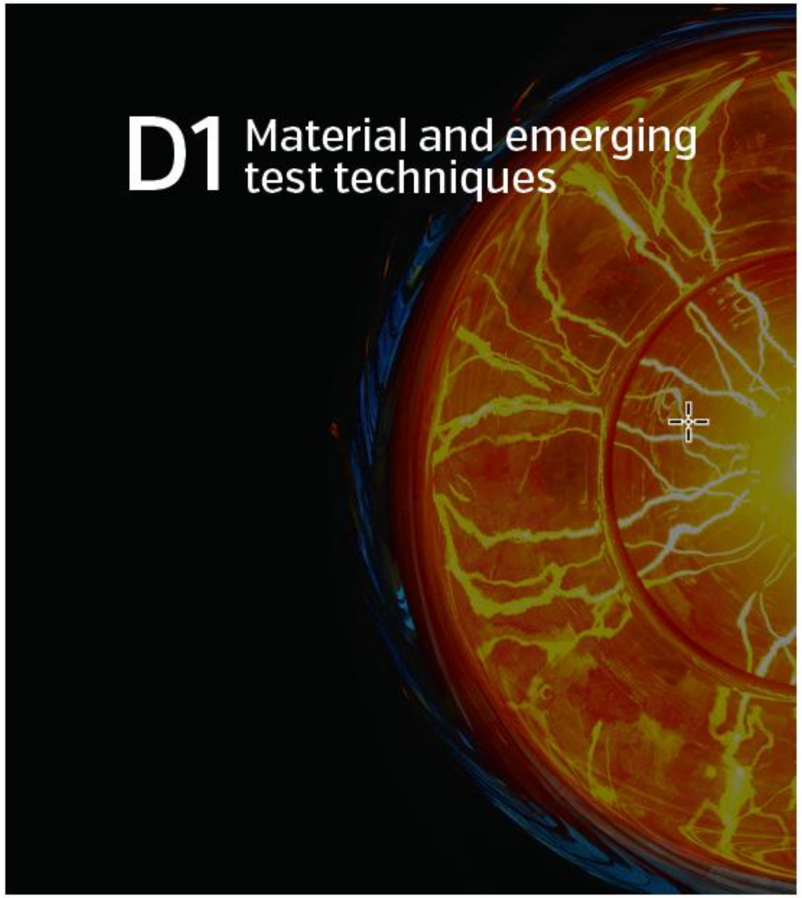
Requirements and application of UHF PD monitoring systems for gas insulated systems

Wojciech Koltunowicz (Convener of WG D1.66)

2025-03-19

For power system expertise



Requirements and application of UHF PD monitoring systems for gas insulated systems

cigre TECHNICAL BROCHURES
May 2024 - Reference 933

WG D1.66

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Chapter 1 – Introduction

Scope of the activity

CIGRE WG D1.66 was tasked with defining requirements for GIS Partial Discharge Monitoring systems to ensure that signals from incipient PD defects are reliably detected, monitored, and interpreted, so that asset managers can take prompt and appropriate actions to prevent equipment malfunction

UHF PDM systems are in widespread use throughout the world. In the last 10 years more than 700 systems have been installed on more than 85,000 UHF sensors (representative samples)

Chapter 2 - Demands on modern GIS PD monitoring

For one GIS owner, the appropriate strategy may be to install PDM systems on all of their GIS installations at or above a specified voltage level for the whole of the actual operational lifetime, while for another GIS owner, it may be optimal to install PDM systems based on the risk and criticality of individual substations

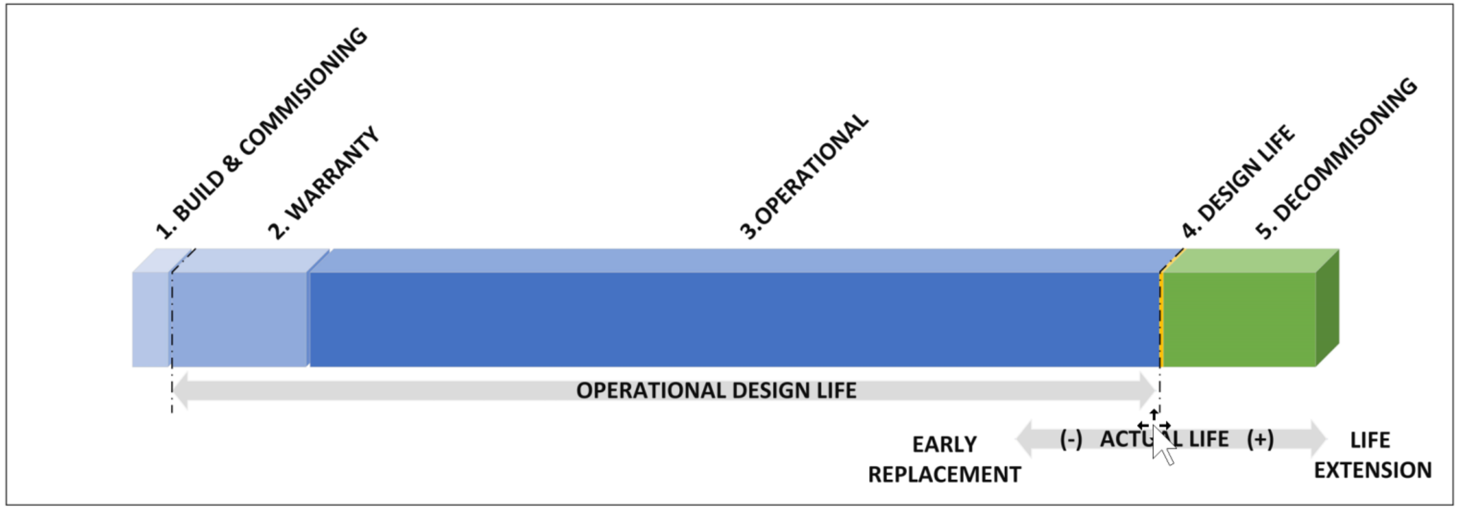

Figure 1 - The five value stages of GIS ownership

Chapter 2 - Demands on modern GIS PD monitoring

		manufacturing period	<1979	1979-1983	1984-1988	1989-1993	1994-1998	1999-2003	2004-2007
CIGRE , 3rd inquiry	100 - 200 kV	MaF, per 100 bay years	2.0	1.25	0.65	0.125	0.15	0.1	0.3
		thereof dielectric failures 1)	29%	20%	50%	50%	60%	43%	86%
		dielectric failures per 100 bay years 1)	0,58	0,25	0,33	0,06	0,09	0,04	0,26
	300 - 500 kV	MaF, per 100 bay years	4.0	2.0	1.3	0.6	0.4	0.3	0.55
		thereof dielectric failures 1)	23%	23%	11%	45%	70%	82%	40%
		dielectric failures per 100 bay years 1)	0,92	0,46	0,14	0,27	0,28	0,25	0,22
GIS Userforum	123 kV	dielectric failures, per 100 bay years	0.2	0.04		0.05		0.0	
	420 kV	dielectric failures, per 100 bay years	0.0	0.11		0.09			

1) updated based on detailed data of the 3rd CIGRE inquiry

Figure 2 - Comparison of the reliability data presented in the 3rd CIGRE international enquiry [and collected by the GIS Userforum

Chapter 2 - Demands on modern GIS PD monitoring

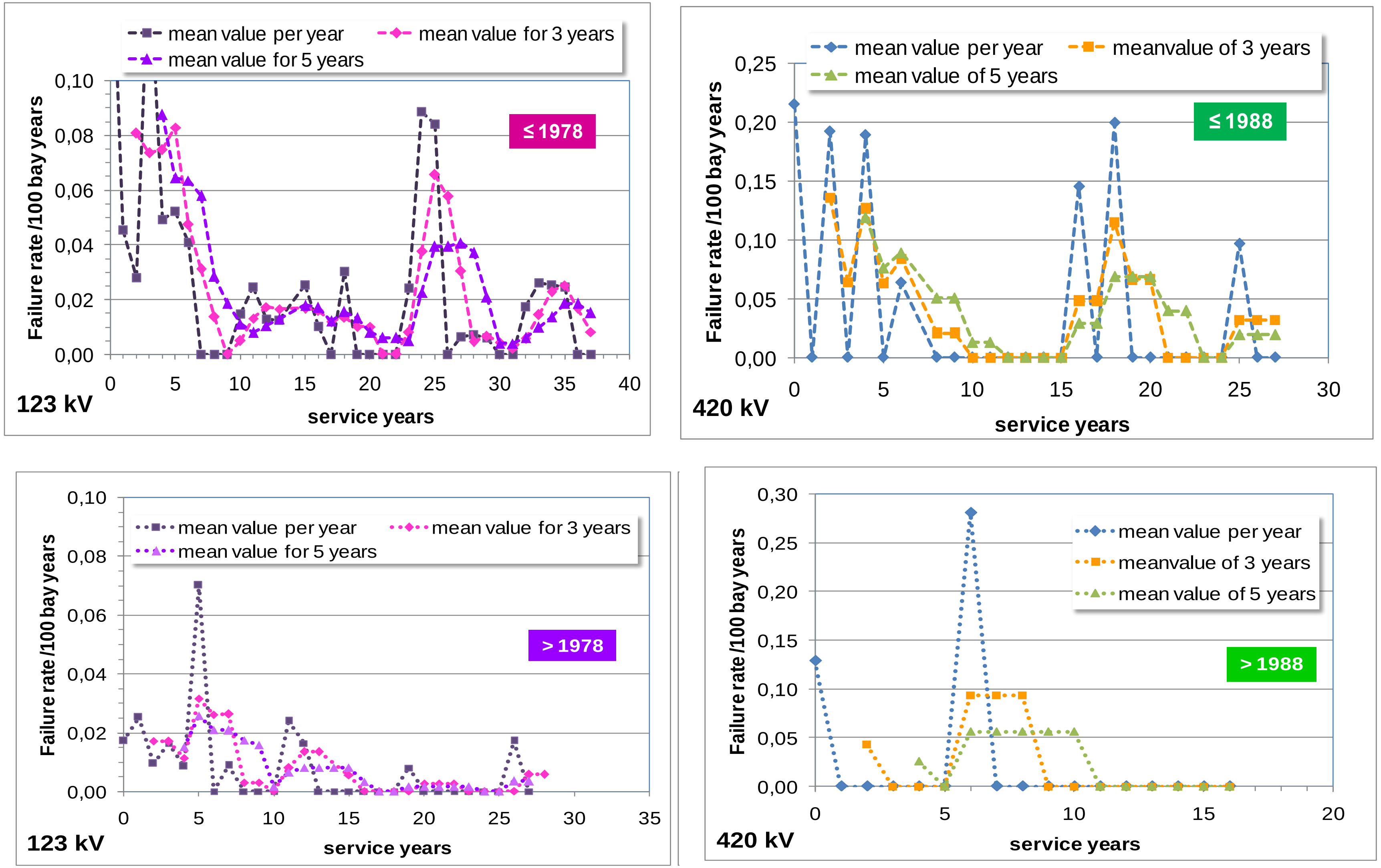

Figure 3 – Failure rates in GIS

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Chapter 2 - Demands on modern GIS PD monitoring

