



European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

Technical Report TA User Project

Evaluation of Non-Conventional Sensor Technologies for use in Medium Voltage Dry-Air Gas Insulated Switchgear

Grant Agreement No:	654113
Funding Instrument:	Research and Innovation Actions (RIA) – Integrating Activity (IA)
Funded under:	INFRAIA-1-2014/2015: Integrating and opening existing national and regional research infrastructures of European interest
Starting date of project:	01.11.2015
Project Duration:	54 month

Contractual delivery date:	04/11/2019
Actual delivery date:	04/11/2019
Name of lead beneficiary for this deliverable:	David Jebamony, Nuventura GmbH
Deliverable Type:	Report (R)
Security Class:	Public (PU)
Revision / Status:	released

Project co-funded by the European Commission within the H2020 Programme (2014-2020)

Document Information

Document Version: 1
Revision / Status: released

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Document History

Revision	Content / Changes	Resp. Partner	Date
0.1	Document created	D. Jebamony / NUV	17.09.2019
0.2	Updated with citations, table and figure cross-references	D. Jebamony / NUV	21.10.2019

Document Approval

Final Approval	Name	Resp. Partner	Date
Lead beneficiary completed	David Jebamony	NUV	21.10.2019
Review	Ian Gilbert	OCT	21.10.2019

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Table of contents

Executive Summary	5
1 General Information of the User Project.....	6
2 Research Motivation.....	7
2.1 Objectives	7
2.2 Scope.....	7
3 State-of-the-Art	7
4 Testing.....	9
4.1 Test Plan.....	9
4.2 Test Setups and Methodology	9
4.2.1 Temperature sensor testing.....	9
Stress Case 1: Lightning Impulse Voltages applied to sensors.....	10
Stress Case 2: Short Circuit Withstand Current applied to sensors	10
Stress Case 3: Temperature Cycle applied to sensors	11
4.2.2 Antenna testing.....	11
Stress Case 4: Temperature Cycle applied to antennas.....	11
4.3 System Set-up.....	12
4.3.1 Data Management and Processing.....	15
4.3.1.1 System-A	15
4.3.1.2 System-B.....	16
4.4 Results and discussion	16
4.4.1 System-A.....	17
4.4.1.1 Temperature Sensors.....	17
4.4.1.2 Antenna / PD Sensors.....	18
4.4.1.3 System-A Summary	19
4.4.2 System-B.....	19
4.4.2.1 Temperature Sensors.....	19
4.4.2.2 Antenna / PD Sensors.....	20
4.4.2.3 System-B Summary	21
4.5 Conclusions.....	21
5 Open Issues and Suggestions for Improvements.....	21
6 Dissemination Planning.....	22
8 References	23
9 Annex	24
9.1 List of Figures.....	24
9.2 List of Tables.....	24

Abbreviations

<i>AIS</i>	Air Insulated Switchgear
<i>CIV</i>	Corona Inception Voltage
<i>DUT</i>	Device Under Test
<i>EM</i>	Electro-magnetic
<i>EUT</i>	Equipment Under Test
<i>GIL</i>	Gas Insulated transmission Line
<i>GIS</i>	Gas Insulated Switchgear
<i>HFCT</i>	High Frequency Current Transformer
<i>HV</i>	High Voltage
<i>LCA</i>	Lifecycle Assessment
<i>MV</i>	Medium Voltage
<i>OCT</i>	Ormazabal Corporate Technology
<i>PD</i>	Partial Discharge
<i>SAW</i>	Surface Acoustic Wave
<i>SF6</i>	Sulphur Hexafluoride
<i>TA</i>	Trans-national Access
<i>UDEX</i>	Demonstration and Experimentation Laboratory
<i>UHF</i>	Ultra High Frequency

Executive Summary

Nuventura has developed a medium voltage (MV) gas insulated switchgear (GIS) in accordance with IEC 62271-100 and -200 standards that uses dry air as an insulating medium. The use of dry air completely eliminates the environmental concerns surrounding SF₆ use and will enable the industry in transitioning to meet Europe's ambitious climate goals. An additional advantage of using dry air is that sensor solutions can be integrated within the GIS core vessel at manufacturing enabling real-time monitoring of critical asset health and providing operators with benefits such as lower maintenance costs, reduced risk of failures and improved asset management. Asset management one of the key strategies identified within Europe and globally for electricity networks particularly for the physical infrastructure and assets, which are subject to regular maintenance programs.

Lifecycle testing has been carried out in the UDEX laboratory to determine whether it is possible to install non-conventional sensor technology within GIS core vessels to ensure that the sensors can continue to operate in real electrical network conditions and do not adversely impact the switchgear operation or safety. The scope of the testing quantified the functional and non-functional performance of the sensors and antennas after they have been subjected to different stresses commonly seen in MV GIS. The outcome of the testing will determine if the sensor systems are suitable for integration into the Nuventura GIS and if there are any restrictions or limitations that must be noted for safe operation.

The flexibility of the UDEX laboratory allows for the configuration of a real distribution network fulfilling the requirements of the proposed research areas. The use of climatic chambers, high voltage, high power and IEC 60270 partial discharge measurement systems enabled the testing of sensor solutions against stresses incurred in real distribution networks.

The Transnational Access has provided Nuventura with free access to a laboratory which would not have been able to easily access or would have required complex co-ordination across multiple paid commercial facilities. The UDEX laboratory has a fully operational distribution network for the purposes of research and Nuventura, being a startup, has benefited from learning crucial features of the suitability of sensors for use within MV GIS.

Principal conclusions from the work carried out are:

- Existing temperature and partial discharge sensors are able to functionally measure even after subjected to stresses seen in MV GIS however the reliability of such products could be improved.
- Non-functional testing has shown that the sensors are able to withstand the harsh conditions in MV GIS such as high temperatures, short circuits and impulse voltages without degrading and creating partial discharge within the switchgear.
- The quality of the sensors could impact whether the MV GIS would pass the type test certification as breakdown could occur before the rated lightning impulse voltage is reached.

Lessons learned:

- While both sensor systems were able to pass non-functional tests, the quality of the temperature sensor design have a large impact on whether they will meet the strict qualification requirements (e.g. IEC62271-200 type tests) to be used in MV GIS.
- Long term tests under load are required to be able to test the stability of sensors as there are fluctuations that could be missed by performing short term analysis only.

