

The use of multiple sensors, of electrical and non-electrical type, for online PD measurement of cables , transformers, switchgears and motors

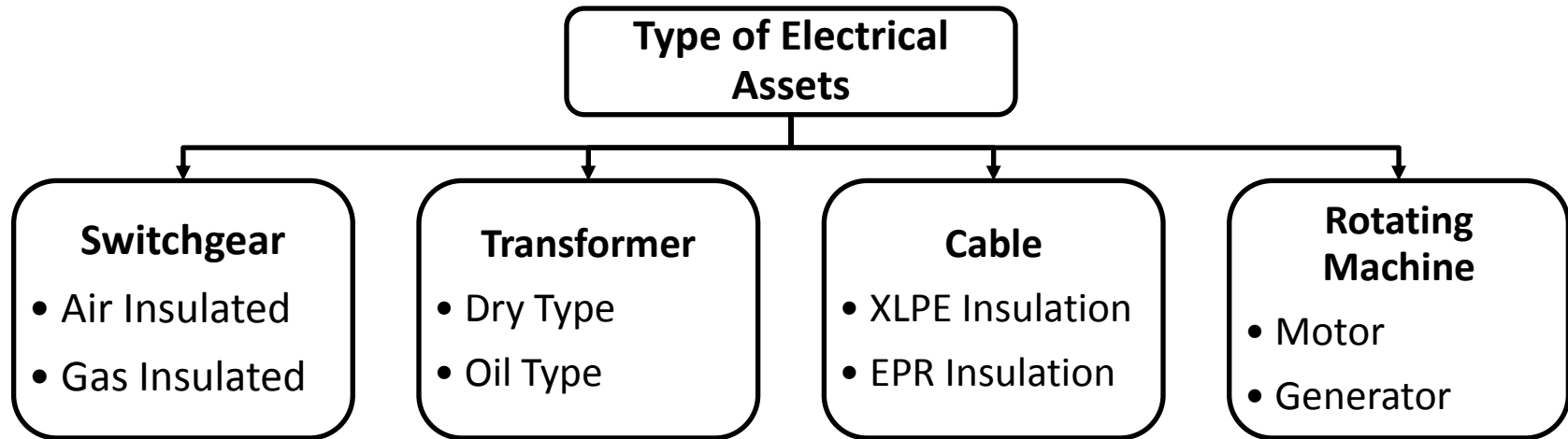
BY

LEE WAI MENG
ELECTRICAL PE/LEW (230KV GRADE)

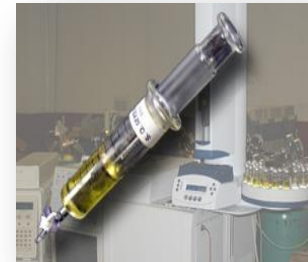
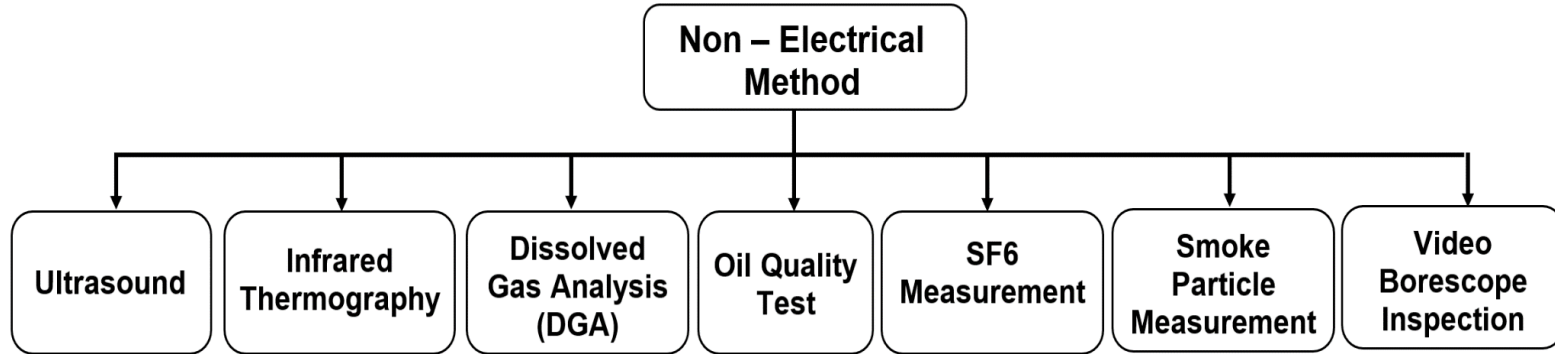
About Us

- J.M. Pang & Seah (Pte) Ltd (JMPS) was established on 21st January 1976 as a Electrical & Mechanical Engineering Consultancy company.
- In August 2012, JMPS became a part of **Pon** group of Companies, a Dutch international trading and service organization with a workforce of 13,000 people spread over 450 locations in 32 countries.
- In May 2019, JMPS and QPM were merged to form On Engineers Pte Ltd
- Our services:
 - **Condition Monitoring Business**
 - LEW (Licensed Electrical Worker) services
 - Electrical Site testing and maintenances
 - Electrical System Study using ETAP and SKM software
 - M & E Consultancy

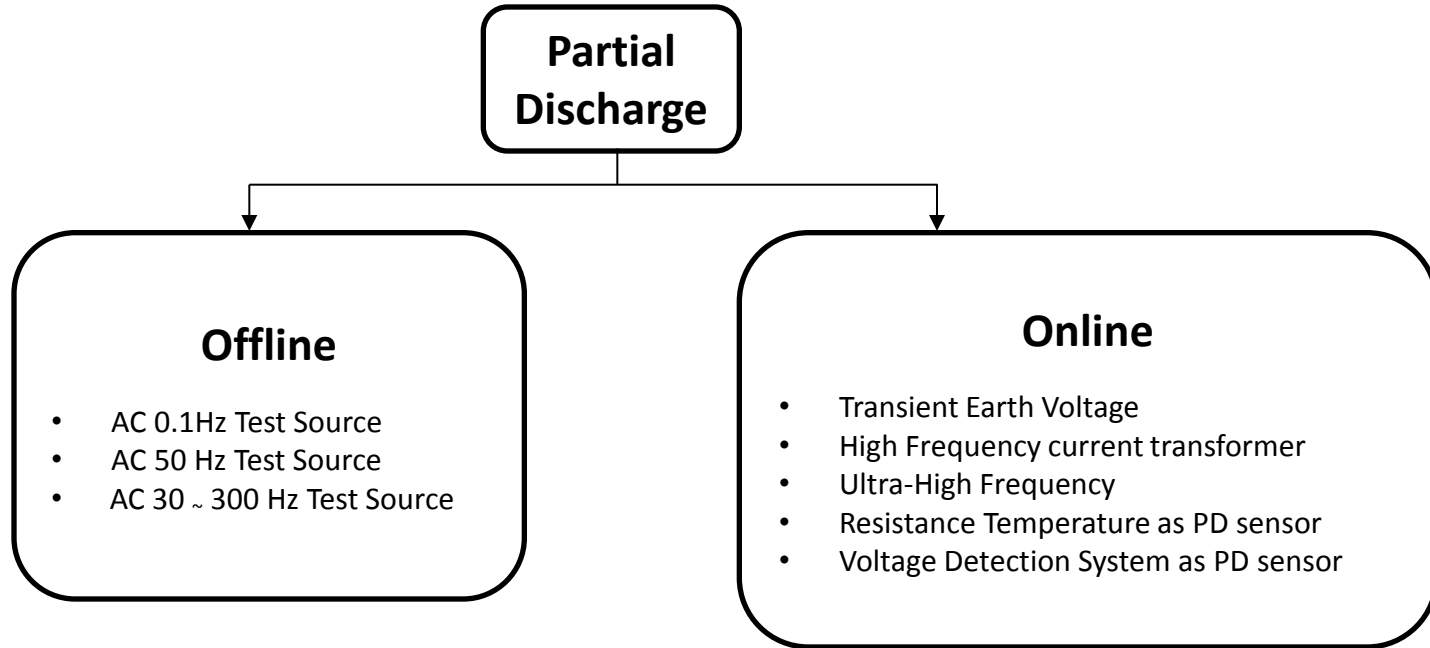
Types Of Electrical Assets



Non – Electrical Method of PD detection



Electrical Method Of PD detection



Non – Electrical Method of PD Detection

Ultrasound

- Sound waves beyond the hearing range of the human ear.
- Audio Sound Waves
 - In the range of human hearing (20Hz to 5000Hz).
- Airborne Ultrasound Waves
 - Frequency above the audible range(20kHz to 40kHz).