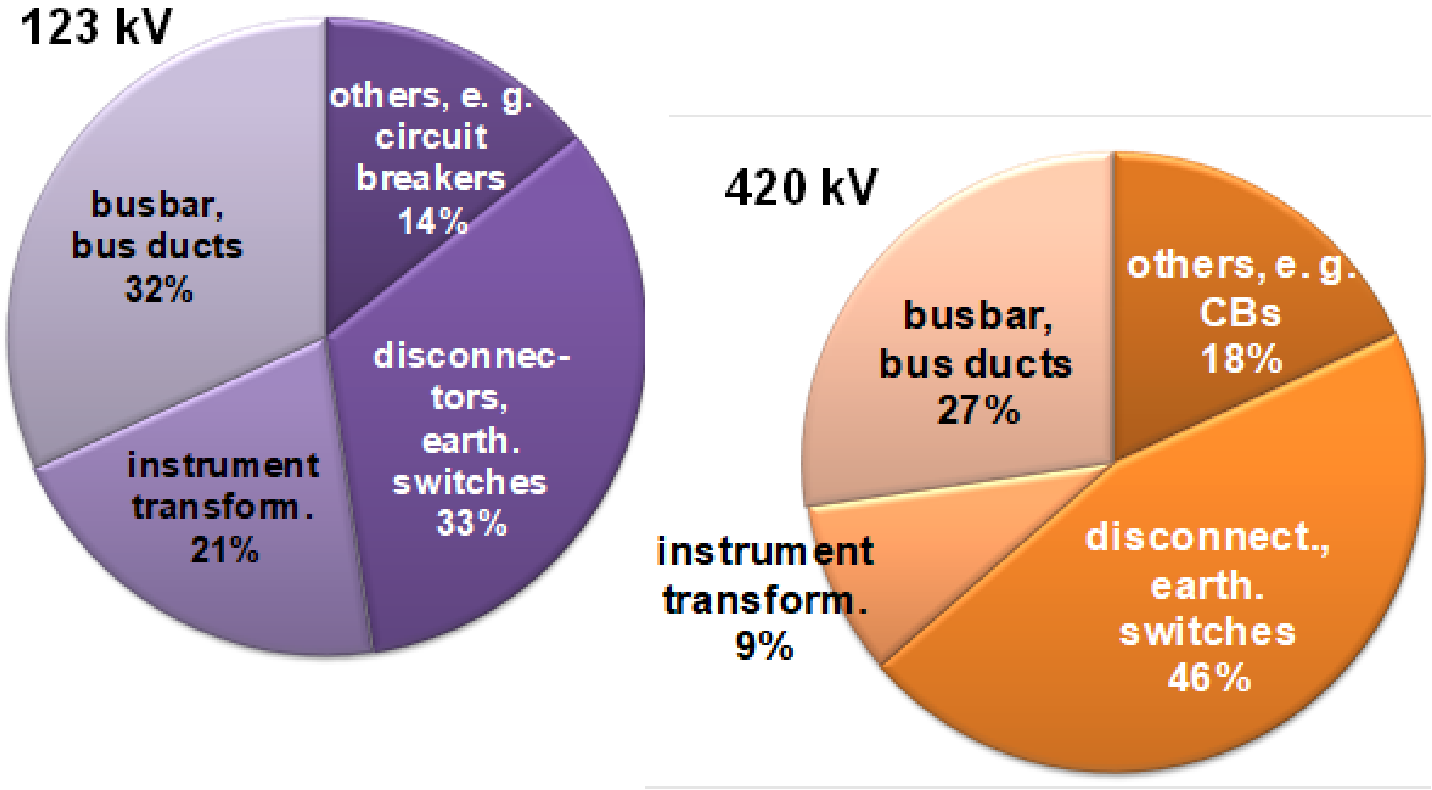


Figure 4 - Main root causes of failures in 123 kV and 420 kV GIS

In modern GIS, the failure rate should decrease, owing to lessons learned, improvements in design, and quality of the components installed

Inversely, if the GIS is PD-free, then the probability of failure is lower; PDM use contributes more to asset management decision making for maintenance and end-of-life prediction.

Chapter 3 – Functions and features of current PDM Systems

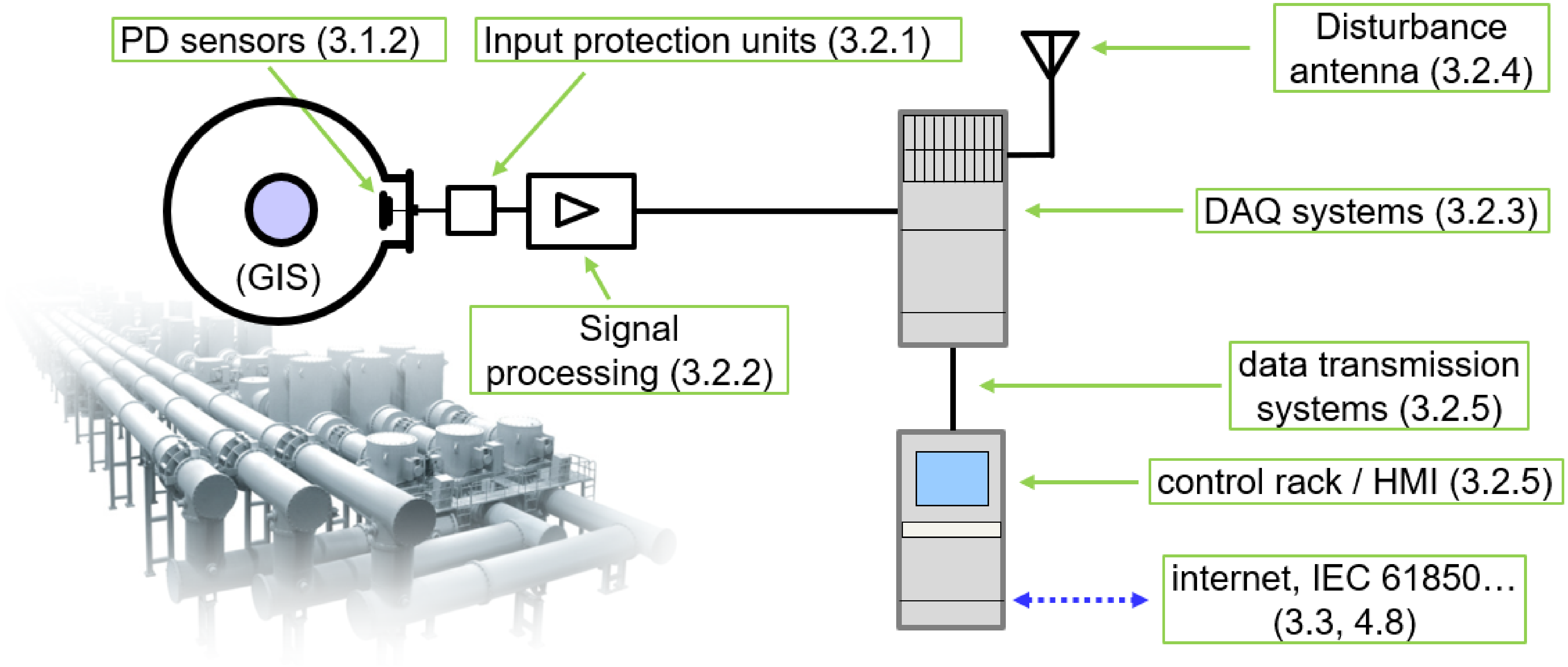


Figure 5 - General Architecture of current PD monitoring systems

Chapter 3 – Functions and features of current PDM Systems

Figure 6 - Examples of GIS/GIL UHF PD sensors

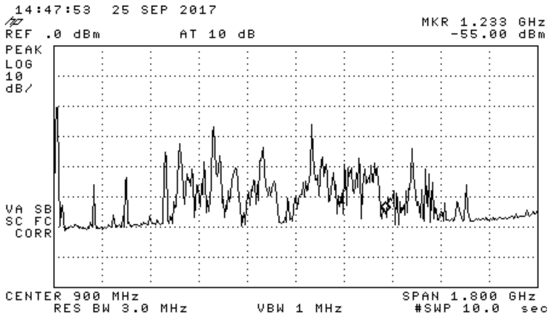
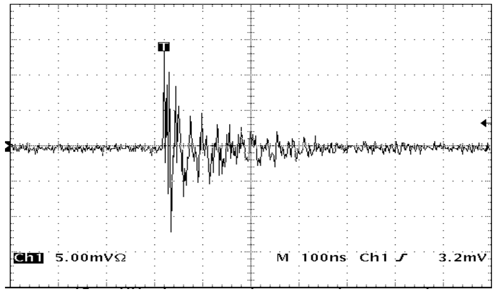
<table>
<tr><th>Frequency Domain PD Signal @ sensor output</th><th>Time Domain PD Signal @ sensor output</th></tr>
<tr><td>
</td><td>
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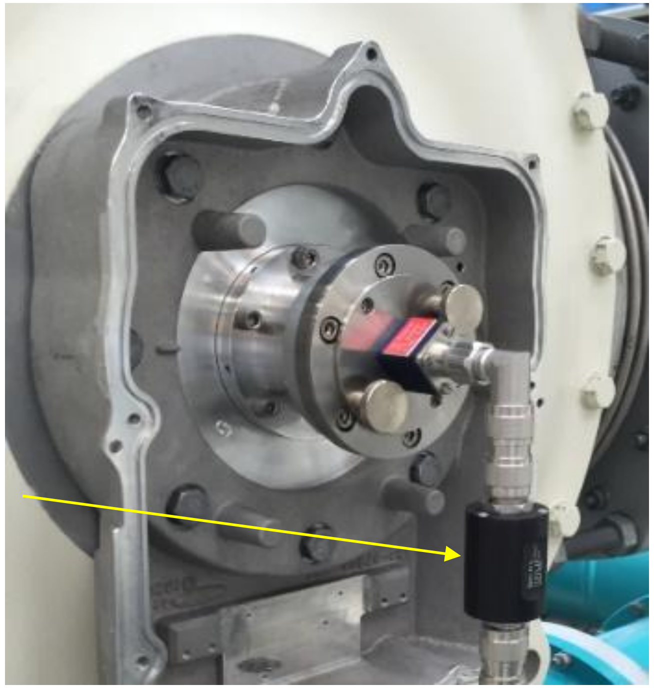
Figure 7 - UHF impulse measured at the output of an internal sensor