1 General Information of the User Project

TA Call No.	6
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Host research infrastructures	UDEX
Start date for the access	10.09.2019
End date for the access	04.10.2019

USER PROJECT	
User Project acronym	LCA
User Project title	Evaluation of Non-Conventional Sensor Technologies for use in Medium Voltage Dry Air+Gas Insulated Switchgear
Main scientific/technical field	Smart Grid Life time assessment
Keywords (5 max., free text)	Smart Grid, IoT, sensors, switchgear, Life time assessment

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2 Research Motivation

Nuventura has developed a medium voltage (MV) gas insulated switchgear (GIS) in accordance with IEC 62271-100 and -200 standards that uses dry air as an insulating medium. The use of dry air completely eliminates the environmental concerns surrounding SF₆ use and will enable the industry in transitioning to meet Europe's ambitious climate goals. An additional advantage of using dry air is that sensor solutions can be integrated within the GIS core vessel at manufacturing enabling real-time monitoring of critical asset health and providing operators with benefits such as lower maintenance costs, reduced risk of failures and improved asset management. Asset management one of the key strategies identified within Europe [1] and globally for electricity networks particularly for the physical infrastructure and assets, which are subject to regular maintenance programs.

2.1 Objectives

Lifecycle testing has been carried out in the UDEX laboratory to determine whether it is possible to install non-conventional sensor technology within GIS core vessels to ensure that the sensors can continue to operate in real electrical network conditions and do not adversely impact the switchgear operation or safety. The scope of the testing quantified the functional and non-functional performance of the sensors and antennas after they have been subjected to different stresses commonly seen in MV GIS. The outcome of the testing will determine if the sensor systems are suitable for integration into the Nuventura GIS and if there are any restrictions or limitations that must be noted for safe operation.

2.2 Scope

The flexibility of the UDEX laboratory allows for the configuration of a real distribution network fulfilling the requirements of the proposed research areas. The scope of the testing is to quantify the functional and non-functional performance of commercially available non-conventional UHF sensor systems after they have been subjected to different stresses commonly seen in MV GIS. The use of climatic chambers, high voltage, high power and IEC 60270 partial discharge measurement systems enabled the testing of sensor solutions against stresses incurred in real distribution networks.

3 State-of-the-Art

Passive sensor solutions now exist which can be expected to operate in critical assets such as transformers and HV gas insulated transmission lines (GIL) for many years without failure (under normal operating conditions) [2] and subsequently without the need for replacement. While it has also been used MV air insulated switchgears (AIS) or within cable compartments in MV GIS [3], it is as yet unknown how they will perform in the harsh operating conditions within the MV GIS core vessel which is subjected to higher temperatures, stresses from higher electric fields as well as shocks and vibrations during normal operations, such as opening and closing of the circuit breaker. The sensor systems are able to measure temperature and partial discharge (PD) occurring in critical assets and use these to identify failing insulation and deteriorating health of the assets. The temperature sensors use Surface Acoustic Wave (SAW) wireless technology for measuring temperature. PD measurement is via the non-conventional method as per IEC 62478.

Detection of PD by electrical methods can be broadly categorised into:

1. the conventional method based on the IEC 60270 standard; and
2. those that are implemented using non-conventional methods based on the IEC 62478 standard.

The conventional method of partial discharge (PD) detection is very accurate and measures electrical pulses caused by PD in the frequency range below 1 MHz as per the IEC 60270 standard. This is suitable for controlled laboratory environments but is susceptible to high electrical noise in live environments. It is also intrusive, requiring outages to the device under test for the measuring period, and comparatively costly making it unsuitable for continuous online monitoring.

In order to avoid the issues associated with high electrical noise on site, alternative non-conventional methods which operate in higher frequency ranges are required. Commercially available solutions exist that are economically viable and non-intrusive allowing for continuous monitoring in real life conditions without outages to

the equipment. These can be classified as internal (invasive) or external (non-invasive) sensors, according to whether they are mounted inside or outside the equipment.

The UHF method is a non-conventional method that includes passive sensors which can be installed inside the metallic chambers of GIS compartments such as the core vessel. The absence of active electronics and moving components in the sensors means that they can be expected to operate for long periods of time without maintenance. As they are classified as invasive, they can also be mounted inside the core GIS vessel during manufacture. The advantages of this are the high sensitivity to discharges due to inner electrical resonance, low inherent losses and high immunity to electrical noise interference. Additionally, it is expected that any insulation defect detected from a sensor inside the switchgear confines the detection to be inside this particular switchgear (including cable terminations connected to it).

The UHF method has been shown to be suitable to detect different types of discharge seen in critical assets [4] [5]. However, such systems have not been used inside MV GIS core tanks where the critical insulation, switching and breaking occurs.

4 Testing

EUT (sensors and antennas) as well as accompanying transceiver and software was tested from two commercially available sensor systems. The vendors for the systems and all identifying elements such as part number, software name, etc. has been kept anonymous and they are only referred to as System or Vendor -A or -B.

All functional measurement testing of the EUT (sensors and antennas) was carried out in the smart grid demonstration and experimentation laboratory (UDEX) in Bilbao, Spain, provided through this ERIGrid project. The UDEX laboratory has a fully operational distribution network for the purposes of research allowing for easy setup and testing of various scenarios that could occur in real life distribution networks. The main functional testing planned was to identify if the sensor systems would continue to measure the temperature and/or partial discharge from within a simulated MV GIS environment before, during and after being subjected to the different stresses that occur in MV GIS. The different stresses simulated in the facilities include high lightning impulse voltages, short circuit currents and temperature cycles on the EUT and a replica GIS tank was used as the Device Under Test (DUT).

Non-functional testing was also carried out in the facilities to evaluate if the EUT deteriorated or degraded after being subjected to the stresses.

