-entrance conductors, the grounding electrode conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.
[a]This table also applies to the derived conductors of separately derived ac systems.
[b]See installation restrictions in 250.64(A).

Table 250.102(C)(1) Grounded Conductor, Main Bonding Jumper, System Bonding Jumper, and Supply-Side Bonding Jumper for Alternating-Current Systems

Size of Largest Ungrounded Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil)		Size of Grounded Conductor or Bonding Jumper* (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	See Notes 1 and 2.	

Notes:
1. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum, the grounded conductor or bonding jumper shall have an area not less than 12½ percent of the area of the largest ungrounded supply conductor or equivalent area for parallel supply conductors. The grounded conductor or bonding jumper shall not be required to be larger than the largest ungrounded conductor or set of ungrounded conductors.
2. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum and if the ungrounded supply conductors and the bonding jumper are of different materials (copper, aluminum, or copper-clad aluminum), the minimum size of the grounded conductor or bonding jumper shall be based on the assumed use of ungrounded supply conductors of the same material as the grounded conductor or bonding jumper and will have an ampacity equivalent to that of the installed ungrounded supply conductors.
3. If multiple sets of service-entrance conductors are used as permitted in 230.40, Exception No. 2, or if multiple sets of ungrounded supply conductors are installed for a separately derived system, the equivalent size of the largest ungrounded supply conductor(s) shall be determined by the largest sum of the areas of the corresponding conductors of each set.
4. If there are no service-entrance conductors, the supply conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.
*For the purposes of applying this table and its notes, the term *bonding jumper* refers to main bonding jumpers, system bonding jumpers, and supply-side bonding jumpers.

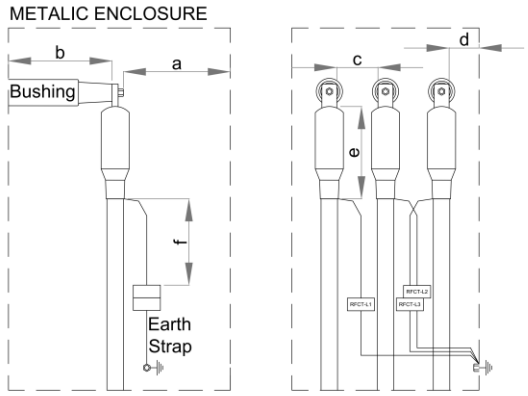
Figure 4: Extracts from NFPA 70 2017 (also known as National Equipment Code)

Appendix III Example installation documentation for internal sensors

RFCT/HFCT installation

All the following points must be completed for each Panel by a Competent person working in accordance with local safety standards and this method statement. This document should be kept current and updated following any activity within the switchgear.

Substation Name			
Engineers Name			
Switchgear Information			
Manufacture			
Model			
Serial Number		Year of Manufacture	
Voltage rating (V)		System Voltage (V)	
Short Circuit Rating		Current Rating (A)	
Earthing and Protection	State standard to which the system is compliant		
Cable Box Information			
Cable box / Cable identification			
Number of cables per phase		Three core / Single core	
Cable Insultation	XLPE / PILC / EPR / Other (please state)		
Clearances (All dimensions in mm)			



Minimum clearance distances permitted when using air insulated terminations.

240 mm for 6.6 kV
320 mm for 11 kV
320 mm for 14.8 kV
520 mm for 20kV
640 mm for 33kV

	L1	L2	L3
a			
b			
c			
d. (Minimum)			
e			
f			

Confirm f is greater than applicable minimum clearance distance and is not less than distances a, b, c and d	

CT Serial Number			
L1	L2	L3	Common Earth (L1, L2, L3)

Photographic documentation	File
Cable box warning sticker fitted	
CT Wire routing	
Cable Compartment Post installation showing clearances	

I confirm the information submitted above is correct:	Print:	Sign:
Date:		

Other partial discharge sensor installation

All the following points must be completed for each Panel by a Competent person working in accordance with local safety standards and this method statement. This document should be kept current and updated following any activity within the switchgear.

Substation name			
Engineer name			
Switchgear Information			
Manufacture			
Model			
Serial number		Year of manufacture	
Voltage rating (V)		System voltage (V)	
Short circuit rating		Current rating (A)	
Earthing and protection	State standard to which the system is compliant		
Panel Information			
Panel identification			
Number of cables per phase		Three core / Single core	
Cable insultation	XLPE / PILC / EPR / Other (please state)		

Sensor Serial Number(s)			
Position	**Type**	**Serial**	**Minimum clearance (sensor or cabling)**

Clearances (All dimensions in mm)	
Minimum clearance distances permitted in air. 240 mm for 6.6 kV 320 mm for 11 kV 320 mm for 14.8 kV 520 mm for 20 kV 640 mm for 33 kV	
Confirm all sensors minimum clearance is greater than requirement:	

Photographic Documentation	File
Warning sticker fitted	
Sensor cable routing	
HV compartment(s) post-installation showing clearances	

I confirm the information submitted above is correct:	Print:	Sign:
Date:		

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