Online Airborne Ultrasound Measurement



Oil type Transformer



Air Insulated Switchgear



Online Contact Ultrasound Measurement

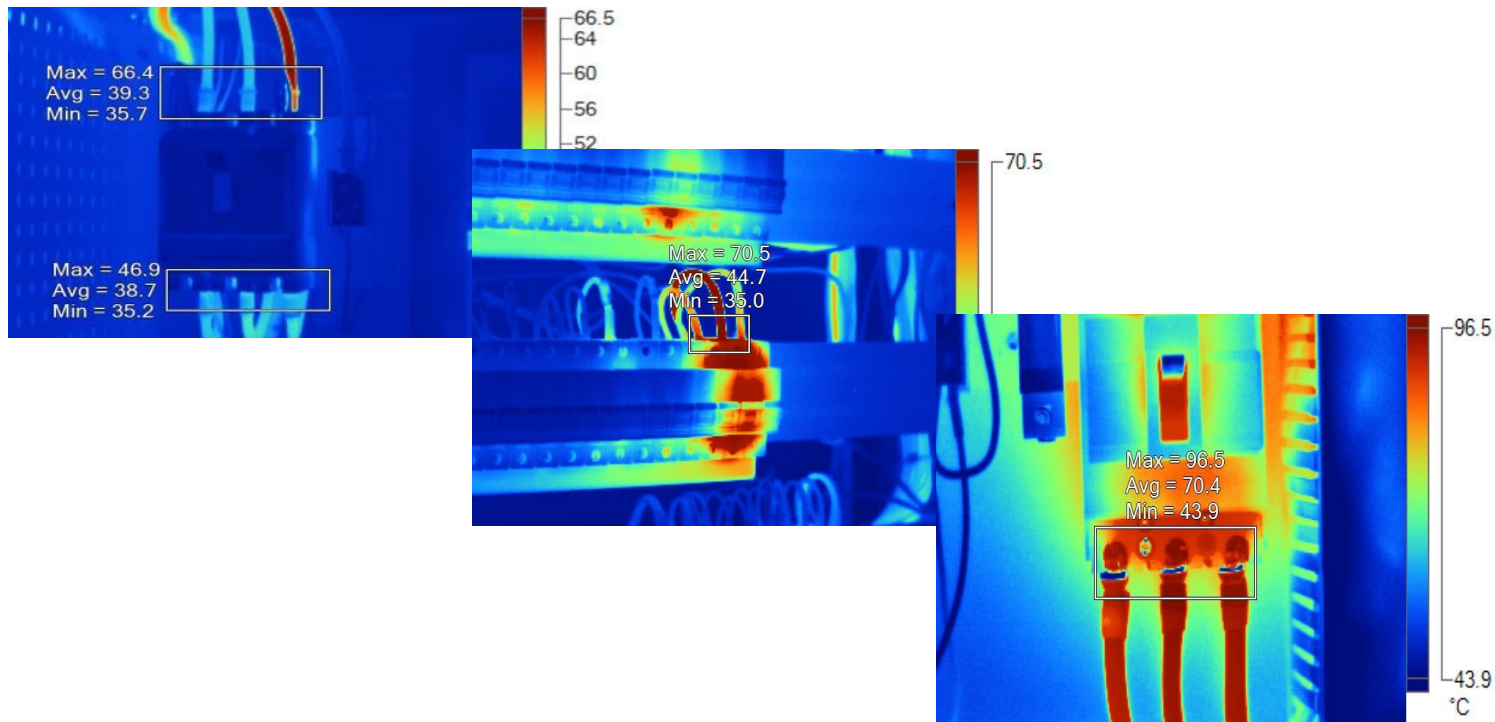


Infrared Thermography

- To find hot spots caused by defects in connections and components.
- To inspect electrical equipment because excess heat is usually the first sign of trouble.



Infrared Thermography



Dissolved Gas Analysis (DGA)

- Diagnostic tools for detecting of transformer oil faults in transformers.
- Reliable results from the removal of an oil sample from the transformer
- Able to be done without de-energization of the transformer.
- Analysis using gas chromatography technique

Dissolved Gas Analysis (DGA)

C57-104-2008 : IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers

Table 1—Dissolved gas concentrations

Status	Dissolved key gas concentration limits [$\mu\text{L/L}$ (ppm) ^a]							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	TDCG ^b
Condition 1	100	120	1	50	65	350	2 500	720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2 500–4 000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4 001–10 000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10 000	>4630

The numbers shown in table in parts per million.

TDCG – Total Dissolved Combustible Gases

Dissolved Gas Analysis (DGA)

C57-104-2008 : Actions Based on TDCG (Table-3)

	TDCG levels (μL/L)	TDCG rate (μL/L/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 4	>4630	>30	Daily	Consider removal from service.
		10 to 30	Daily	Advise manufacturer.
		<10	Weekly	Exercise extreme caution. Analyze for individual gases. Plan outage. Advise manufacturer.
Condition 3	1921 to 4630	>30	Weekly	Exercise extreme caution.
		10 to 30	Weekly	Analyze for individual gases.
		<10	Monthly	Plan outage. Advise manufacturer.
Condition 2	721 to 1920	>30	Monthly	Exercise caution.
		10 to 30	Monthly	Analyze for individual gases.
		<10	Quarterly	Determine load dependence.
Condition 1	≤720	>30	Monthly	Exercise caution. Analyze for individual gases. Determine load dependence.
		10 to 30	Quarterly	Continue normal operation.
		<10	Annual	

Example: If a transformer has a TDCG level of 1300 μL/L (ppm) and generates gas at a constant rate below 10 μL/L (ppm) per day, it should be sampled quarterly, and the operator should exercise caution, analyze for individual gases, and determine load dependence. If the rate increases to 30 μL/L (ppm) per day, the operator should now sample monthly.

SF₆ Gas Measurement – IEC 60480

This multi-functional device allows the determination of three quality parameters with only one measurement. The SF₆ gas is pumped back to the GIS after measurement.

- SF₆ concentration (%)
- Moisture concentration (°C or ppm_v or ppm_w)
- SO₂ concentration (ppm_v)

Impurity	Maximum acceptable levels	
	Rated absolute pressure <200 kPa ^a	Rated absolute pressure >200 kPa ^a
Air and/or CF ₄	3 % volume ^b	3 % volume ^b
H ₂ O	95 mg/kg ^{c,d}	25 mg/kg ^{d,e}
Mineral oil	10 mg/kg ^f	
Total reactive gaseous decomposition products	50 µl/l total or 12 µl/l for (SO ₂ +SOF ₂) or 25 µl/l HF	

^a Within the complete range of re-use pressures, covering all possible applications (both HV and MV insulation systems as well as all circuit-breakers), the low re-use pressure range $p < 200$ kPa has been defined to highlight low pressure insulation systems (typically applied in MV distribution).

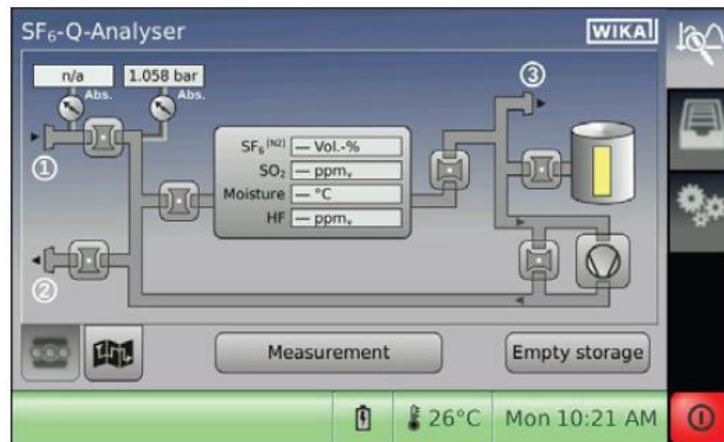
^b In the case of SF₆ mixtures, the levels for these gases shall be specified by the equipment manufacturer.