4.1 Test Plan

WEEK 1	Preliminary information on UDEX configurations & Reception of samples
	Detailed planning and test procedures
	System Setup and preliminary checks
	Functional measurements in experimental network before tests
WEEK 2	Calibrations and Non-functional tests acc. IEC 60270
	Sensor Impulse Testing (EM field Stress Case)
	Functional measurements in experimental network after Impulse
	Sensor Short circuit Testing (Vibration & EM stress)
	Functional measurements in experimental network after SC
WEEK 3	Programmed Sunday start - Sensor Cycle1 (115°C): 0-24h
	Functional performance checks + Sensor Cycle2 (115°C): 24h-48h
	Functional performance checks + Sensor Cycle3 (115°C): 48h-72h
	Functional performance checks + Sensor Cycle4 (115°C): 72h-96h
	Performance checks + Antenna Cycle1 (80°C): 0-24h
	Functional measurements
WEEK 4	Programmed Sunday start - Antenna Cycle2 (80°C): 24h-48h
	Performance checks + Antenna Cycle3 (80°C): 48h-72h
	Performance checks + Antenna Cycle4 (80°C): 72h-96h
	Functional measurements
	Final Non-functional tests acc. IEC 60270
	Final functional measurements, data exchange, review and test completion

4.2 Test Setups and Methodology

4.2.1 Temperature sensor testing

The temperature sensors from both system use Surface Acoustic Wave (SAW) wireless technology for measuring temperature. They are expected to be installed on the busbars of the 36kV GIS and as such will be subjected to (1) lightning impulse voltages of up to 195kV, (2) high electromagnetic and vibrational forces during

circuit breaker opening and (3) temperatures on the busbar of up to 115°C (per IEC 62271-200).

They must continue to perform (1) functionally by continuing to measure temperature and (2) not degrade in such a manner as to create operational or safety risk when subjected to stresses.

Based on this, functional and non-functional tests have been designed for the three different types of stresses mentioned above.

- 1) Perform functional performance tests for each temperature sensor by measuring values under load in UDEX. Compare values with T_{ref}.
- 2) Perform non-functional tests by measuring Corona Inception Voltage (CIV) for each sensor using standard IEC 60270 measurement unit
- 3) Apply stresses to the sensors.
 - a. Stress Case 1: Three sensors to have impulse voltages applied until breakdown is reached
 - b. Stress Case 2: Three sensors to be subjected to short circuit withstand currents of up to 31.5kA for 3 seconds
 - c. Stress Case 3: Three sensors to be subjected to four temperature cycles between 20 °C and 115°C
- 4) Perform functional performance tests for each temperature sensor by measuring the values under load in UDEX. Compare values with T_{ref}.
- 5) Perform final non-functional tests by measuring CIV for each sensor using a standard IEC 60270 measurement unit

Stress Case 1: Lightning Impulse Voltages applied to sensors

Lightning impulses are applied to the sensors as stresses based on what would be expected in MV GIS rated to 36kV under IEC62271.

Samples: 3x temperature sensors from each vendor
 State: Not operating
 Test tension: 195kV (AC) at 50Hz
 Rise time: 1.2 microseconds
 Decay time: 50 microseconds for 50% of test tension voltage

A standard lightning impulse 1.2/50 s voltage is to be used and repeated at 3 impulse shots per step rate to the maximum value noted unless failure is reached and the sensors discharge. Both positive and negative impulses will be tested.

Table 4.1 Impulse Levels to be tested

Cycle No.	% of U _p	Impulse Level (kV)
1	40%	78
2	60%	117
3	80%	156
4	90%	175.5
5	100%	195
6	110%	214.5
7	120%	234

The test is completed for three sensors from each vendor (total of six sensors tested).

Stress Case 2: Short Circuit Withstand Current applied to sensors

Short time and peak withstand current test to be run for:

- 16kA for 1 second
- 25kA for 1 second
- 31.5kA for 1 second
- 31.5kA for 3 seconds

Stress Case 3: Temperature Cycle applied to sensors

Dry Heat cyclic, according to IEC 60068-2-30.

Samples: 3x sensors including cables and connectors for each vendor

State: Not operating

Test cycle:	(+25 ±3)°C, (0.5 ±3)% r.H => (+115 ±3)°C, (0.5 ±3)% r.H	3:00 hrs
	(+115 ±3)°C, (0.5 ±3)% r.H	9:00 hrs
	(+115 ±3)°C, (0.5 ±3)% r.H => (+25 ±3)°C, (0.5 ±3)% r.H	3:00 hrs
	(+25 ±3)°C, (0.5 ±3)% r.H	9:00 hrs

Cycles: Four (4) cycles

Duration: 96:00 hours (4 cycles, each 24:00 hrs)

4.2.2 Antenna testing

The antennas for each system fulfil two purposes. They act as an antenna for reception of temperature readings from the temperature sensors using Surface Acoustic Wave (SAW) wireless technology. They are also able to detect partial discharge using Ultra High Frequency (UHF) method a non-conventional PD measurement method as defined in IEC 62478. The antennas will be installed on the inner housing of the GIS tank and as such will be subjected to temperatures of up to 80°C as this is the temperature that the fluid (dry air) is expected to reach under normal operating conditions.

They must continue to perform (1) functionally by continuing to measure partial discharge and receive temperature readings and (2) not degrade in such a manner as to create an operational or safety risk when subjected to stresses.

Based on this, functional and non-functional tests have been designed for the temperature stresses mentioned above.

- 1) Perform functional performance tests for each antenna by:
 - a. measuring temperature values of sensors under load in UDEX. Temperature is compared with values from a thermocouple which is used as reference unit.
 - b. measuring partial discharge from network as voltage is increased steadily. An independent PD measurement unit with coupling capacitor is used as a reference.
- 2) Perform non-functional tests by measuring Corona Inception Voltage (CIV) for each antenna using standard IEC 60270 measurement unit
- 3) Apply stresses to the antennas:
 - a. Stress Case 4: Three antennas to be subjected to four temperature cycles between 20 °C and 80°C
- 4) Perform functional performance tests for each antenna by:
 - a. measuring temperature values under load in UDEX. Temperature is compared with values from a thermocouple which is used as reference unit.
 - b. measuring partial discharge from network as voltage is increased steadily. An independent PD measurement unit with coupling capacitor is used as a reference.
- 5) Perform final non-functional tests by measuring CIV for each antenna using a standard IEC 60270 measurement unit

Stress Case 4: Temperature Cycle applied to antennas

Dry Heat cyclic, according to IEC 60068-2-30

Samples: 3x antennas including cables and connectors for each vendor

State: Not operating

Test cycle:	(+25 ±3)°C, (0.5 ±3)% r.H => (+80 ±3)°C, (0.5 ±3)% r.H	3:00 hrs
	(+80 ±3)°C, (0.5 ±3)% r.H	9:00 hrs
	(+80 ±3)°C, (0.5 ±3)% r.H => (+25 ±3)°C, (0.5 ±3)% r.H	3:00 hrs
	(+25 ±3)°C, (0.5 ±3)% r.H	9:00 hrs

Cycles: Four (4) cycles

Duration: 96:00 hours (4 cycles, each 24:00 hrs)

4.3 System Set-up

Voltage to the UDEX facility was provided by the local utility (Iberdrola) with variable voltage supplied to the UDEX Test Bay via an adjustable transformer output to an intermediary substations (CSC2) with MV switch-gears (see Figure 4.1). The variable voltage 50Hz AC source allows variation of the applied voltage magnitude.