Chapter 3 – Functions and features of current PDM Systems



Input protection module

Acquisition system

Indoor system with 120 channels

Figure 11 – System elements

Chapter 3 – Functions and features of current PDM Systems

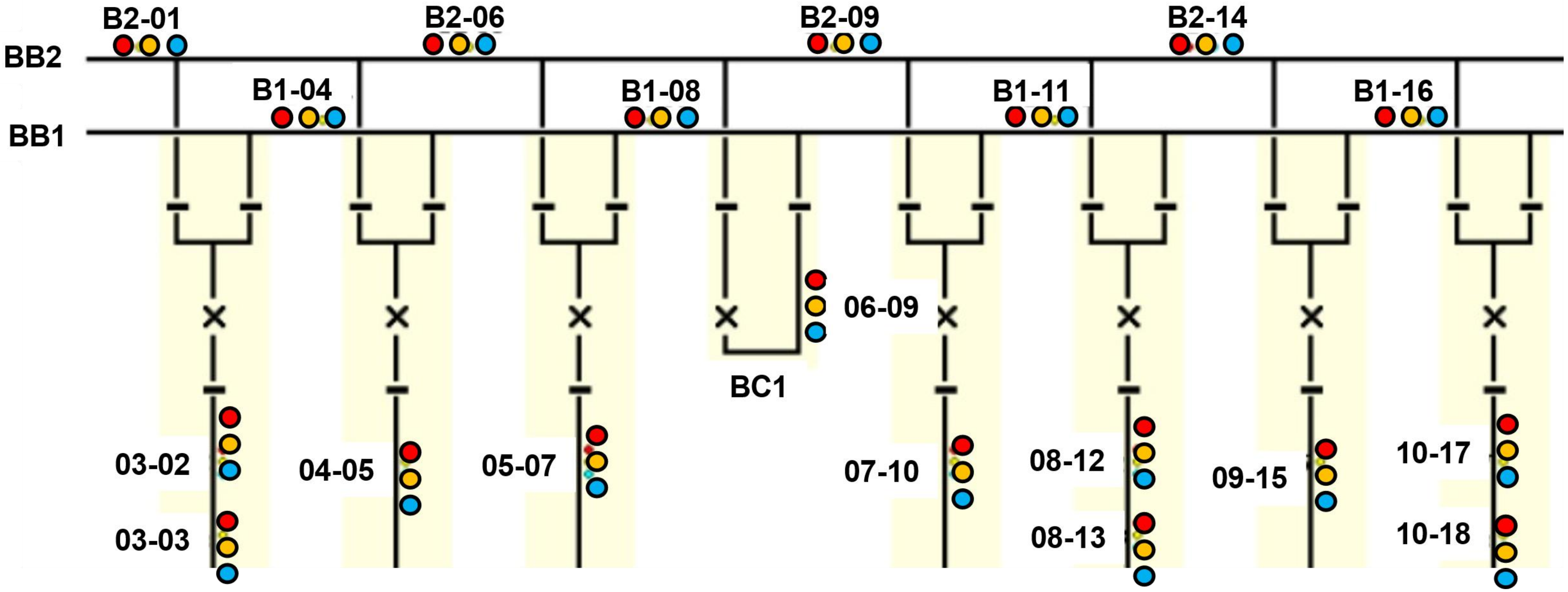


Figure 13 - Example of 400 kV GIS PD monitoring system overview screen

Chapter 3 – Functions and features of current PDM Systems

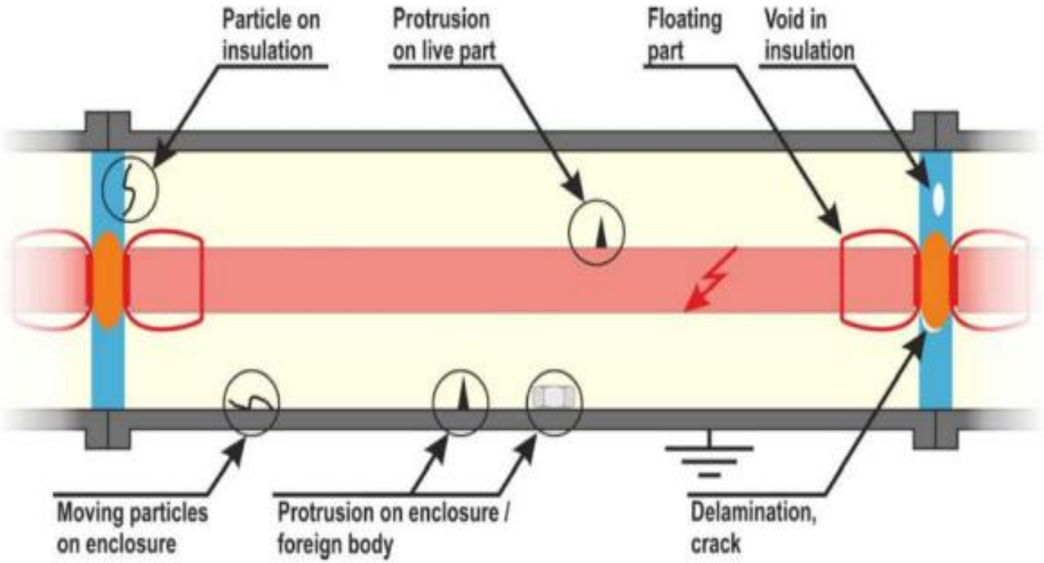


Figure 8 – Typical defects in GIS installation

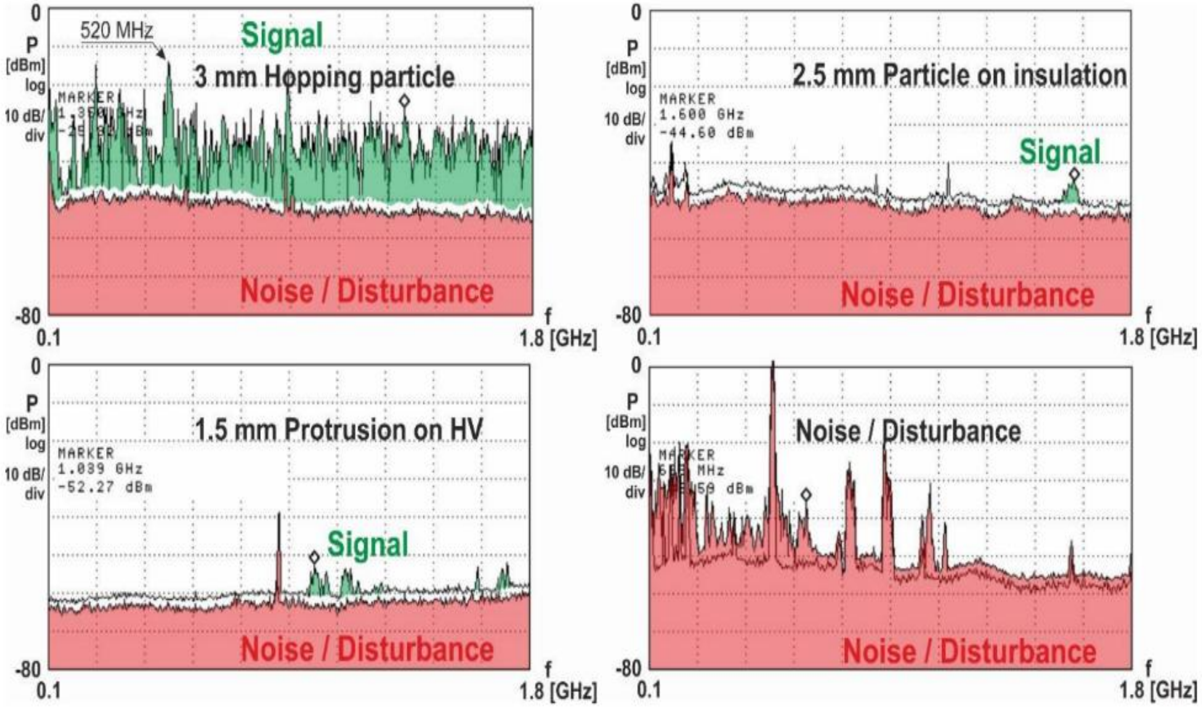


Figure 9 - Examples of UHF spectra for different defects

Chapter 3 – Functions and features of current PDM Systems

Figure 14 - Examples of
phase-resolved PD data patterns

Chapter 3 – Functions and features of current PDM Systems

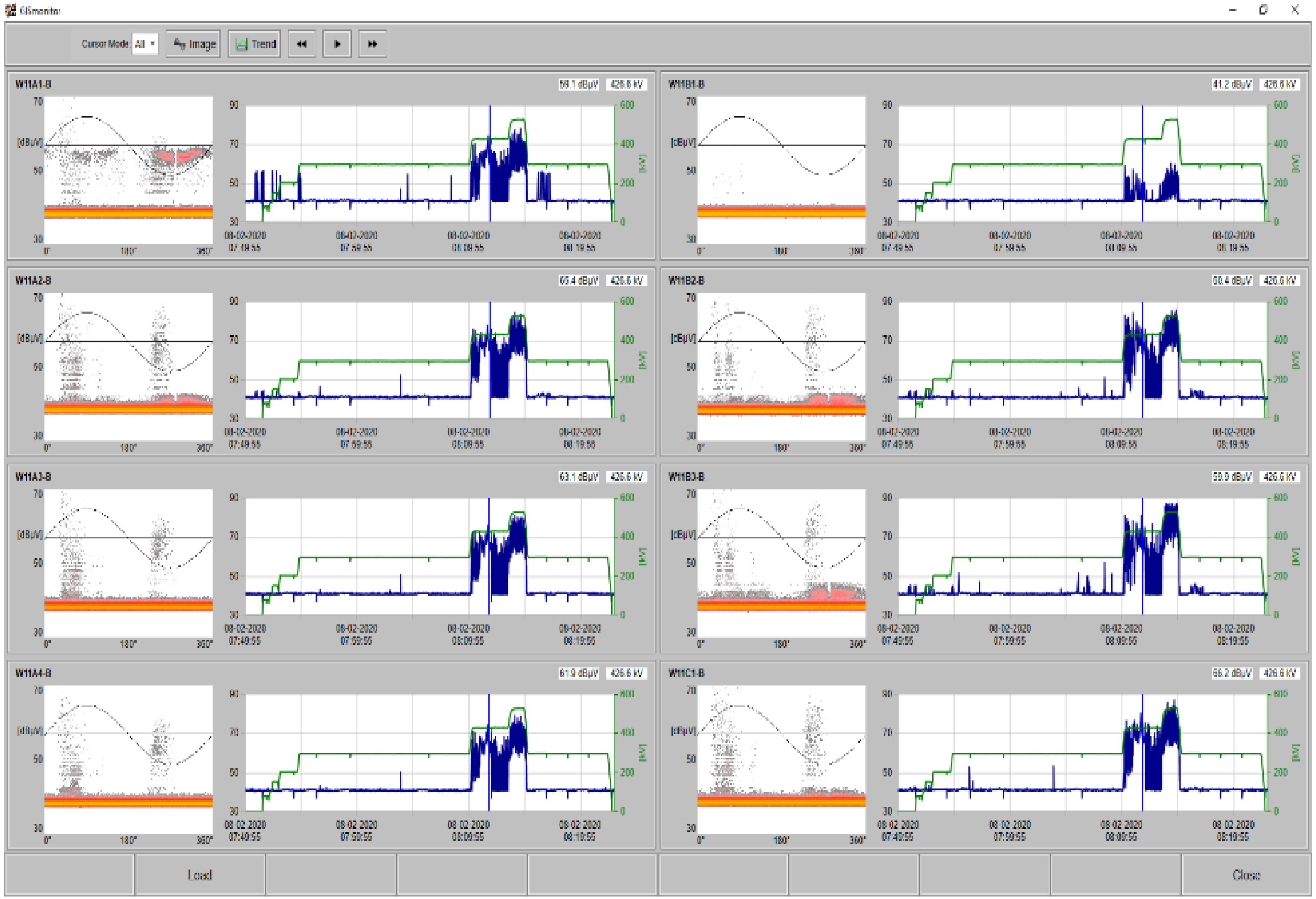


Figure 15 - Screenshot from a PDM system recording data during HV commissioning test

Chapter 3 – Functions and features of current PDM Systems

	Functions and features of the most advanced PDM systems
Strengths	Applicable for all kinds of UHF sensors; internal sensors are preferable owing to better signal-to-noise capability
	With multi-channel synchronous PDM Systems, all PD pulses/events are independently acquired.
	Capable of performing CIGRE TB 654 UHF Sensitivity Procedure Steps 1 and 2
	Provide external communication interfaces in accordance with the appropriate applicable standards (e.g. IEC 61850)
	Integrate PDM systems on GIS of different voltage levels into one general overview control system
	Support the on-site HV acceptance test during commissioning of the GIS; normally a separate, purposely designed HV test mode incl. voltage/PD recording vs. time
	PDMS GUI offers a user-friendly single line diagram; GIS Overview shows suspicious PD signal activity at a glance
	Are scalable/extendable
	Provide remote access to the PDM system
	Most systems provide external UHF disturbances cancellation features (both software- and hardware-based)
	Are safe in operation (protection front end modules) and pose no risk to insulation integrity of GIS/GIL
Weaknesses	**Technical weaknesses:**
	External noise discrimination is often challenging to setup; external disturbances often generate false alarms
	Expert systems are not efficient or accurate
	Alert/warning procedure do not consider results from the sensitivity check and from the signal profile measurements
	Other types of weaknesses:
	Present PDM systems run in stand-alone mode (i.e. they operate in isolation from other monitoring systems)
	FAT for PDM systems are not defined or standardized, making it difficult to assign and assess pass/fail criteria
	Data format and displayed information (graphs, trends, PD patterns, etc.) are not standardized and not compatible between systems of different vendors; PD amplitude reference points are not clearly specified;
	Computers and some DAQ boards of PDM systems have to be replaced after several years of operation; long-time quality and robustness are limited, component obsolescence (a problem intrinsic to electronic hardware)
	By definition,use of multiplexing detection methodologies raises the possibility of missing some intermittent PD signals Use of narrow-band detection methodology without spectrum analysis (wideband scanning) risks missing severely frequency band-limited PD signals