^c 95 mg/kg (95 ppmw) is equivalent to 750 ppmv (750 µl/l) and to a dew point of -23 °C, measured at 100 kPa and 20 °C.

^d Converted to ppmv these levels shall also apply to mixtures until a suitable standard becomes available.

^e 25 mg/kg (25 ppmw) is equivalent to 200 ppmv (200 µl/l) and to a dew point of -36 °C, measured at 100 kPa and 20 °C.

^f If gas handling equipment (pump, compressor) containing oil is used, it may be necessary to measure the oil content of the SF₆. If all equipment in contact with the SF₆ is oil-free, then it is not necessary to measure oil content.



Smoke Particles Measurement



(Portable Smoke detector)

- Suitable for AIS, Transformer Cable box , LV switchboard



Video Borescope Inspection

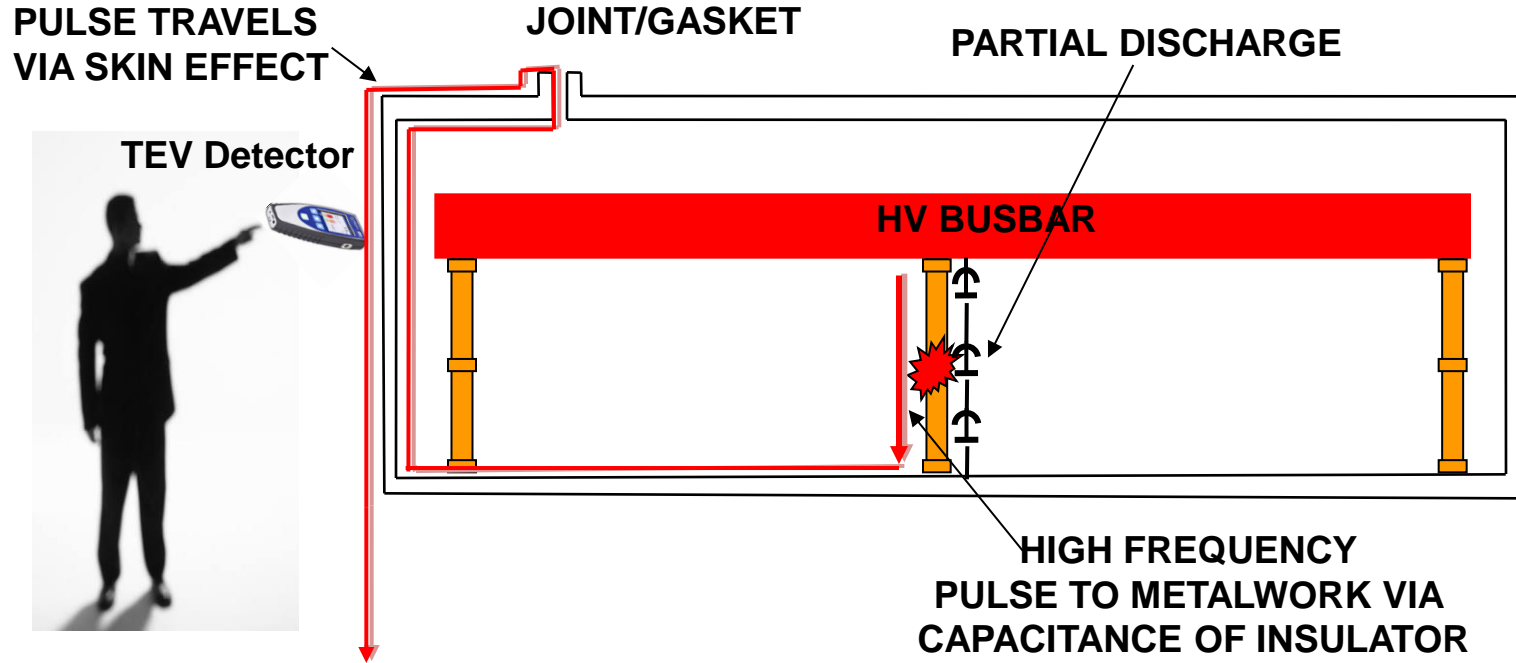


Electrical Method of PD Detection

Transient Earth Voltage (TEV) Sensor

- TEV = Transient Earth Voltage
- Capacitive couplers placed at external metal surface of electrical equipment using a magnet
- Pulse Width – A few tens of nanoseconds
- Bandwidth = $\frac{1}{10 \text{ nanoseconds}}$
= 100 MHz

Principal of Transient Earth Voltage Detection



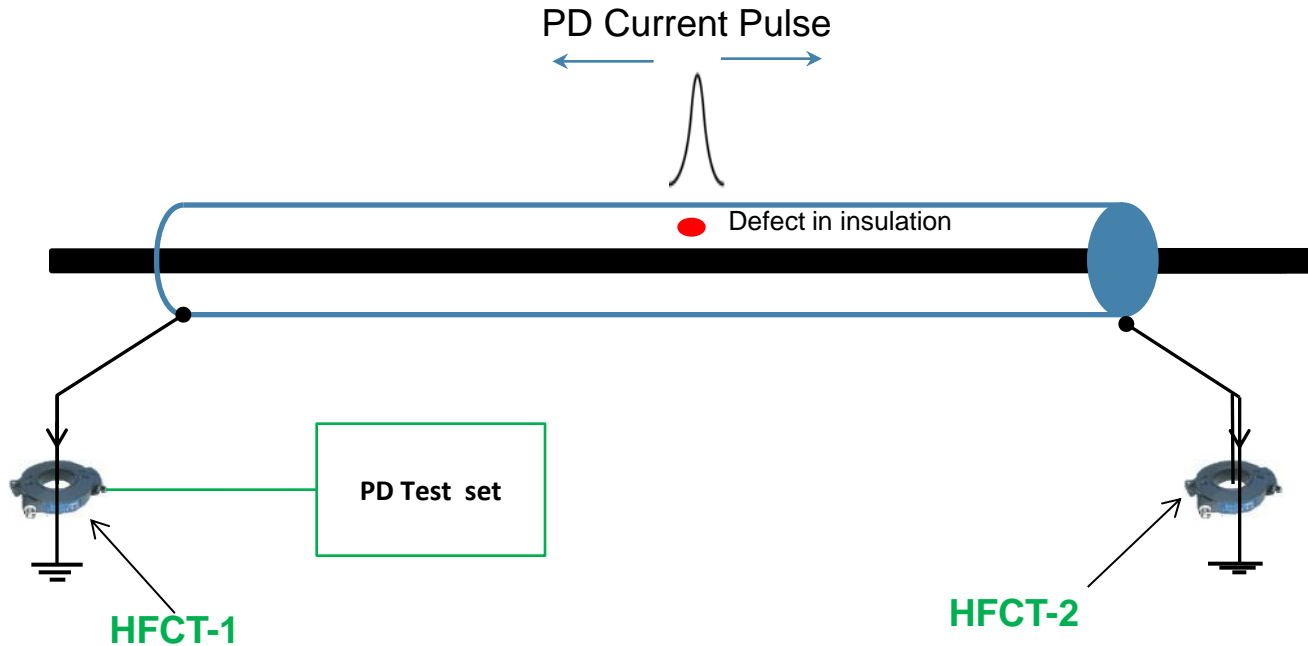
High Frequency Current Transformer (HFCT) Sensor

- HFCT = High Frequency Current Transformer
- Does not respond to 50Hz current
- Frequency range of 100kHz to 25MHz
- Soft ferrite range
- Split core construction



Split core type HFCT sensor

Connection Diagram: Inductive HFCT sensor



Ultra High Frequency (UHF) Sensor

- UHF = Ultra High Frequency
- Response frequency range - 300 MHz to 3,000 MHz
- To detect PD fault that are closer to the sensor location. For instance; UHF sensor is used to detect PD at cable termination.