Functional testing of the EUT (sensors and antennas) is carried out in the UDEX test bay by connecting the supply to a GIS replica tank (DUT) with EUT installed inside the GIS tank.

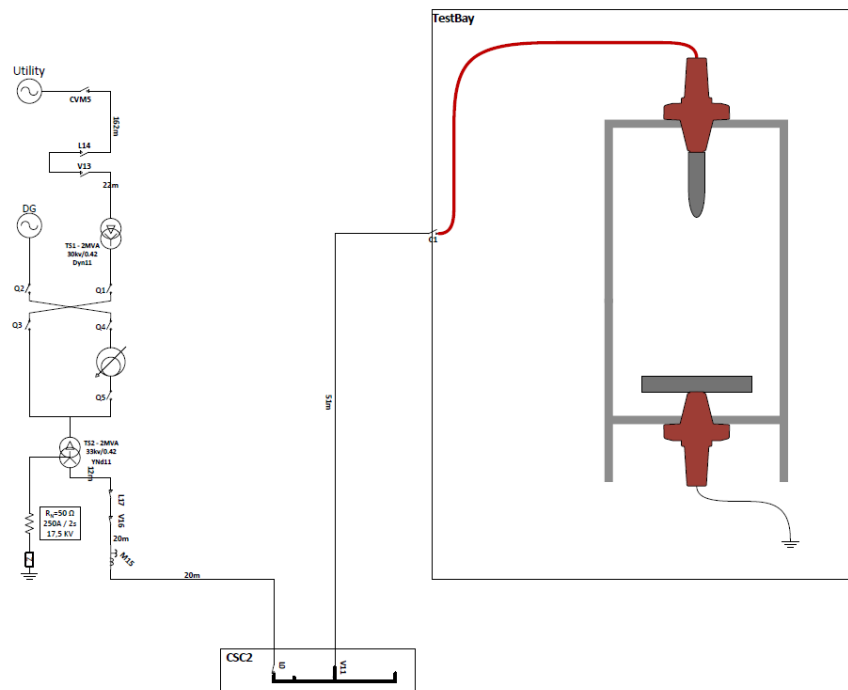


Figure 4.1 Single line diagram of test network with DUT in UDEX

The GIS tank used consists of a steel compartment, with a steel lid providing access to the compartment. The lid consists of a holding arrangement for the antennas as well as hermetically sealed feedthroughs for the SMA interface for the signal reception. The testing of all sensors are run in parallel and data is logged into the respective systems for each of the tests.

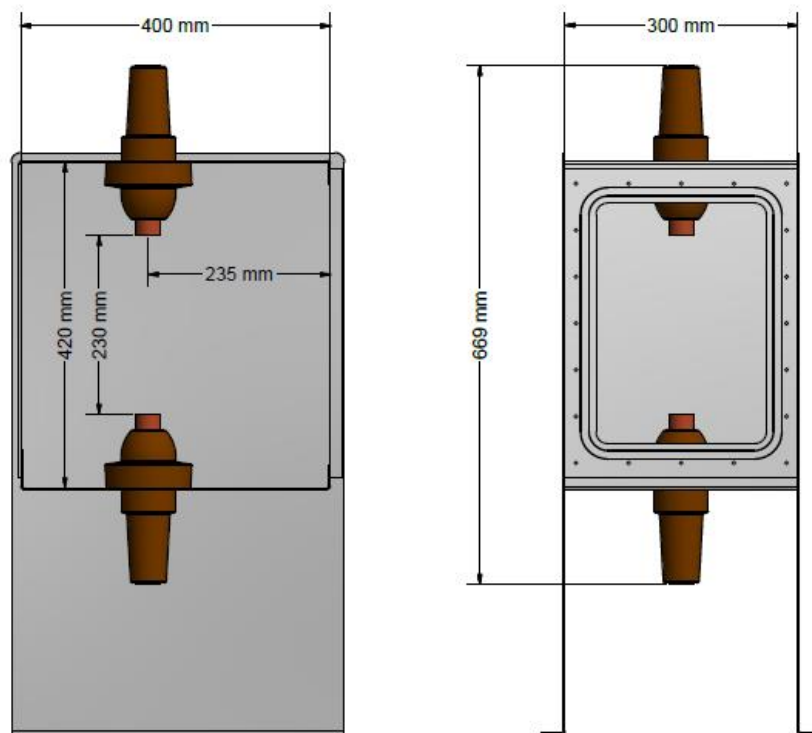


Figure 4.2 Lateral and side view of GIS replica tank (DUT) used to EUT

The tank consists of a single phase with bushings for line voltage and ground (Figure 4.2). The internal connection of the bushings can support various configurations to create partial discharges . such as metal point to metal plate (for Corona discharge) or metal point to acrylic plate (for internal or surface discharges).

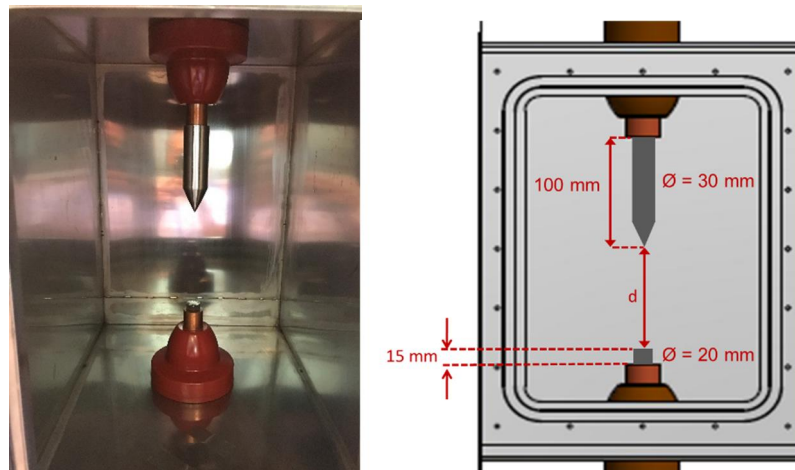


Figure 4.3 DUT setup for creating partial discharge

A PD activity can be established in a controlled manner by applying high voltage across two points and varying the distance between these points. As the points get closer, a discharge is induced due to the increased electric field strength. In Figure 4.3, the setup is shown with a metallic rod with a sharpened tip used to generate corona discharges with the strength of the discharge increasing as the distance to the grounded plate, shown as d , is reduced.