Figure 15 – Weaknesses and Strengths of current PDM systems

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Chapter 4 – Requirements for UHF PDM systems

PD defect / noise	A	B	C	D	E	Human Experts
Particle						
Void						
Protrusion						
Floating Electrode						
Particle on Insulation						
Noise						

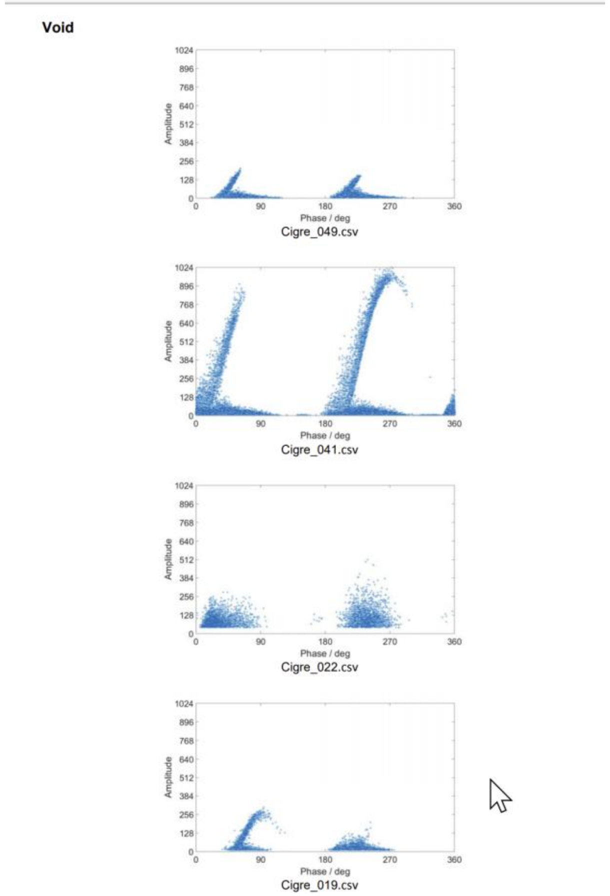
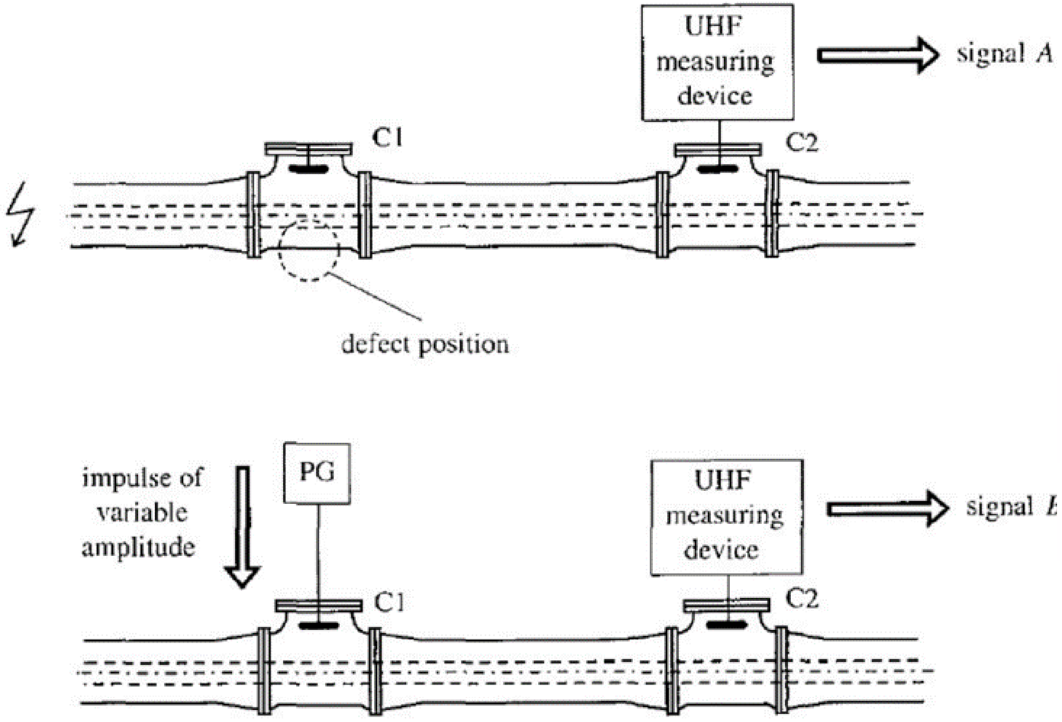


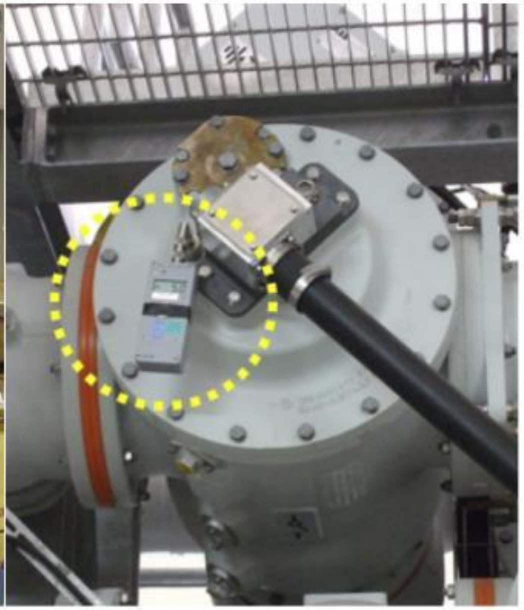
Figure 16 - Results of PD identification by pattern recognition algorithms (A-E) and human experts (green box indicates correct identification)

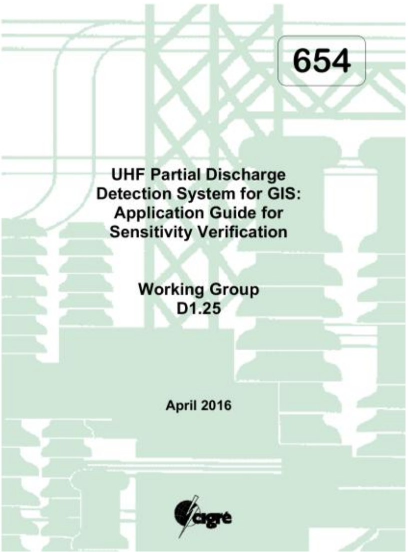
(based on the evaluation of defined PRPS data sets representing PD signals and noise)

Chapter 4 – Requirements for UHF PDM systems

UHF PD measurements in GIS/GIL: System sensitivity check



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UHF Partial Discharge
Detection System for GIS:
Application Guide for
Sensitivity Verification

Working Group
D1.25

April 2016

Test set-up for UHF Sensitivity check according to CIGRE requirements (TB 654)

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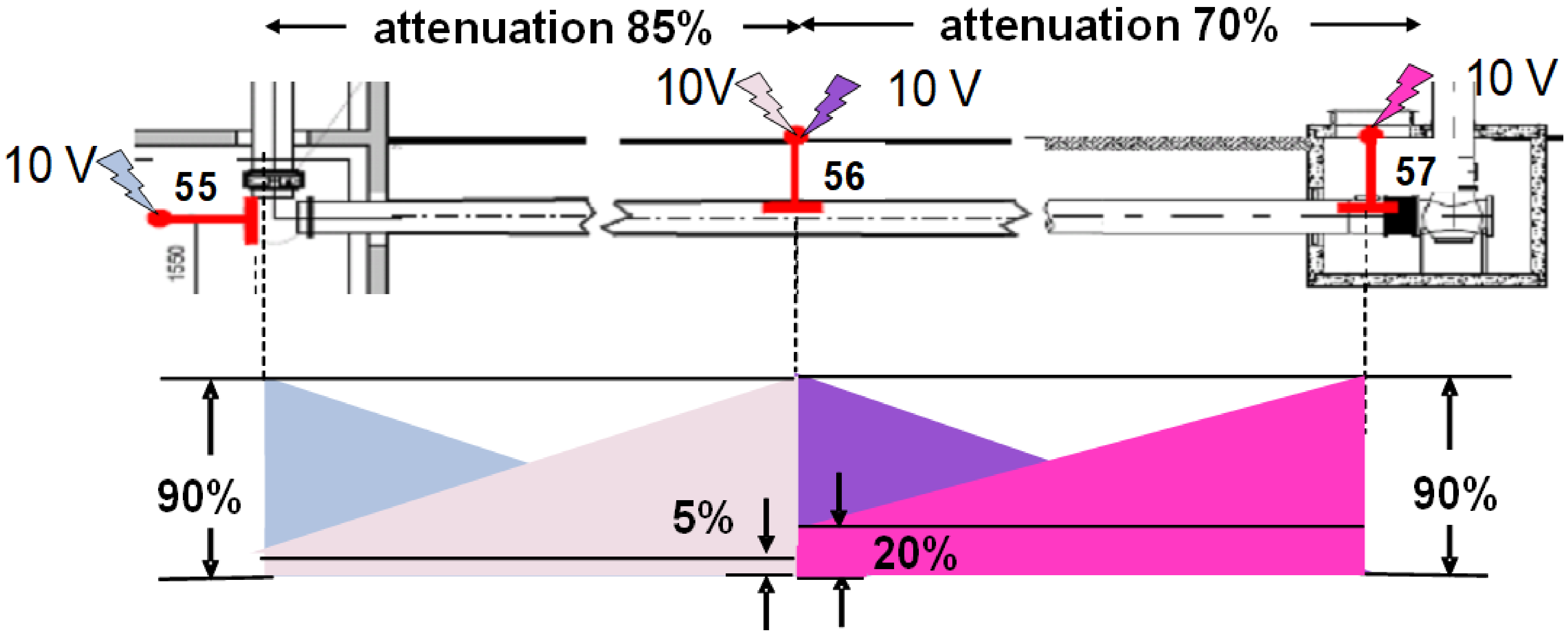
Chapter 4 – Requirements for UHF PDM systems

PD Signal profile measurements



The attenuation profiles are an approximation; they are determined during the Step 2 test by injecting a pulse signal in one sensor, acquiring it at the next adjacent sensor and recording the received signal amplitude.

Figure 17 - PDM system commissioning – attenuation signal profile measurments

Chapter 4 – Requirements for UHF PDM systems

Warning and alert procedure

The determination of an appropriate alert level can be derived from the information gathered during the CIGRE TB 654 Sensitivity Verification Steps 1 and 2.