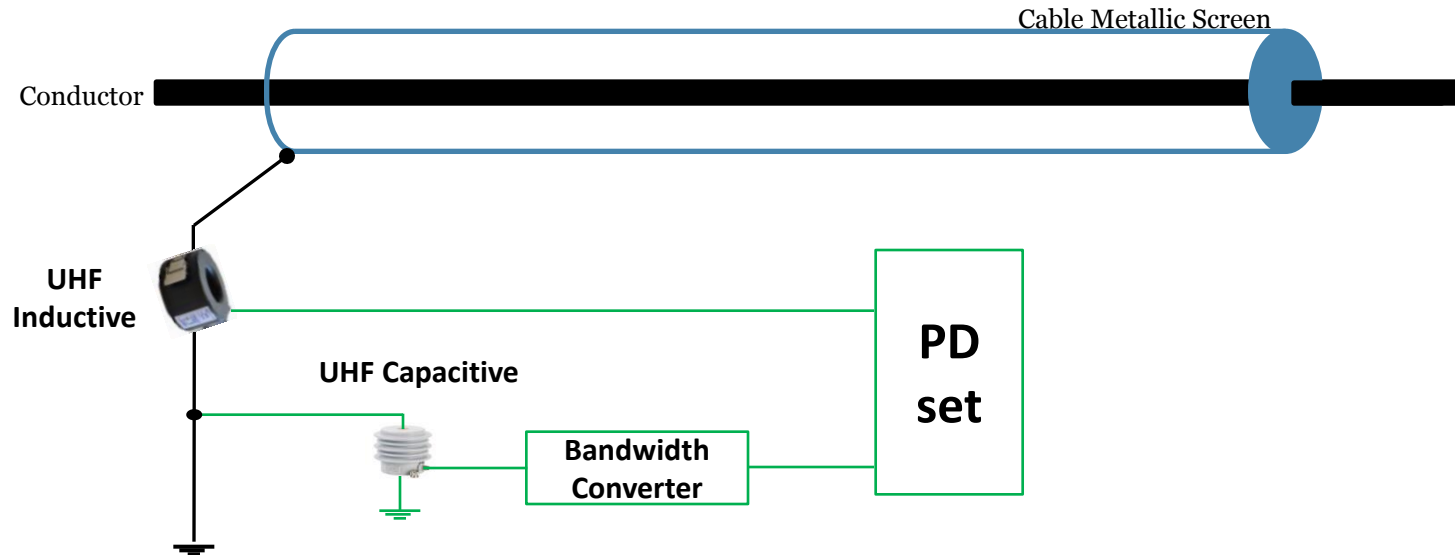


Inductive type UHF Sensor
100 MHz – 450MHz
10MHz – 200MHz



Capacitive type UHF Sensor
100MHz-1,000MHz

Connection Diagram: UHF Capacitive and UHF Inductive Sensor



Online PD Measurement using UHF sensor



To detect PD fault that are closer to the sensor location



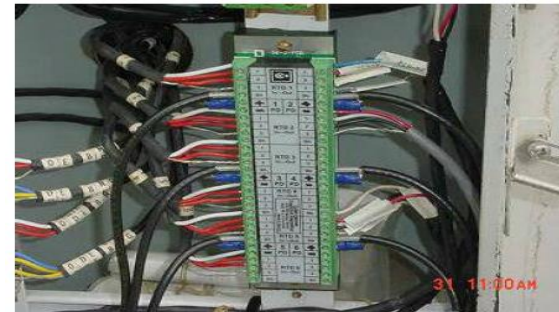
Embedded Non PD Sensors

Resistance Temperature Detector (RTD) as Embedded PD Sensor

- RTD = Resistance Temperature Detector
- Temperature sensor that contain resistor that change resistance value as temperature changes
- Act as antenna type PD Sensor to detect defects in stator winding



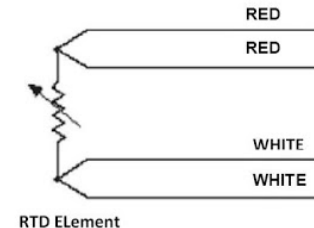
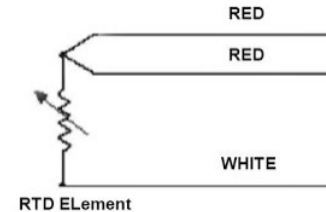
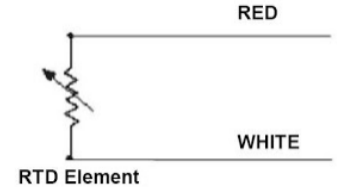
Resistant Temperature Detector