Figure 4.4 UDEX lab setup showing DUT setup

The antennas are connected to the respective vendors transceiver where data is received, processed, analysed and stored on a laptop for later analysis (Figure 4.5).



Figure 4.5 Setup of antennas, sensors and monitoring systems

The arrangement of antennas and measurement of temperature sensor values is compared with a reference temperature sensor. The reference sensor (T_{ref}) measured values were acquired using RS-Pro 52 Digital Thermometer (Thermocouple type K) as shown in Figure 4.6.



Figure 4.6 Setup of reference temperature (T_{ref})

Reference partial discharge in the system was measured using an ekor.pdm which uses:

- a Low Frequency coupling capacitor on Channel-1 connected to the MV distribution network
- a HFCT (high frequency current transformer) on Channel-2 connected to the earthing connection of the DUT.

The reference system is shown in Figure 4.7 below.



Figure 4.7 Reference PD system with coupling capacitor (left) and HFCT sensor (right)

4.3.1 Data Management and Processing

The data for the UDEX systems was recorded and processed as follows:

- Circuit setup was saved as a screenshot;
- Voltage applied was recorded in CSV file and via screenshots;
- Relevant values for reference partial discharge in the system was noted for each the relevant tests and screenshots captured; and
- Reference temperature was manually noted down for each test.



Figure 4.8 Control centre for UDEX environment

4.3.1.1 System-A

Sensor System-A data measurements were recorded and processed as follows:

- Partial discharge functional test . all data was captured for the test via a local logging of GUI data to CSV log file. Additionally, a screenshot was also taken for the test duration; and
- Temperature functional test . all data was captured for the test via a local logging of GUI data to CSV log file. Additionally, a screenshot was also taken for the test duration.
- The non-functional testing results compares the before and after results of the IEC60270 testing of partial discharge generated by the EUT. All results are manually noted and screenshots of the PRPD patterns are saved.

4.3.1.2 System-B

Sensor System-B measurements were recorded and processed as follows:

- Partial discharge functional test . all data was captured for the test via automated logging of data to the transceiver unit which was then stored as a CSV log file. Additionally, a screenshot was also taken for the test duration.
- Temperature functional test . all data was captured for the test automated logging of data to the transceiver unit which was then stored as a CSV log file. Additionally, a screenshot was also taken for the test duration.
- The non-functional testing results compares the before and after results of the IEC60270 testing of partial discharge generated by the EUT. All results are manually noted and screenshots of the PRPD patterns are saved.

4.4 Results and discussion

The live network (shown in red in Figure 4.9 below) is shown with voltage applied to the UDEX test bay.

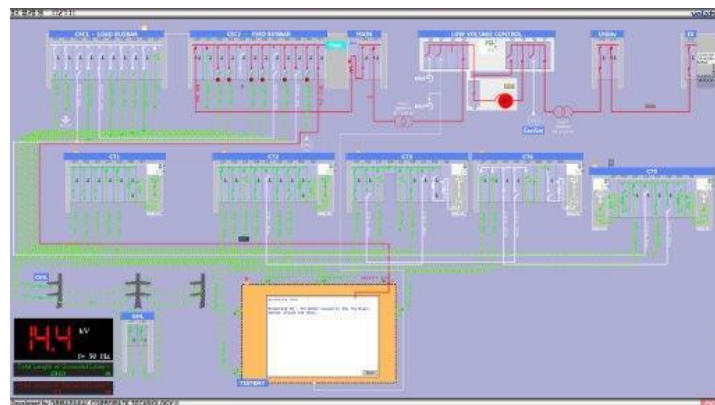


Figure 4.9 Control of test voltage from UDEX

The voltage is applied to the DUT in UDEX and increased steadily.

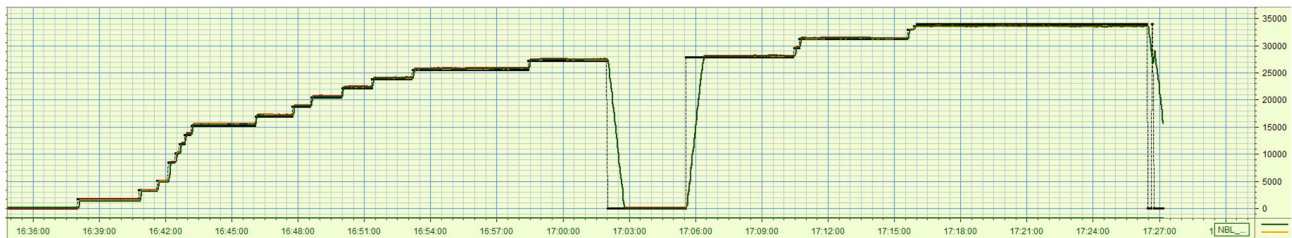


Figure 4.10 Voltage increase used in partial discharge testing

As the voltage is increased, the partial discharge generated in the DUT increases and is recorded in the reference system. The LF channel (Figure below) shows that at 29kV, approximately 420pC of discharge is measured. The PRPD pattern shows that corona discharge is present as well as other noise in the system (Figure 4.11).