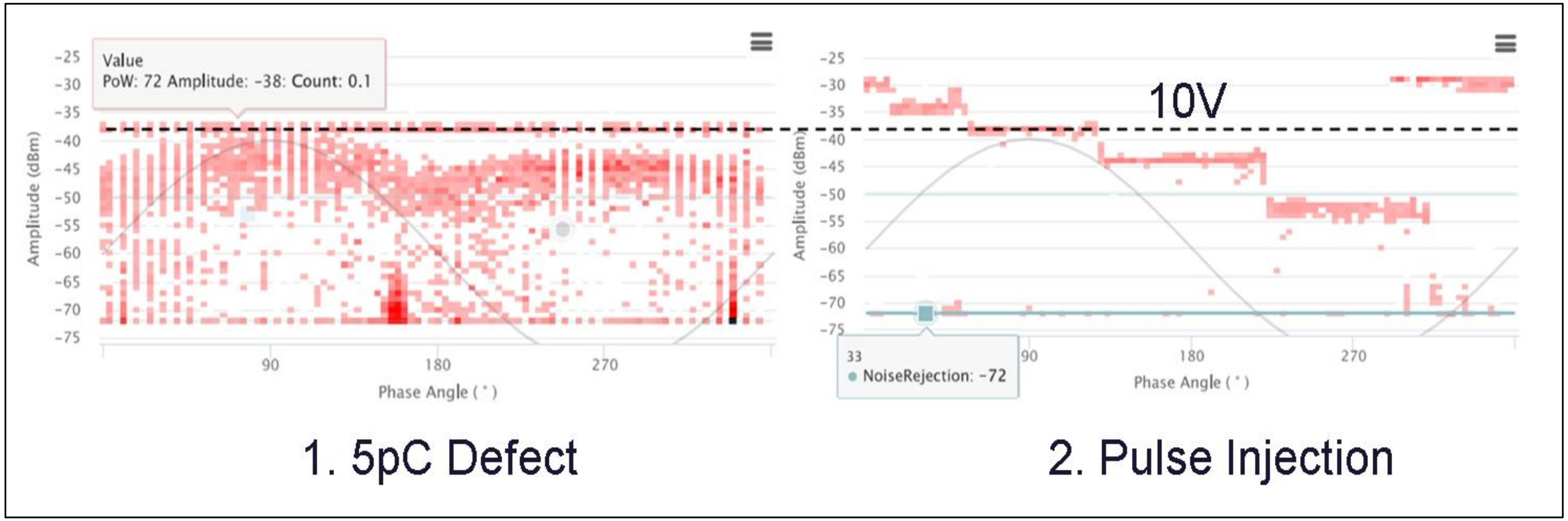
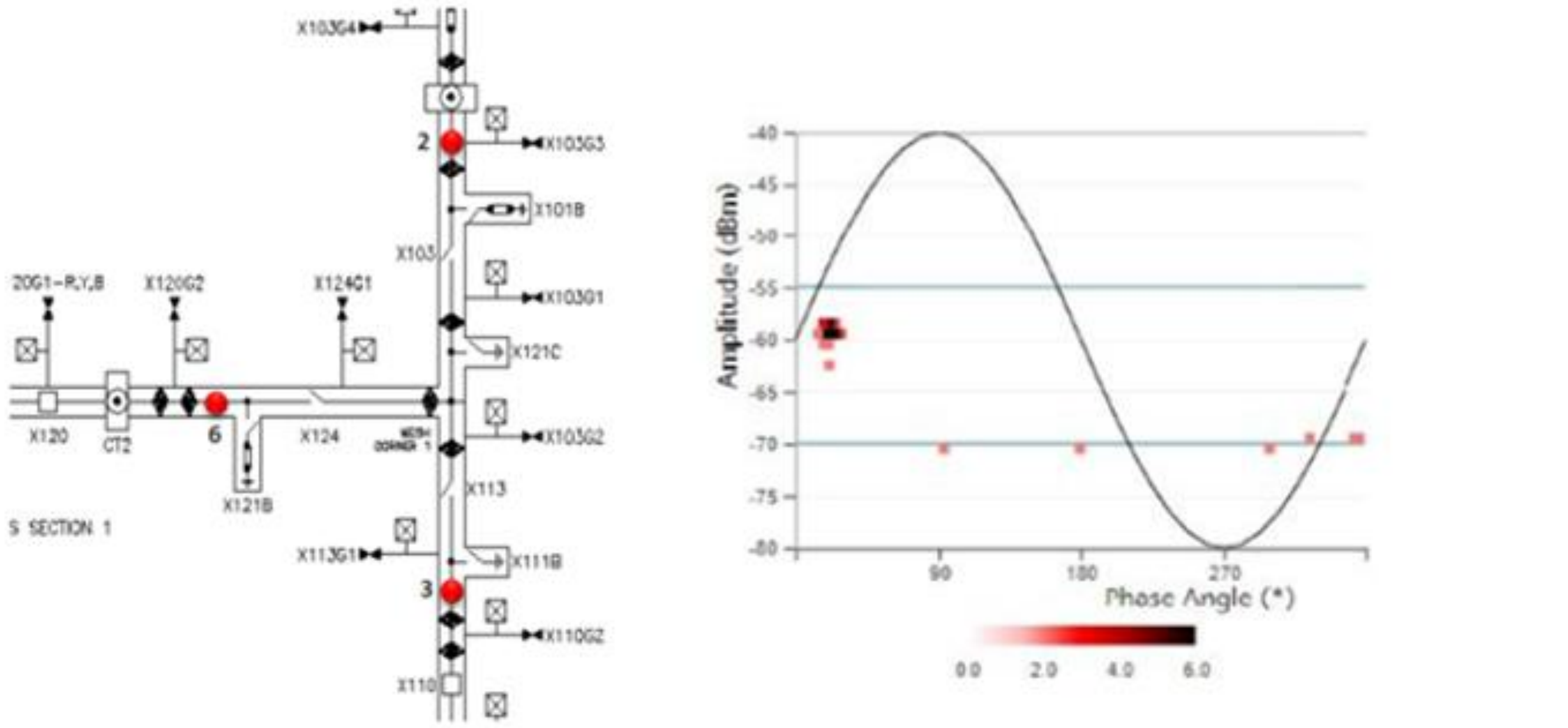


Figure 19 - Sensitivity Step 1 Test Result

A 5 pC mobile particle defect is measured with an amplitude of -37 dBm, corresponding to an artificial pulse magnitude of 10 V.

Chapter 4 – Requirements for UHF PDM systems



10V injected at sensor 2 and received at sensor 6; the sensitivity level of channel 6 is equivalent to -59 dBm

Chapter 4 – Requirements for UHF PDM systems

Warning and alert procedure

The data acquisition threshold, known as DT_B, can be set according to the results of the TB 654 Sensitivity Test Step 2. The threshold shall be between the sensitivity level A_s, and the background noise level. When there are multiple adjacent sensors, the lowest value of A_s shall be used.

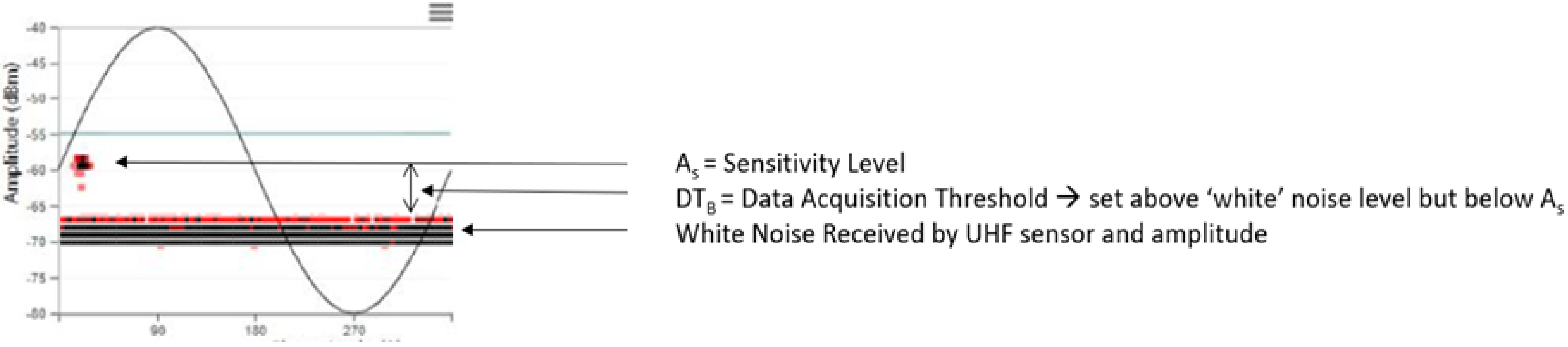


Figure 21 - Illustration of determination of DT_B

Chapter 4 – Requirements for UHF PDM systems

Warning and alert procedure

If the values recorded by the PDM system during Step 1 are declared as *APD* and the attenuation between two sensors in Step 2 are measured and declared as *ATT*, then an alert level (*AL*) can be defined as follows:

$$AL = APD - \alpha ATT$$

The value of α represents an estimation of the relative distance of the partial discharge source between two sensors. Typically, a value of α = 0.5 can be used to represent the attenuation of the signal at the mid-point of two sensors. If the same PD source can be detected at two adjacent sensors, it is possible to improve the estimate of α and thus determine the alert level more accurately.

Chapter 4 – Requirements for UHF PDM systems

Warning and alert procedure

Simplified Method

Following the case study above, we can state that *APD* = -37 dBm and *ATT* = 22 dBm. Therefore, the alert threshold level for sensor 6 shall be:

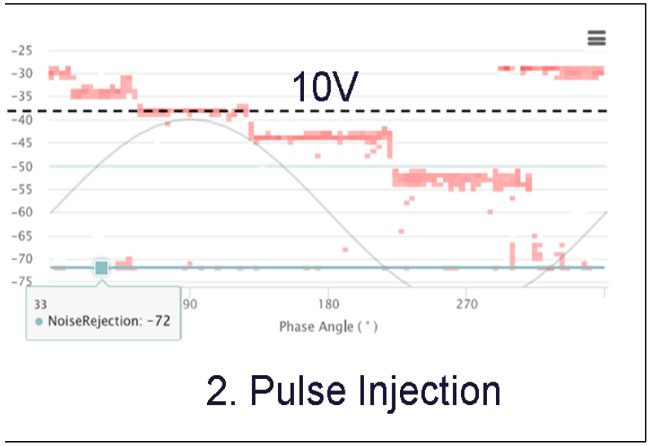
$$AL = -37 - (0.5 \times 22) = -48\ dBm$$

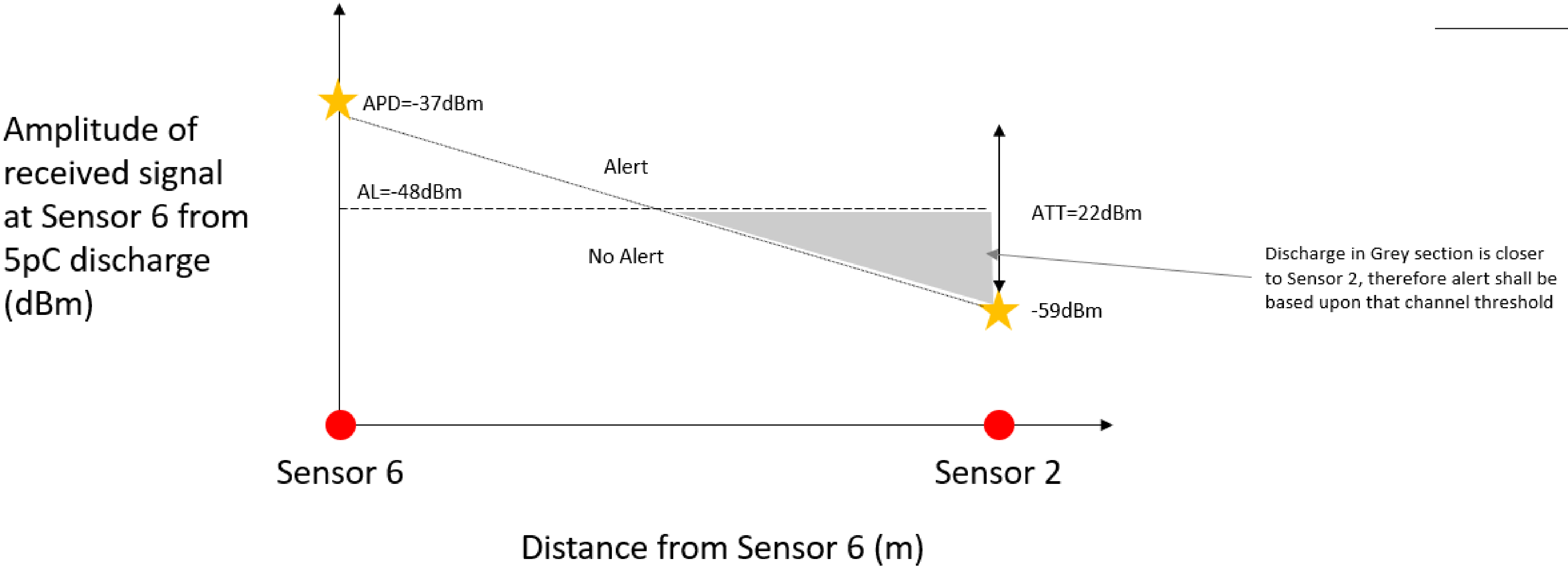
Only a partial discharge signal recorded at Sensor 6 of a value above -48 dBm can be declared as greater than or equal to 5 pC (assuming linear attenuation) and an alert may be raised. If the value is less than -48 dBm, then the level shall be checked on Sensor 2, and an alert may still be raised. This procedure is visualized in Figure 4.26.