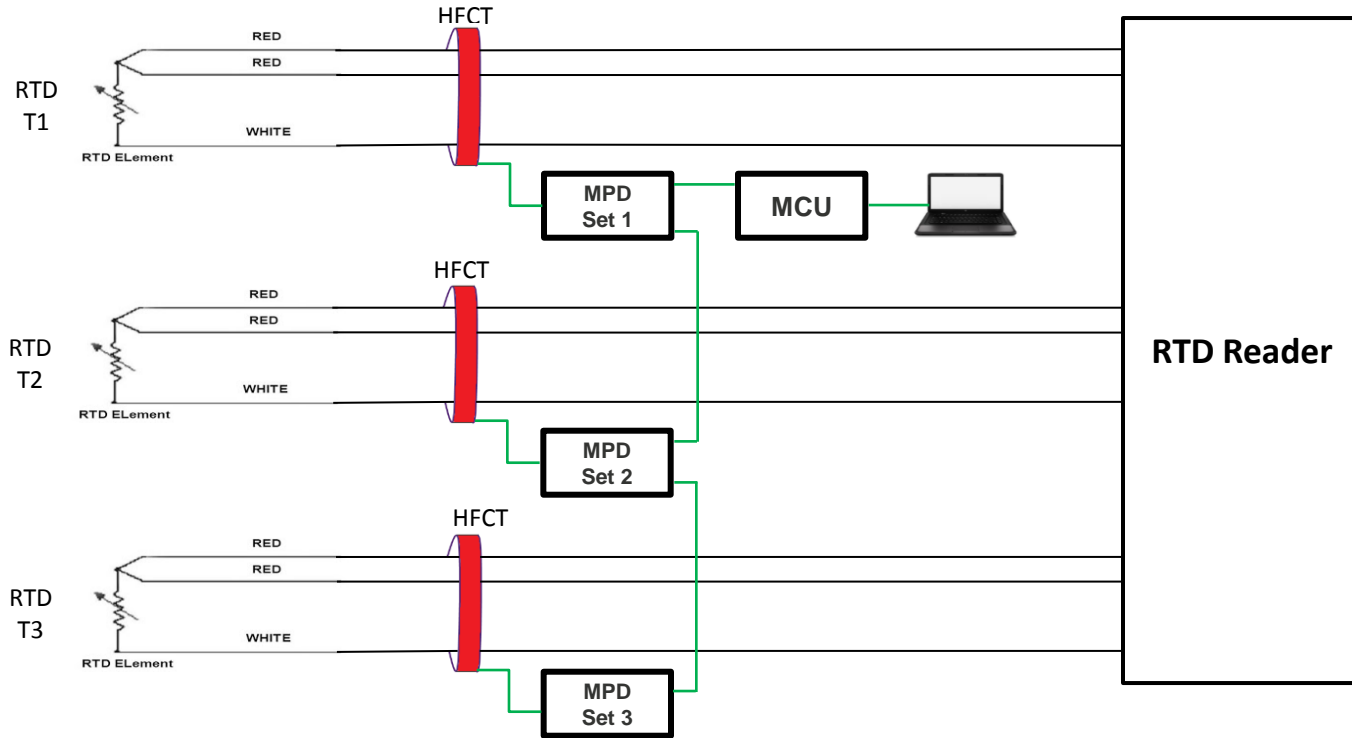
Terminal Box

Physical Construction of RTD element and the lead wires

- Two wire Configuration
- Three wire Configuration
- Four wire Configuration

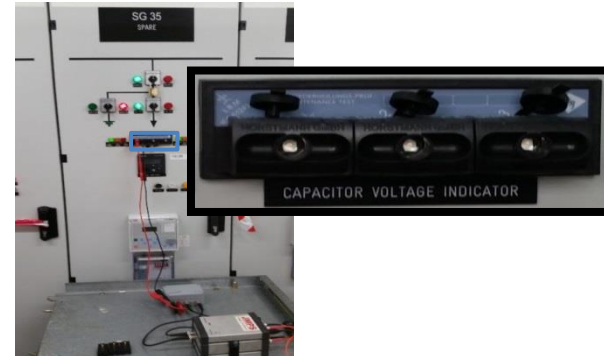


Connection Diagram: Existing RTD as Embedded PD Sensor

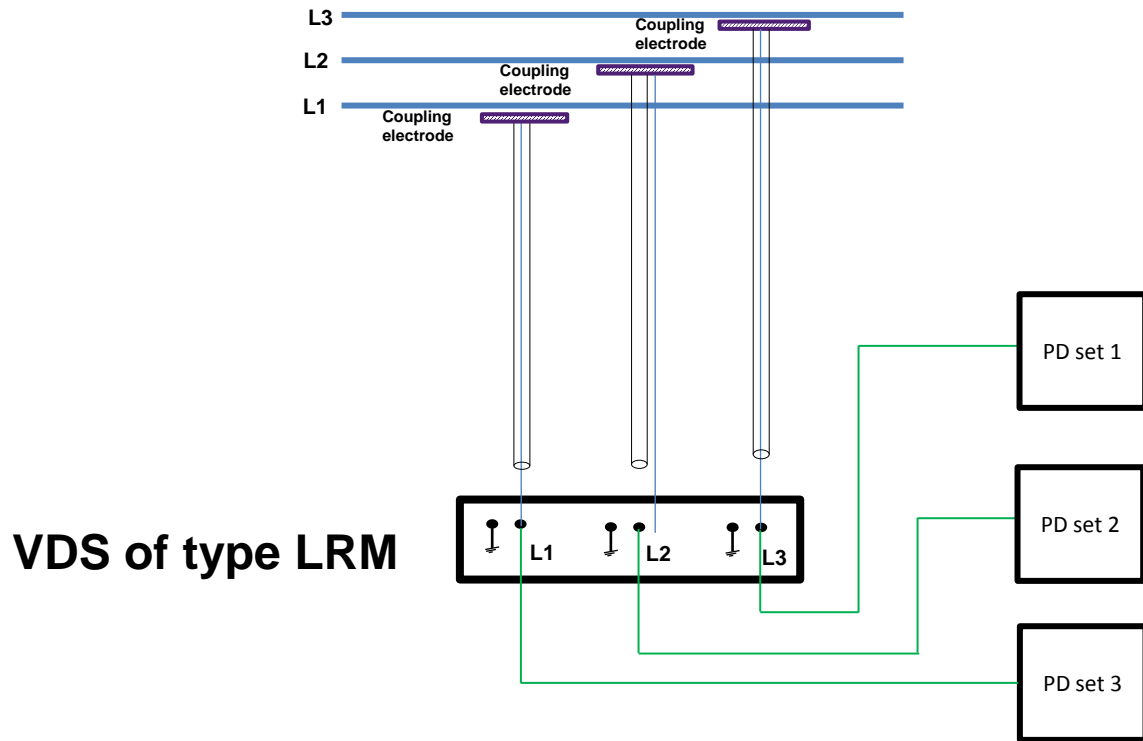


Voltage Detection System (VDS) as Embedded PD Sensor

- VDS = Voltage Detection System
- Devices used to detect the presence or absence of operating voltage.
- Act as antenna type PD Sensor to detect defects at the cable termination



Connection Diagram: VDS as Embedded PD Sensor



Online PD Measurement Using VDS as Embedded PD Sensor

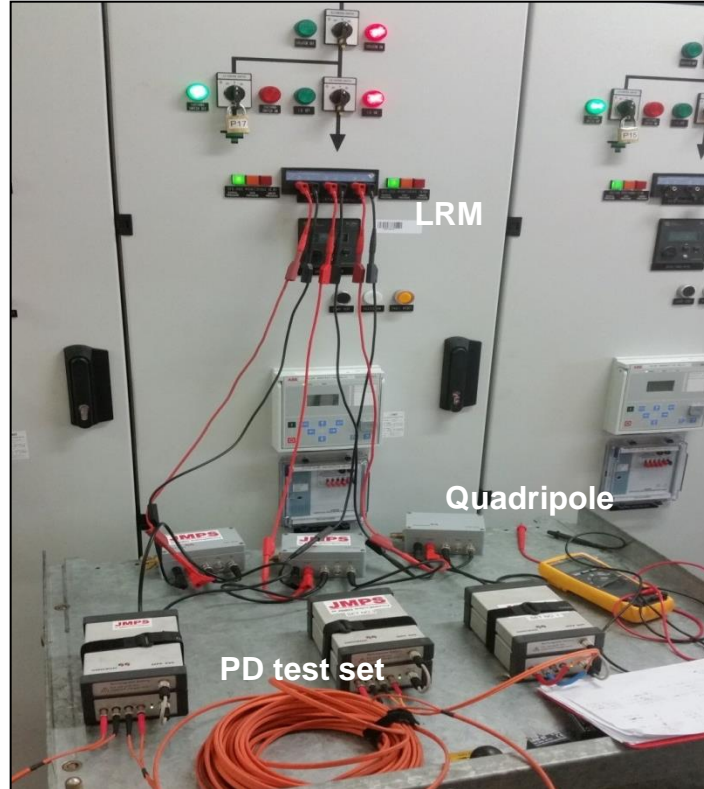


ABB GIS

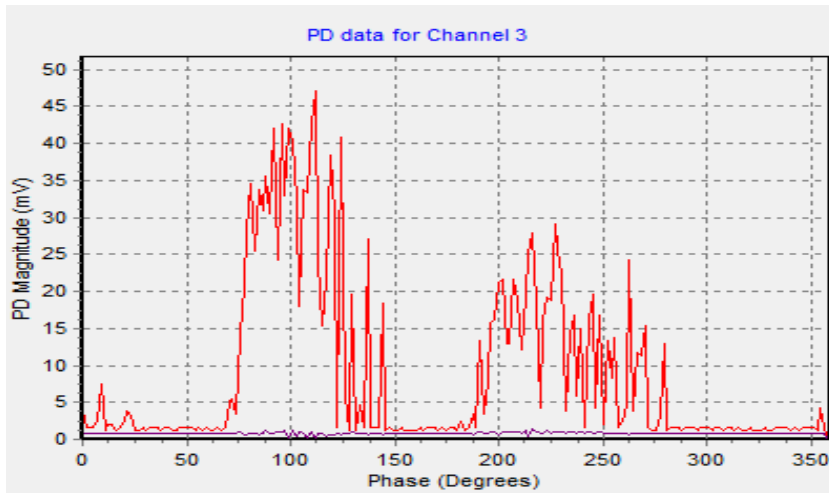
Case Studies

Case Studies 1:

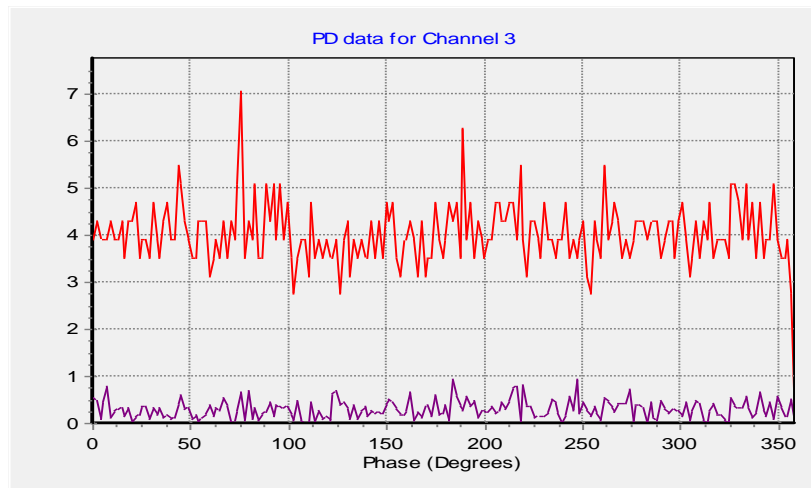
- Device Under Test (DUT):
 - **2.5MVA 22kV/420V Oil type Transformer at a Chemical Plant in Jurong Island**
- Type of Partial Discharge Sensor Used:
 - **Airborne Ultrasonic sensor**
 - **TEV sensor**
- Date:
 - **29th January 2016**