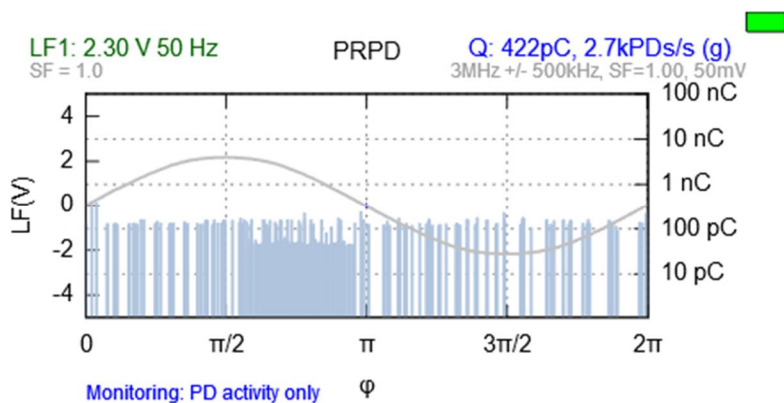


Figure 4.11 PD reference reading on Coupling Capacitor

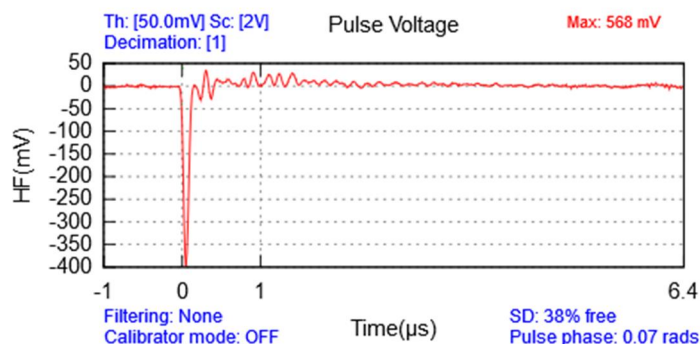


Figure 4.12 PD reference reading on HFCT sensor

4.4.1 System-A

4.4.1.1 Temperature Sensors

The temperature sensors were considered to pass the test if they record a temperature difference after the stress case of within 1°C of the reference temperature T_{ref} of the conductor under load.

A summary of the temperature sensors results for System-A were as follows:

- Three of the three (100%) sensors tested were able to functionally perform and measure temperature after being subjected to lightning impulses up to 195kV.
- Two of the three (67%) sensors tested were able to functionally perform and measure temperature after being subjected to short circuit withstand currents of 31.5kA for 3 seconds.
- Two of the three (67%) sensors tested were able to functionally perform and measure temperature after being subjected to temperature cycles between 20 and 115°C. One of the sensors, SenA11, was noted to have an inconsistent reading as in Figure 4.13.

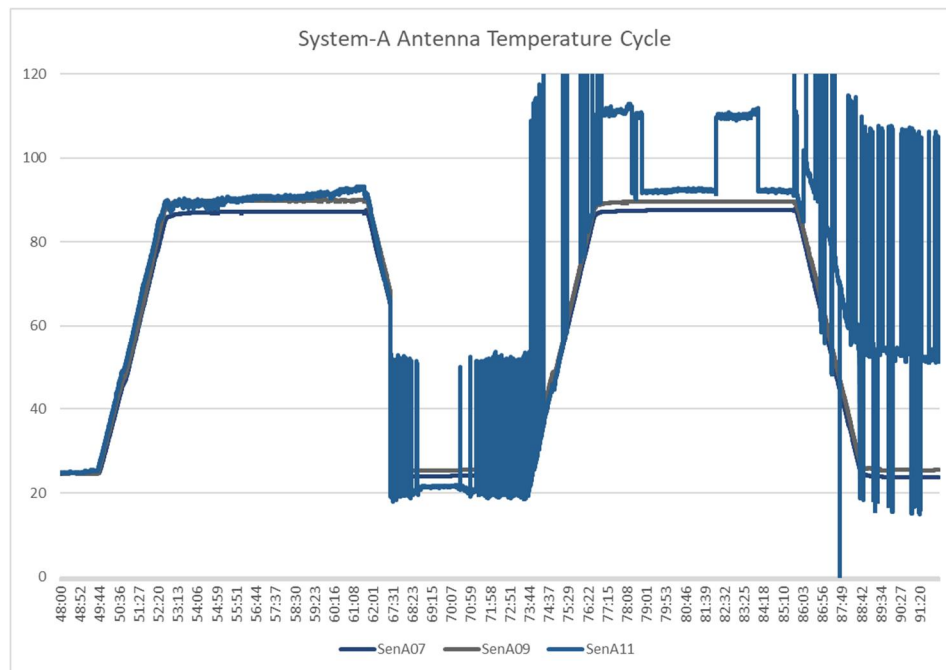


Figure 4.13 System-A temperature monitoring

The non-functional testing results show that all the sensors from System-A are not adversely affected by the different stresses as there was no additional PD generated by the sensors. They would be expected to operate safely during normal operating conditions without creating an additional risk for the GIS. Care must still be taken in the design and placement of the sensors to ensure that the clearances within the MV GIS tank are sufficient and they do not cause a breakdown.

4.4.1.2 Antenna / PD Sensors

Two of the three antennas for System-A were all able to detect partial discharge after being subjected to temperature stresses. As shown in Figure 4.14 below, AntennaA01 and AntennaA02 were able to detect discharges while AntennaA03 was not able to detect discharge as the voltage and discharge in the DUT increased. Note that the discharges were identified as surface discharges (SD) which includes corona discharges as per the vendors algorithm. The level measured by the antennas, Q_{uhf} as indicated in the vertical axis, is a non-physical quantity in a non-linear scale. It is a measured increase in detection of electromagnetic radiation from a baseline over time. They were also able to detect increases in amount of discharge present.

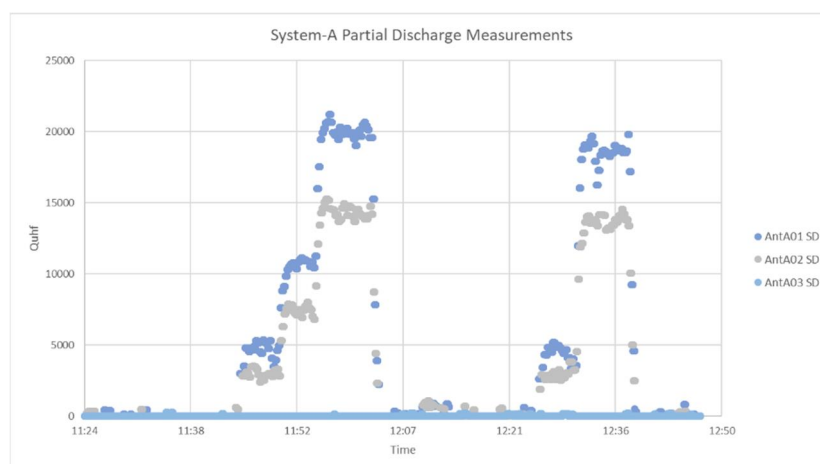


Figure 4.14 System-A partial discharge monitoring

Further analysis of the individual antenna measures in Figure 4.15 shows that AntennasA01 and A02 were

detecting the surface discharges in its low frequency band (centred at 300MHz) and not the medium (600MHz) or high frequency (1200MHz) bands. AntennaA03 shows very weak levels of detection.