For instances where a sensor has multiple adjacent sensors, then the lowest value for *AL* for each sensor pairing shall be used for that sensor, to ensure the 5 pC coverage at all points.

Chapter 4 – Requirements for UHF PDM systems

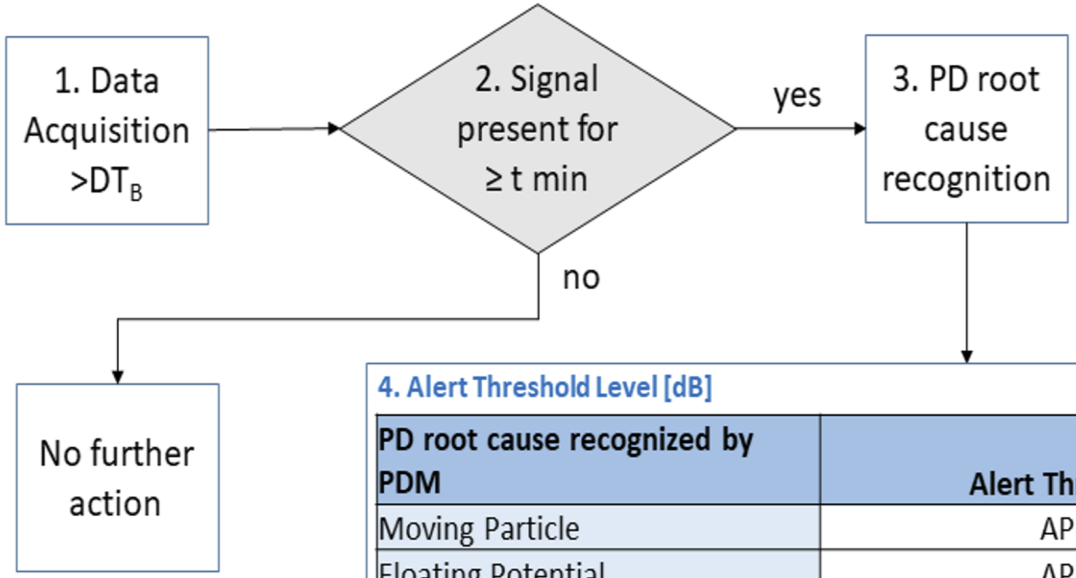
Warning and alert procedure





Chapter 4 – Requirements for UHF PDM systems

Warning and alert procedure



4. Alert Threshold Level [dB]

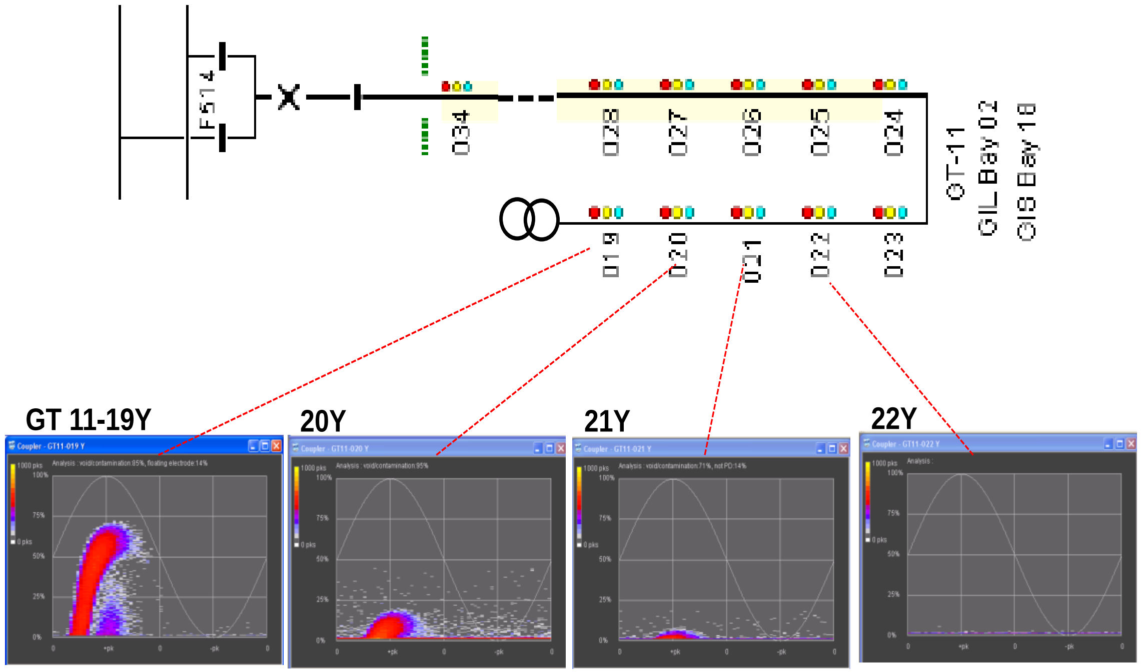
PD root cause recognized by PDM	Alert Threshold Level
Moving Particle	APD- α ATT
Floating Potential	APD- α ATT
Void in Insulator	APD- α ATT
Protrusion	APD- α ATT - p dB
Particle on Insulation	APD- α ATT - p dB
Noise	no Alarm

APD = signal amplitude measured in dB for a Moving Particle in Step1 of Sensitivity Test
ATT = difference between APD and Signal strength at sensor 2 location during commissioning
α = Estimation factor of relative distance between sensors
p = Adjustment factor for alternative defects

Figure 22 - Warning and alert procedure

Chapter 4 – Requirements for UHF PDM systems

Risk assessment procedure



		GT11-19Y
		CIGRE TF D1.03.09
		calculation of failure probability based on PD diagnostics
		PD defect type: Void
		proposed diagnosis confidence: 100 % a) 75 % b)
location		no influence
		failure probability due to location
voltage level and wave shape		
AC voltage level	1	service voltage = 1, over voltage = 0,5
inception by transient voltages	0	yes = 0,7, no = 0, unknown/ no effect = 1
	25,0 %	**failure probability due to voltage dependencies**
time dependencies		
trend of magnitude	1	continous=?, decrease=?, increase=? , unknown=1
activity	1	intermittend = 0, continuous = 1, unknown = 1
phase angle	1	stabelised = 1, variable = 0,5, unknown = 1
inception voltage	1	increasing = 0, decreasing=1 unknown = 1
	50,0 %	**failure probability due to time dependencies**
defect type properties		
size, number, shape	____	not available by PD diagnostics
		failure probability due to criticality of defect
minimum failure probability	0 %	
maximum failure probability	100 %	
defect specific risk =	**75,0 %**	
total failure probability =	**75,0 %** a)	**81,3 %** b)

The PD signal was acquired at service voltage and the PD inception not directly related to a transient voltage. The activity was continuous and its phase position stable.

Figure 23 – Example of dielectric failure probability calculation according to TB 525

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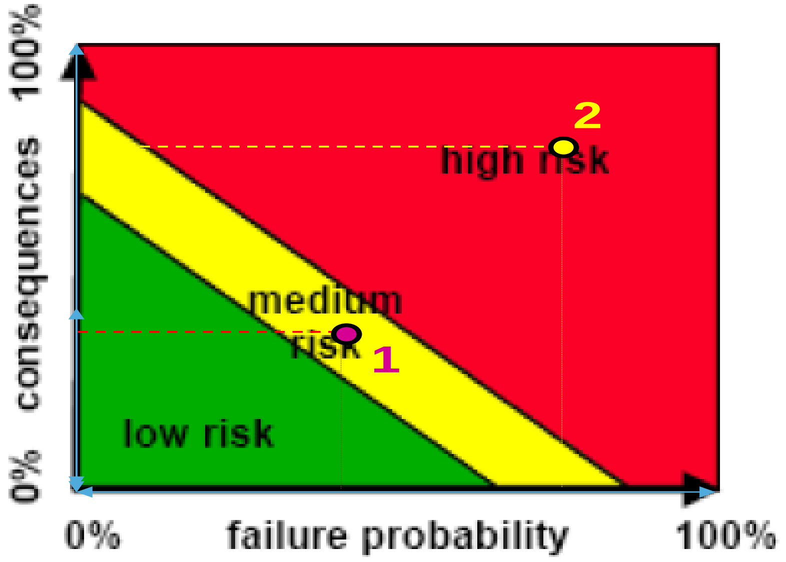
Chapter 4 – Requirements for UHF PDM systems

Risk assessment procedure

Example is related to a power station infeed, for which outage costs for non-delivered energy had been agreed, i.e. indicating the substation is of high importance. Moreover, spare parts were presumably not available and a long duration of repair work had to be assumed. Hence, high consequences of 80% were estimated.



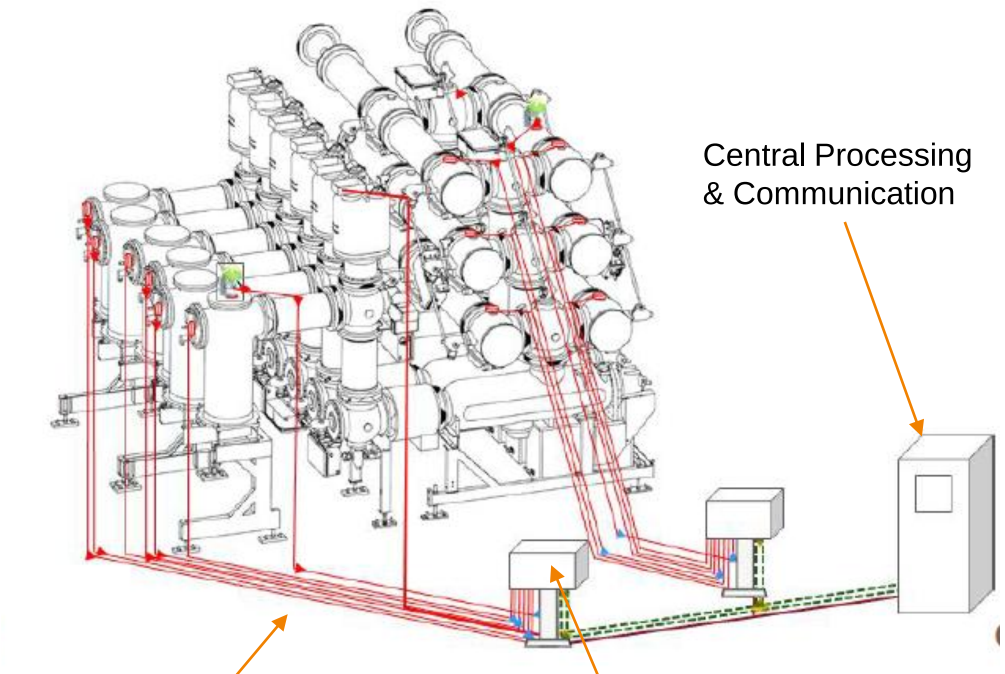
Chapter 6 – Conclusions

- New drivers and expectations for condition monitoring systems are described.
- The technical advantages and features of different monitoring solutions currently available on the market are shown and the minimum requirements for a GIS PDM system are given.
- One of the most pressing challenges facing GIS PDM systems is to significantly reduce the number of false alarms, and for this purpose, a novel warning/alert procedure is proposed. It recommends using the results from the CIGRE TB 654 UHF sensitivity check along with UHF signal attenuation profiles to set threshold values for each UHF sensor.
- Accurate and reliable automated PD defect type recogntion plays a privotal role in both reducing false alarms and revealing defects which actually pose risk to operation and thus has to be further developed and implemented.