PD detection using TEV Sensor

Phase Resolved TEV
Transformer 001



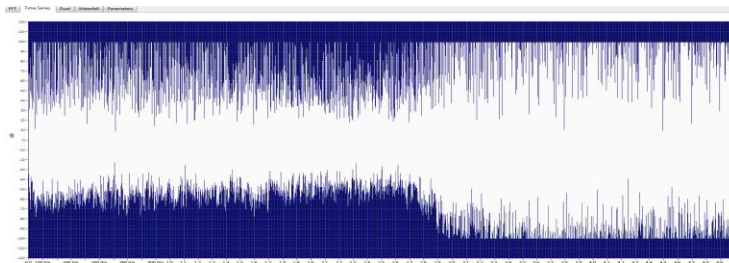
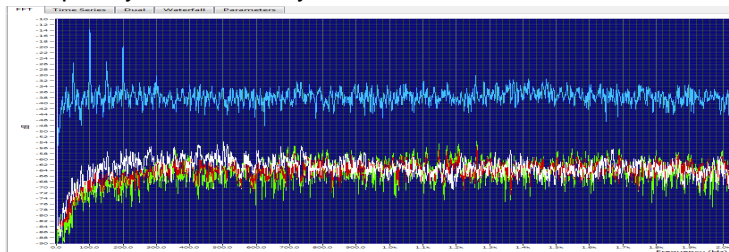
Phase Resolved TEV
Transformer 002



PD detection using Airborne Ultrasonic Sensor

Transformer 001

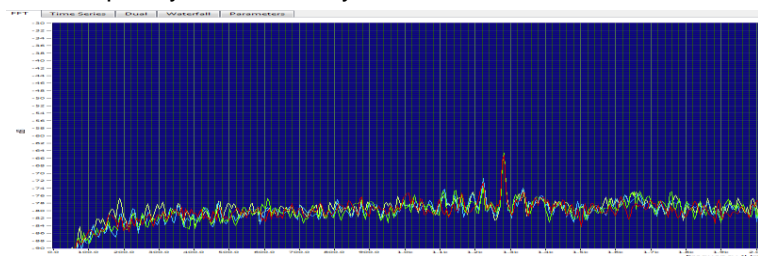
Frequency Domain Analysis



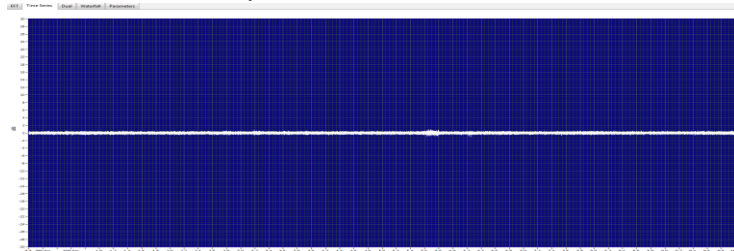
Audio Analysis => **High level abnormal ultrasound was detected**

Transformer 002

Frequency Domain Analysis



Time Domain Analysis



Audio Analysis => **No Abnormal ultrasound was detected.**

Photos of PD during SDM



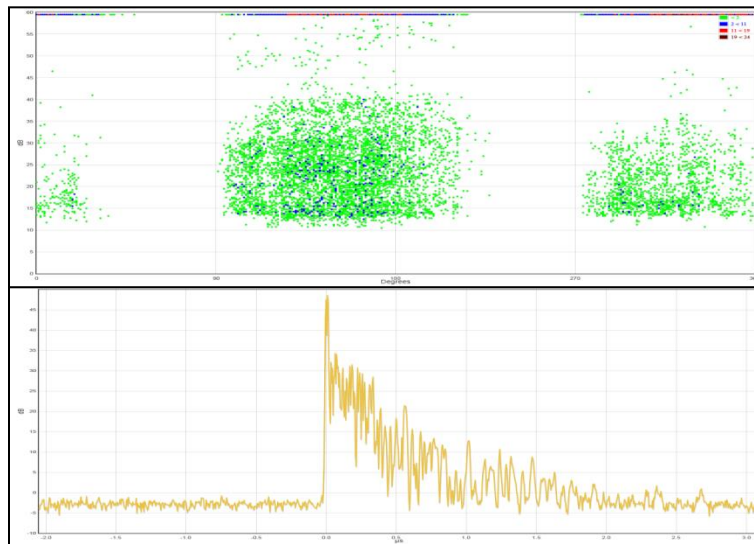
Case Studies 2:

- Device Under Test (DUT):
 - **22kV Areva, GIS Switchgear @ Wafer Fab in Pasir Ris**
- Type of Partial Discharge Sensor Used:
 - **Contact Ultrasonic sensor**
 - **Capacitive UHF sensor**
 - **TEV sensor**
 - **HFCT sensor**
- Date:
 - **14th November 2016**

PD detection using TEV Sensor

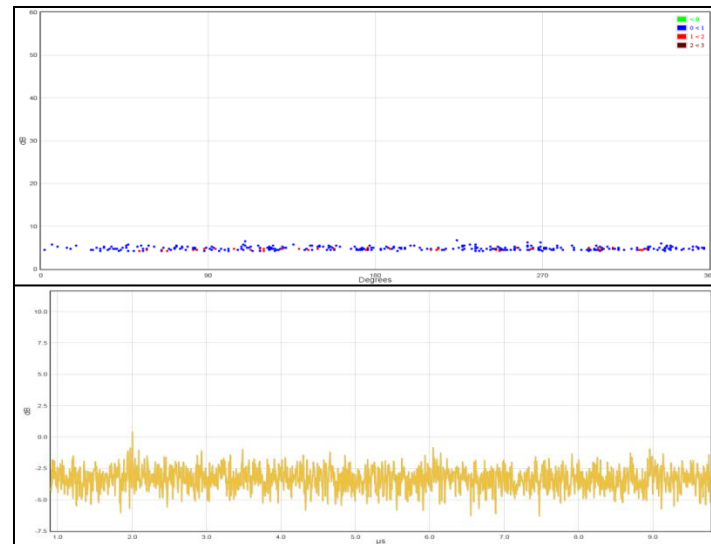
Phase Resolved TEV

(Before replacement of terminations on 02nd Nov 2016)



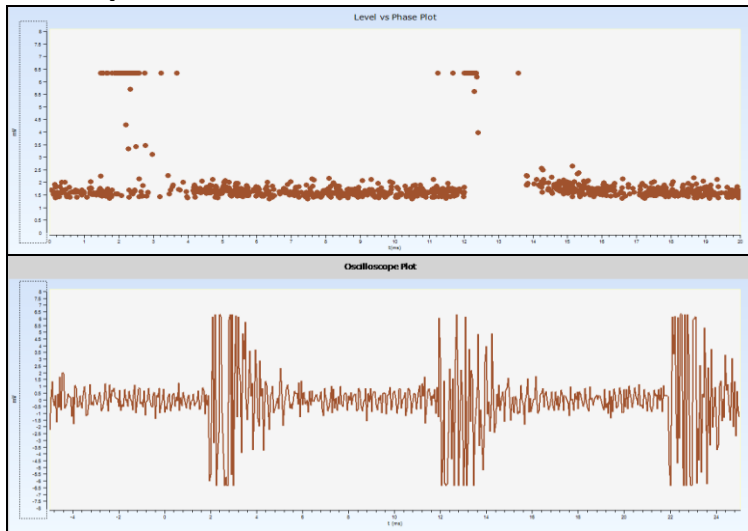
Phase Resolved TEV

(After replacement of terminations on 10 Jan 2017)