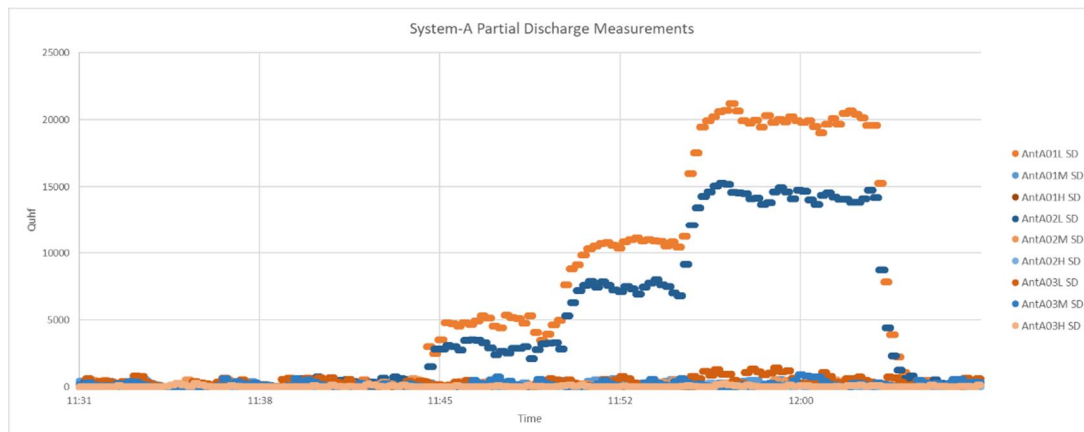


Figure 4.15 Analysis of frequency detection of signals

The antennas were all able to receive the temperature readings from the SAW temperature sensors indicating that the antennas were able to withstand the high temperatures without losing their calibrations to the SAW sensors.

The non-functional testing shows that the antennas from System-A are not adversely affected by the high temperatures stresses experienced in MV GIS and are able to operate safely during normal operating conditions. The antennas will not deteriorate in a manner that creates additional partial discharge or introduces potential failures and as such can be used as partial discharge measurement systems inside MV GIS.

4.4.1.3 System-A Summary

A summary of the results is shown in Table 4.2 below. System-A passed all non-functional tests and would be expected to safely operate within an MV GIS environment. However, the functional performance of the sensors has been shown to be affected by the conditions within MV GIS and would suggest that some of these sensors may fail and not be able to accurately measure temperature or partial discharge for the lifespan of the GIS without replacement.

Table 4.2 Summary of System-A results

System-A		Functional		Non-functional	
EUT	Stress Applied	Measure	Result	Measure	Result
Temperature Sensors	Lightning Impulse	Temperature		IEC 60270	
Temperature Sensors	Short Circuit	Temperature		IEC 60270	
Temperature Sensors	Temperature cycling (115°C)	Temperature		IEC 60270	
Antenna / PD Sensor	Temperature cycling (80°C)	Temperature		IEC 60270	
Antenna / PD Sensor	Temperature cycling (80°C)	Partial Discharge		IEC 60270	

4.4.2 System-B

4.4.2.1 Temperature Sensors

The temperature sensors were considered to pass the test if they record a temperature difference after the

stress case of within 1°C of the reference temperature T_{ref} of the conductor under load.

A summary of the temperature sensors results for System-B were as follows:

- Three of the three (100%) sensors tested were able to functionally perform and measure temperature after being subjected to lightning impulses up to 195kV.
- Three of the three (100%) sensors tested were able to functionally perform and measure temperature after being subjected to short circuit withstand currents of 31.5kA for 3 seconds.
- Two of the three (67%) sensors tested were able to functionally perform and measure temperature after being subjected to temperature cycles between 20 and 115°C. One of the sensors was noted to have an inconsistent reading as in Figure 4.16 .

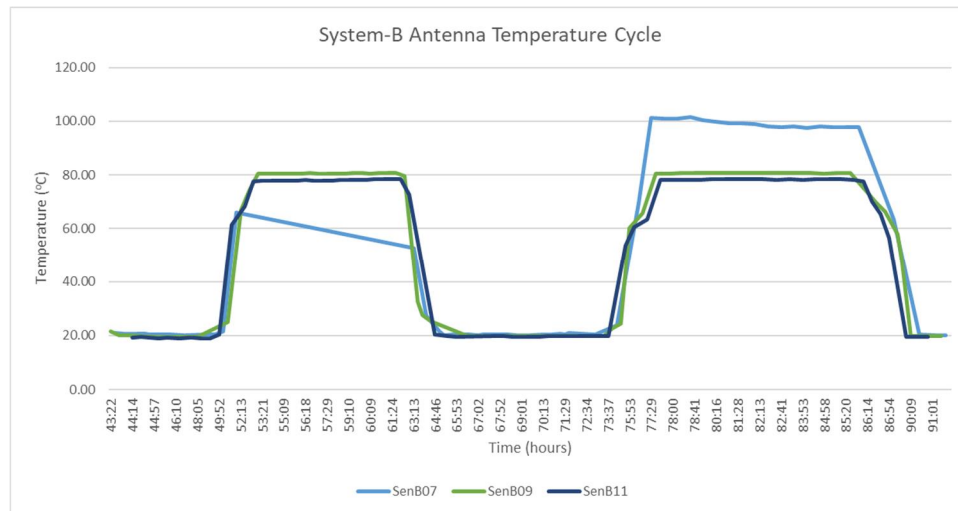


Figure 4.16 System-B temperature monitoring

The non-functional testing results show that all the sensors from System-B are not adversely affected by the different stresses as there was no additional PD generated by the sensors. They would be expected to operate safely during normal operating conditions without creating an additional risk for the GIS. Care must still be taken in the design and placement of the sensors to ensure that the clearances within the MV GIS tank are sufficient and they do not cause a breakdown.

4.4.2.2 Antenna / PD Sensors

All three antennas for System-B were all able to detect partial discharge after being subjected to temperature stresses (Figure 4.17).