PARADIMO 100

Ultra-high-frequency partial discharge monitoring system for GIS and GIL

Central Server Concept vs. New IoT Concept



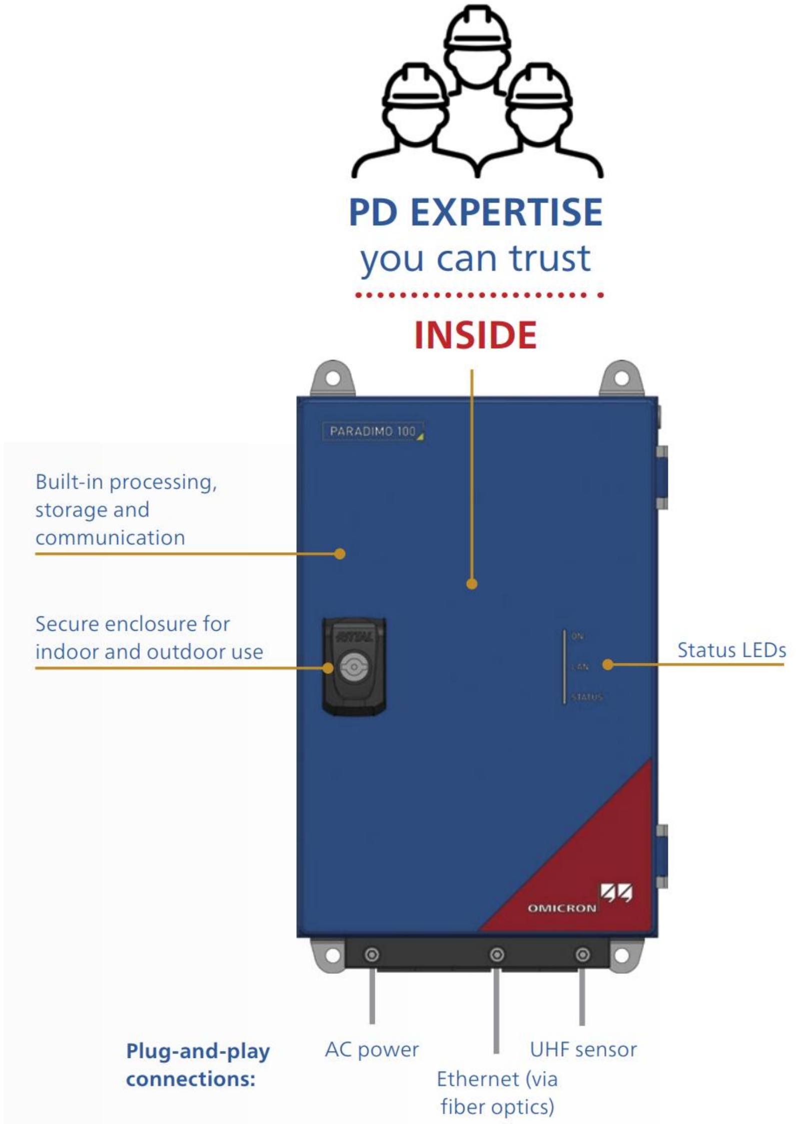
short analog connections

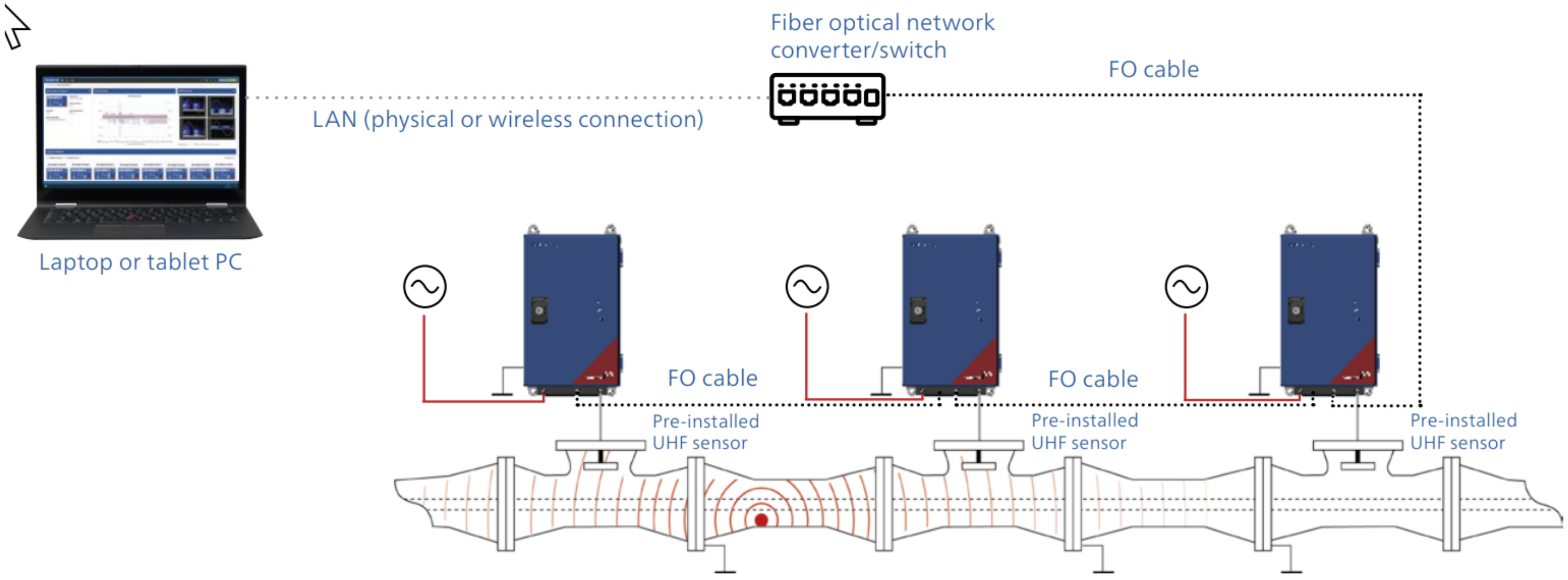
Processing, Digitization & Communication
in one unit close to the coupler

Your Benefits:
- Less HW required (e.g. no server)
- Less SW required (All-in-one Unit)
- High sensitivity due to short analog cables
- Easy integration into IT network

PARADIMO 100

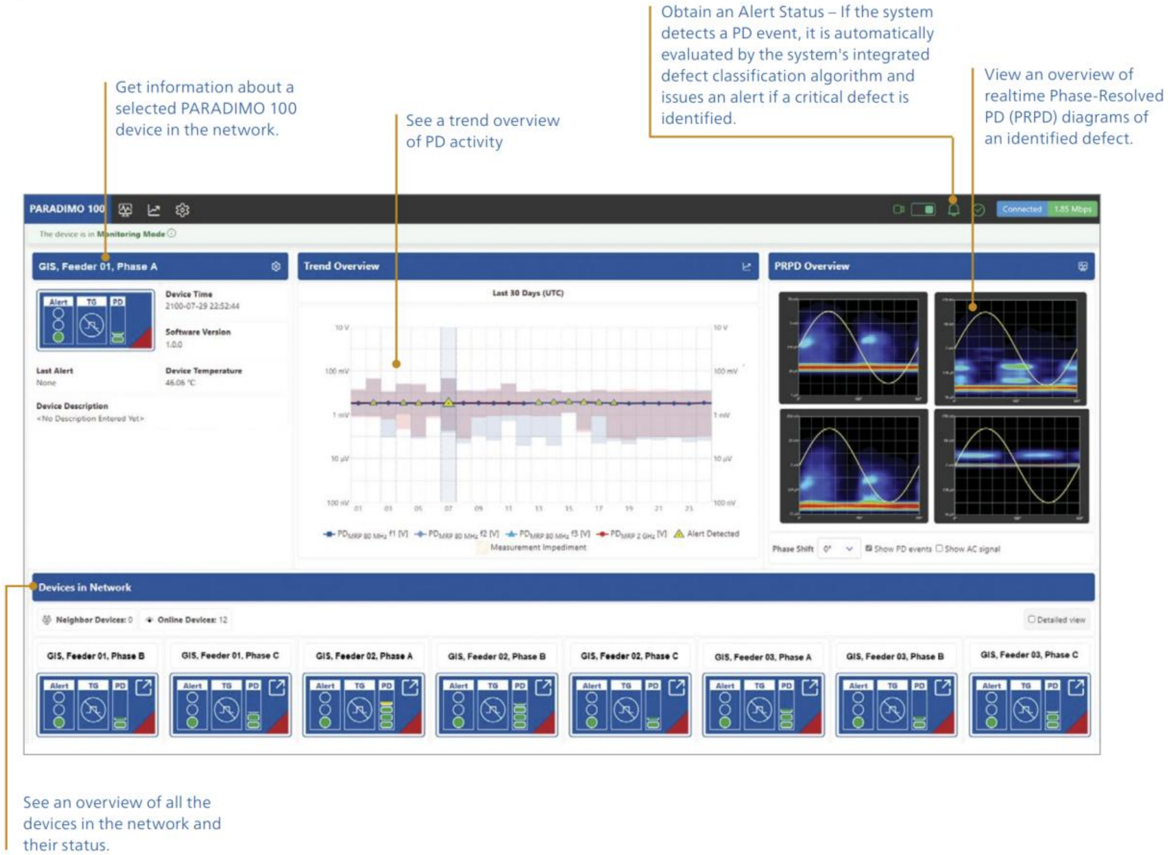
Ultra-high-frequency PDM System for GIS and GIL