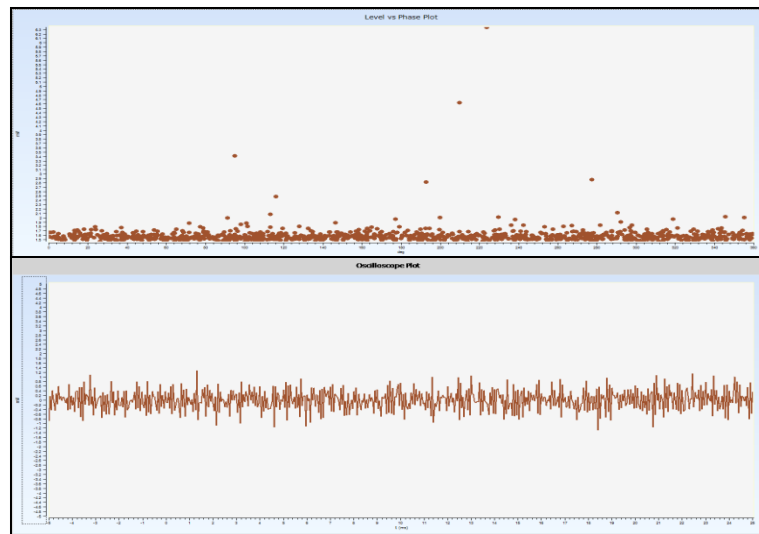


PD detection using Contact Ultrasonic Sensor

Phase Resolved Ultrasound
(Before replacement of terminations on 02nd Nov 2016)

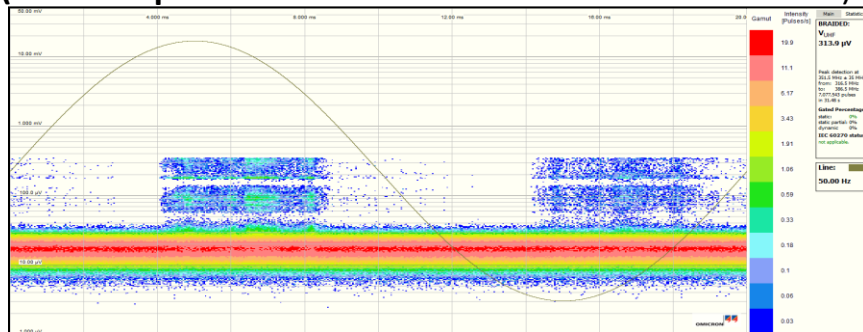


Phase Resolved Ultrasound
(After replacement of terminations on 10 Jan 2017)

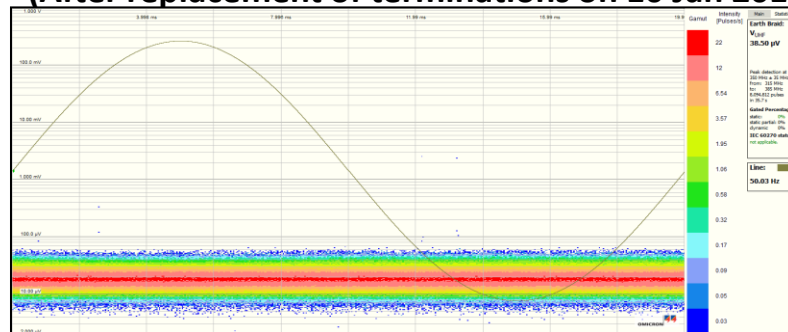


PD detection using Capacitive UHF Sensor

Phase Resolved UHF
(Before replacement of terminations on 02nd Nov 2016)



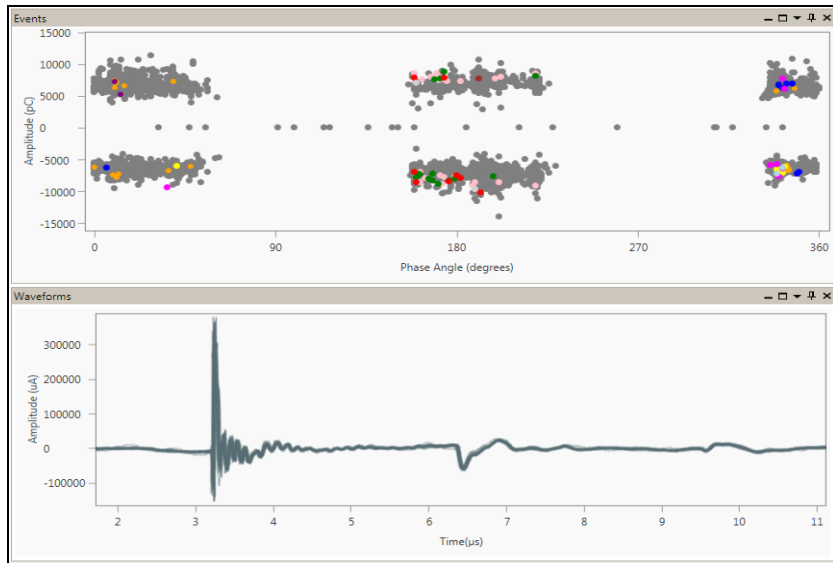
Phase Resolved UHF
(After replacement of terminations on 10 Jan 2017)



PD detection using HFCT Sensor

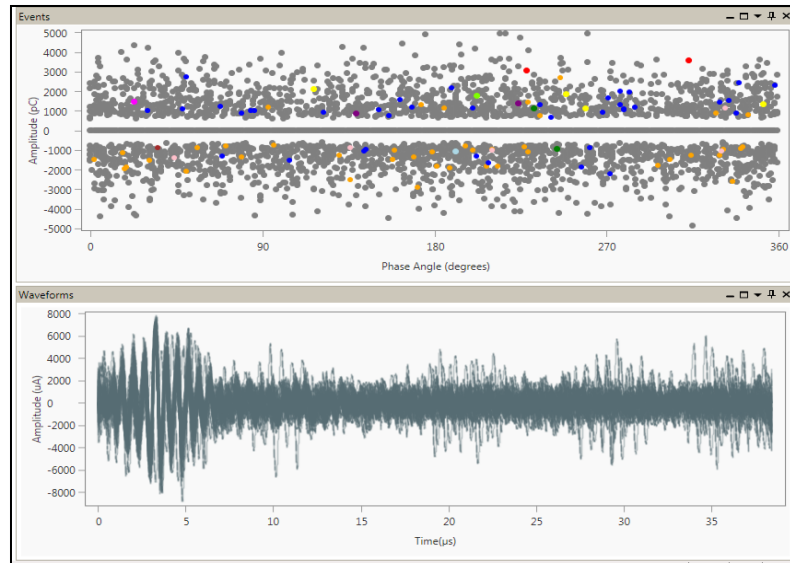
Phase Resolved HFCT

(Before replacement of terminations on 02nd Nov 2016)



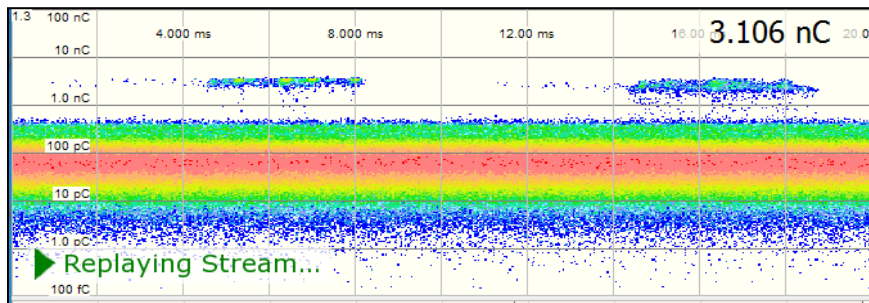
Phase Resolved HFCT

(After replacement of terminations on 10 Jan 2017)

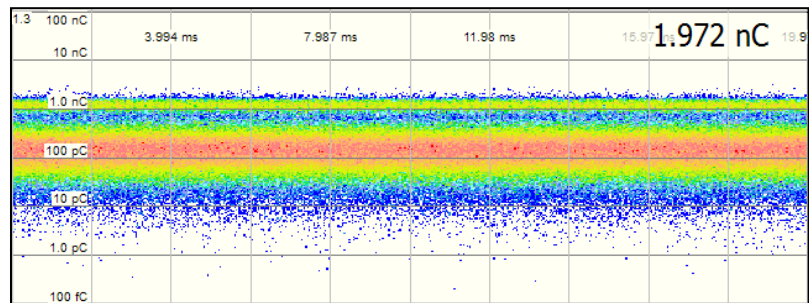


PD detection using HFCT Sensor

Phase Resolved HFCT
(Before replacement of terminations on 02nd Nov 2016)



Phase Resolved HFCT
(After replacement of terminations on 10 Jan 2017)



Photos of PD during SDM



Observation : Partial Discharge at the Cable Termination of the Blue Phase.