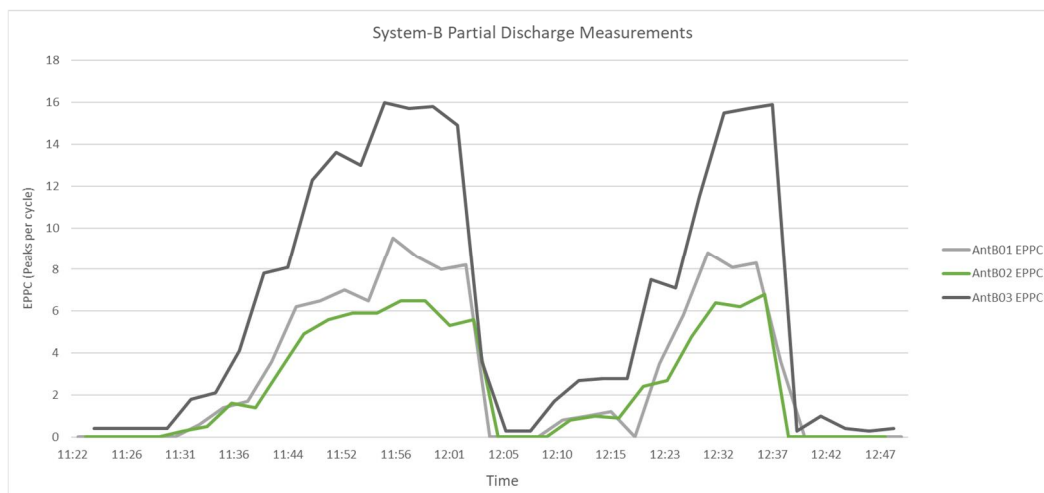


Figure 4.17 System-B partial discharge monitoring

Additionally, they were all able to receive the correct temperature readings from the SAW temperature sensors indicating that the antennas were able to withstand the high temperatures without losing their calibrations to the SAW sensors.

The non-functional testing shows that the antennas from System-B are not adversely affected by the high temperatures stresses experienced in MV GIS and are able to operate safely during normal operating conditions. The antennas will not deteriorate in a manner that creates additional partial discharge or introduces potential failures and as such can be used as partial discharge measurement systems inside MV GIS.

4.4.2.3 System-B Summary

A summary of the results is shown in Table 4.1 below. System-B passed all non-functional tests and would be expected to safely operate within an MV GIS environment. The functional performance of the sensors has been shown to be affected by high temperatures seen on the conductors within MV GIS and would suggest that some of these sensors may fail and not be able to accurately measure temperature for the lifespan of the GIS without replacement.

System-B		Functional		Non-functional	
EUT	Stress Applied	Measure	After	Measure	After
Temperature Sensors	Lightning Impulse	Temperature		IEC 60270	
Temperature Sensors	Short Circuit	Temperature		IEC 60270	
Temperature Sensors	Temperature cycling (115°C)	Temperature		IEC 60270	
Antenna / PD Sensor	Temperature cycling (80°C)	Temperature		IEC 60270	
Antenna / PD Sensor	Temperature cycling (80°C)	Partial Discharge		IEC 60270	

Table 4.3 Summary of System-B results

4.5 Conclusions

Principal conclusions from the work carried out are:

- Existing temperature and partial discharge sensors are able to functionally measure even after subjected to stresses seen in MV GIS however the reliability of such products could be improved.
- Non-functional testing has shown that the sensors are able to withstand the harsh conditions in MV GIS such as high temperatures, short circuits and impulse voltages without degrading and creating partial discharge within the switchgear.
- The quality of the sensors could impact whether the MV GIS would pass the type test certification as breakdown could occur before the rated lightning impulse voltage is reached.

Lessons learned:

- While both sensor systems were able to pass non-functional tests, the quality of the temperature sensor design have a large impact on whether they will meet the strict qualification requirements (e.g. IEC62271-200 type tests) to be used in MV GIS.
- Long term tests under load are required to be able to test the stability of sensors as there are fluctuations that could be missed by performing short term analysis only.

5 Open Issues and Suggestions for Improvements

While this testing carried out showed that sensors are able to be installed in MV GIS and withstand the harsh conditions while continue to function and not impact operational safety, it does not identify if the sensors can continue to operate safely for 30 years within this environment. An improvement would include accelerated

failure of sensors system components using a salt spray method or subjecting the EUT to temperatures similar to a switchgear environment for extended periods of time.

Also, the current testing was carried out using a replica GIS tank as a DUT however there were a number of limitations in this approach as it did not use a real MV GIS under pressure. Improvements would include running any future tests using a real dry air+MV GIS under pressure with sensors installed inside. This would be very useful as a development cycle to understand whether sensors would cause dielectric or other standardized IEC62271 type tests to fail if used in MV GIS.

Other functional testing that could be carried out using a real MV GIS interconnected into an MV distribution grid such as UDEX would be:

- accelerated failure of switchgear components such as epoxy insulators or bushings inside the MV GIS tank using salt spray or other methods and testing sensitivity of sensor systems to act as an early warning detection
- simulating failure of joint connectors to identify if the temperature sensors are able to act as an early warning detection system
- testing single and multiple insulation failure types to understand and fine-tune performance of non-conventional (IEC 62478) sensor systems can identify different types of insulation failure within MV GIS and interconnected networks

Overall UDEX has the necessary facilities and capabilities in-house to carry out all such proposed testing and would be a suitable candidate for future collaborations.

6 Dissemination Planning

The work carried out during this transnational access is planned to be presented to the CIRED 2020 conference in Berlin.

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9 Annex

9.1 List of Figures

Figure 4.1	Single line diagram of test network with DUT in UDEX.....	12
Figure 4.2	Lateral and side view of GIS replica tank (DUT) used to EUT	13
Figure 4.3	DUT setup for creating partial discharge	13
Figure 4.4	UDEX lab setup showing DUT setup	14
Figure 4.5	Setup of antennas, sensors and monitoring systems	14
Figure 4.6	Setup of reference temperature (T _{ref}).....	14
Figure 4.7	Reference PD system with coupling capacitor (left) and HFCT sensor (right)	15
Figure 4.8	Control centre for UDEX environment.....	15
Figure 4.9	Control of test voltage from UDEX.....	16
Figure 4.10	Voltage increase used in partial discharge testing.....	16
Figure 4.11	PD reference reading on Coupling Capacitor	17
Figure 4.12	PD reference reading on HFCT sensor	17
Figure 4.13	System-A temperature monitoring	18
Figure 4.14	System-A partial discharge monitoring.....	18
Figure 4.15	Analysis of frequency detection of signals.....	19
Figure 4.16	System-B temperature monitoring	20
Figure 4.17	System-B partial discharge monitoring.....	21

9.2 List of Tables

Table 4.1	Impulse Levels to be tested	10
Table 4.2	Summary of System-A results.....	19
Table 4.3	Summary of System-B results.....	21