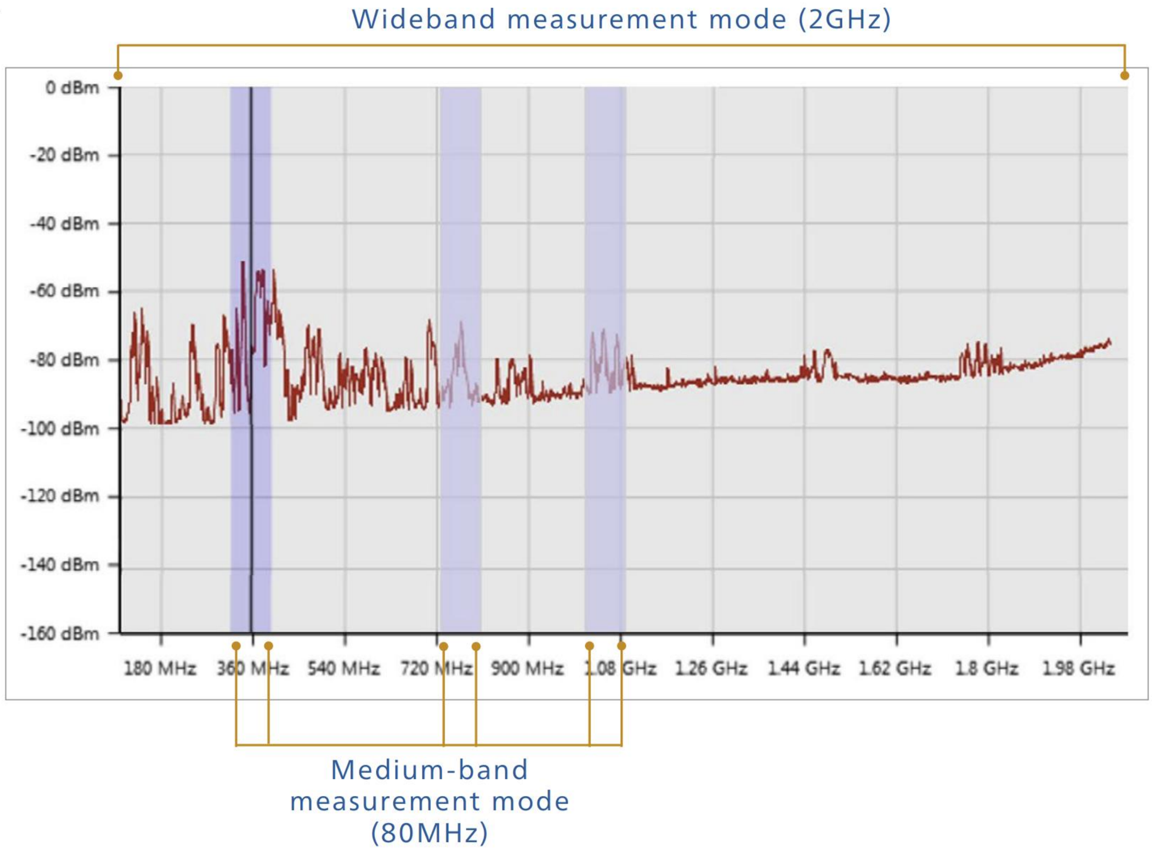




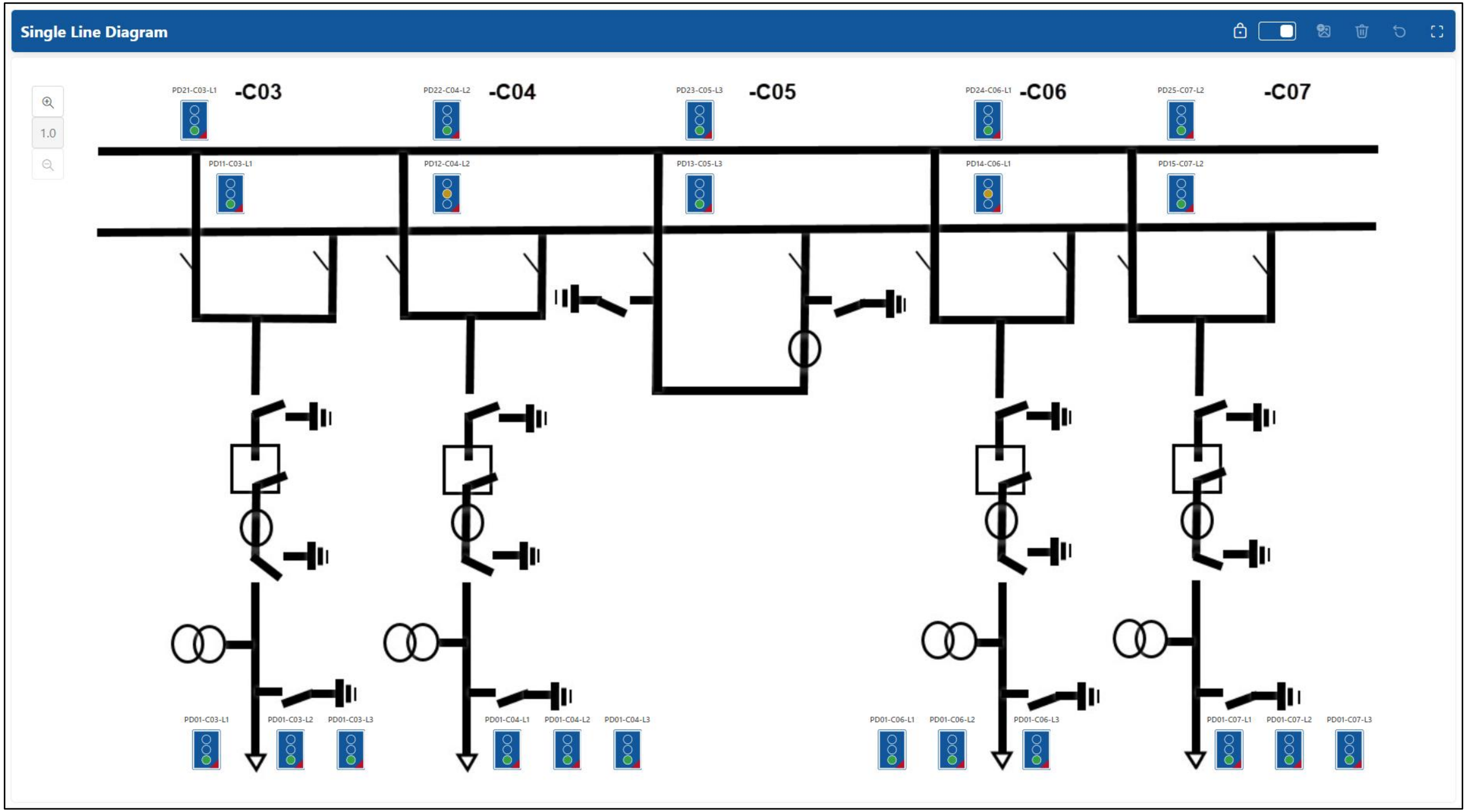
Connection of PARADIMO 100 devices via a fiber optical network converter/switch to a PC or tablet computer using a web browser for remote network access.

PARADIMO 100



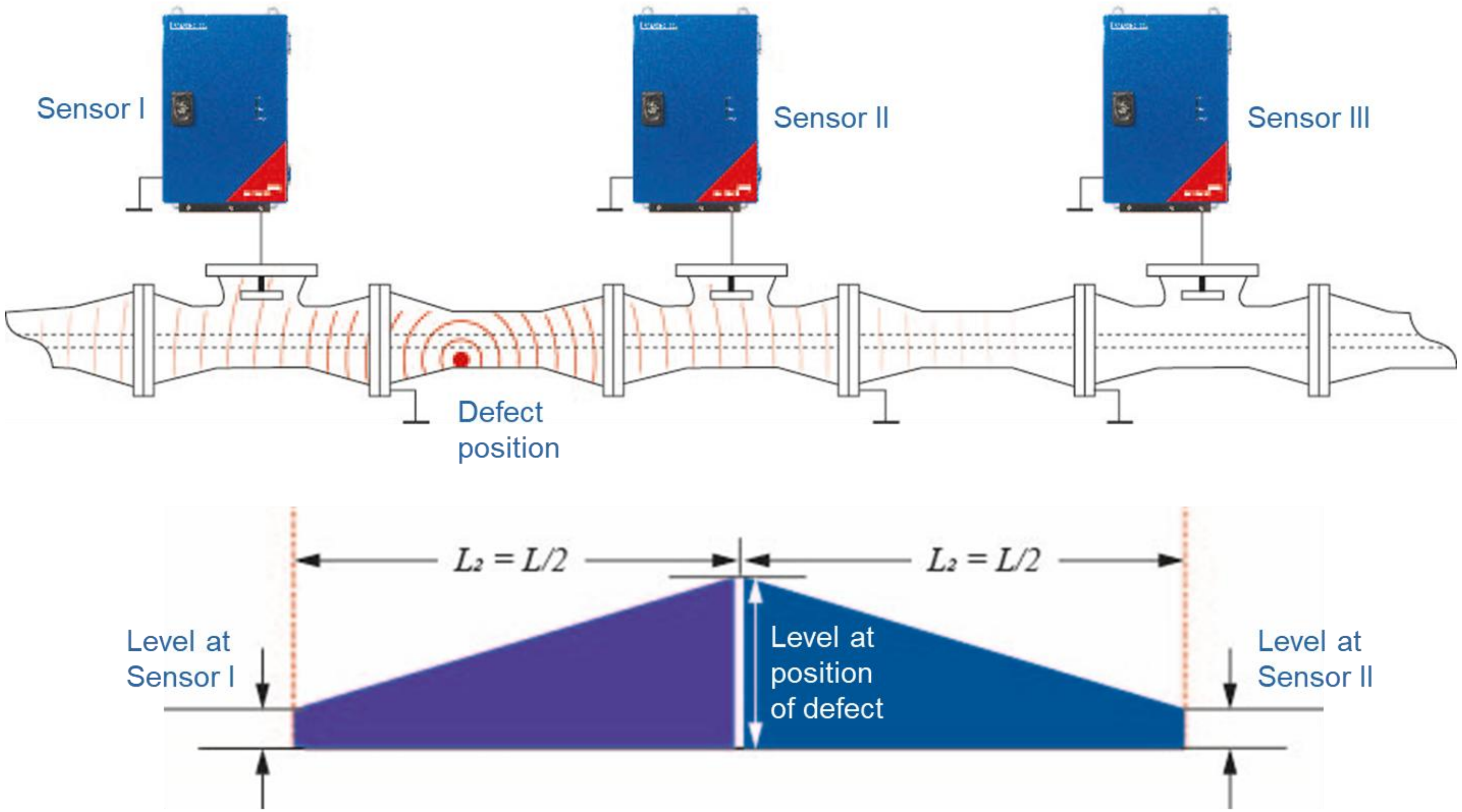


System Overview



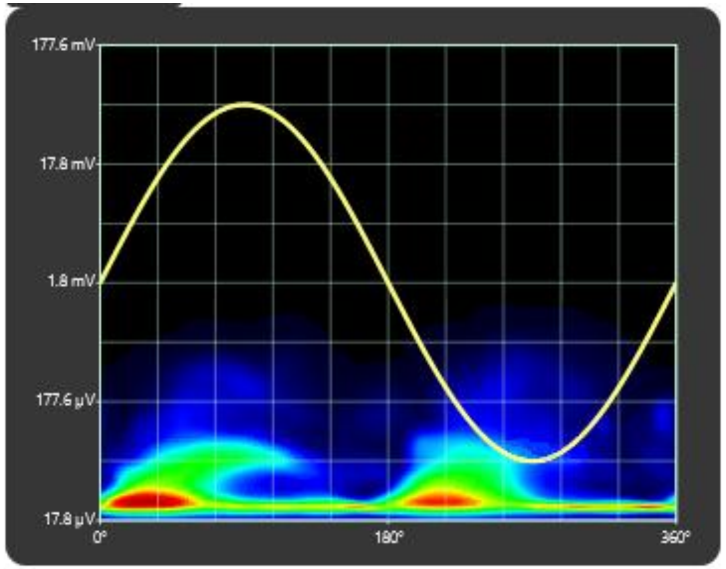
Smart alarming algorithm

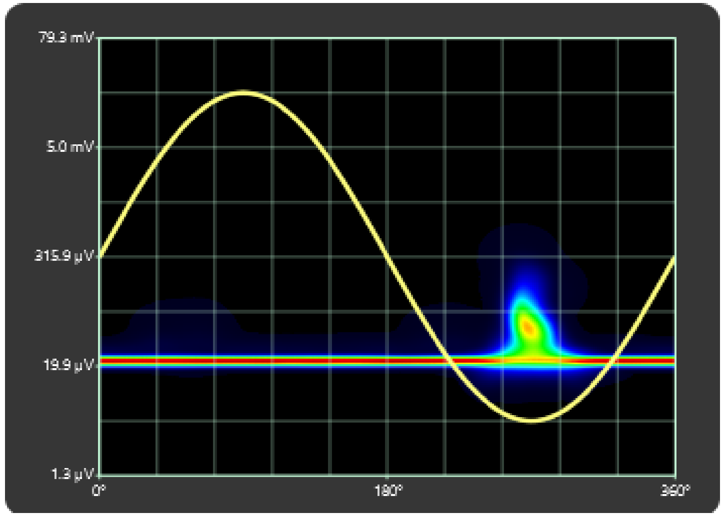
- The alerting algorithm takes the attenuation between neighboring sensors into consideration for the continuous evaluation of monitored PD levels.



Attenuation profile – Linear approximation of the attenuation profile for a PD defect location in the middle of 2 sensors (Cigrè TB 654).

UHF PDM system





UHF PD Monitoring in 400 kV GIS

Thank you for your attention

wojciech.koltunowicz@omicronenergy.com