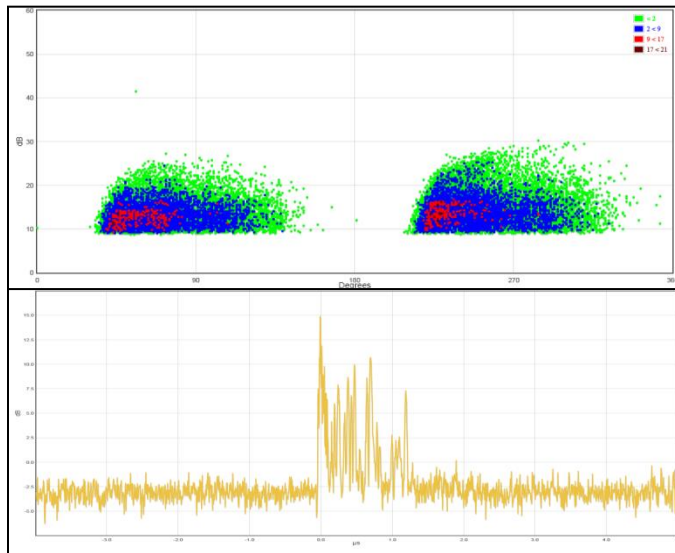
Case Studies 3:

- Device Under Test (DUT):
 - **2MVA, 22kV/420V Oil Type Transformer @ a Biofuel plant**
- Type of Partial Discharge Sensor Used:
 - **TEV sensor**
 - **Capacitive UHF sensor**
 - **HFCT sensor**
- Date:
 - **18th May 2017**

PD detection using TEV Sensor

Phase Resolved TEV

(Before replacement of terminations on 18th May 2017)



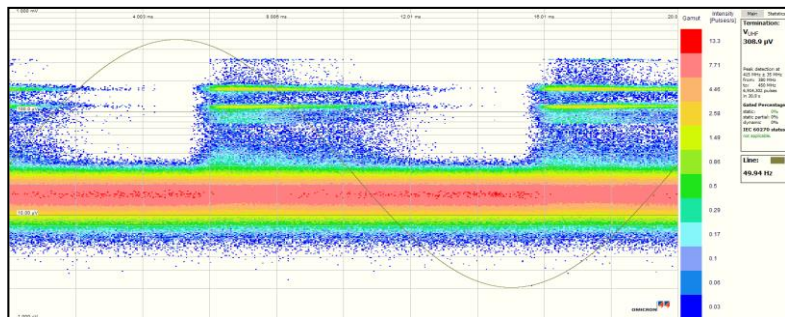
Phase Resolved TEV

(After replacement of terminations on 07th Sept 2017)

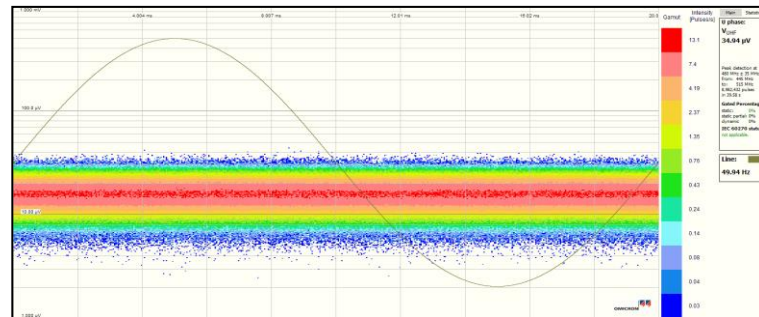


PD detection using Capacitive UHF Sensor

Phase Resolved UHF
(Before replacement of terminations on 18th May 2017)



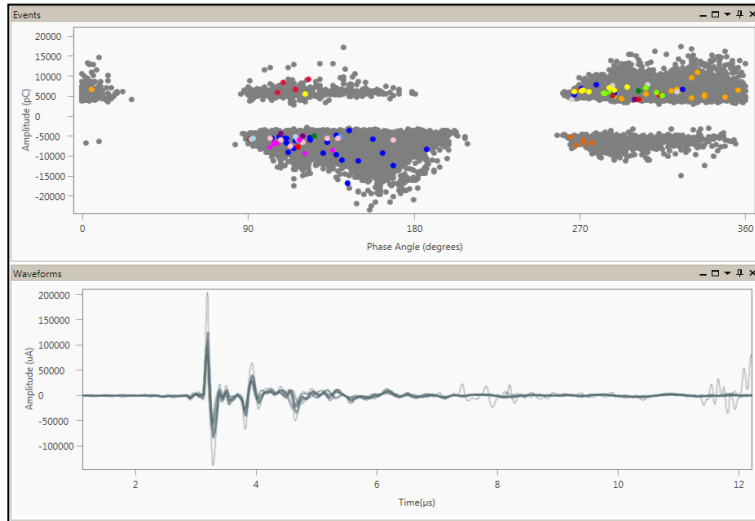
Phase Resolved UHF
(After replacement of terminations on 07th Sept 2017)



PD detection using HFCT Sensor

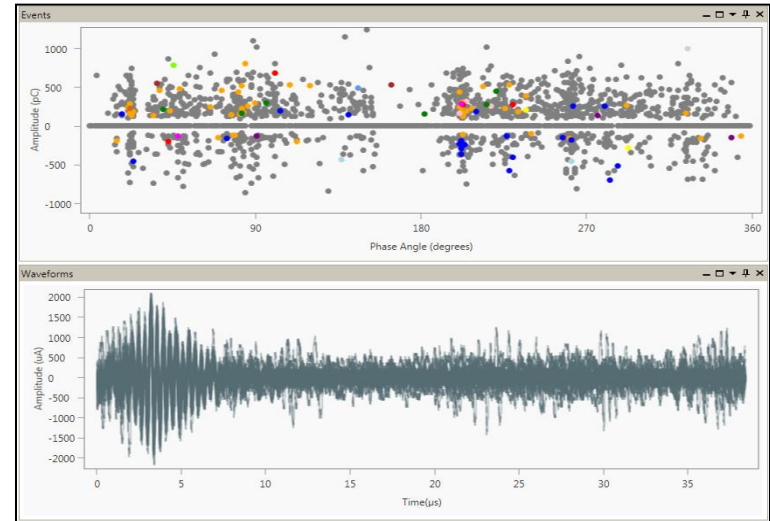
Phase Resolved HFCT

(Before replacement of terminations on 18th May 2017)

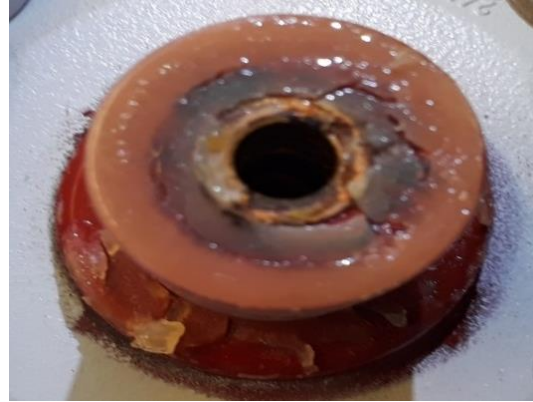
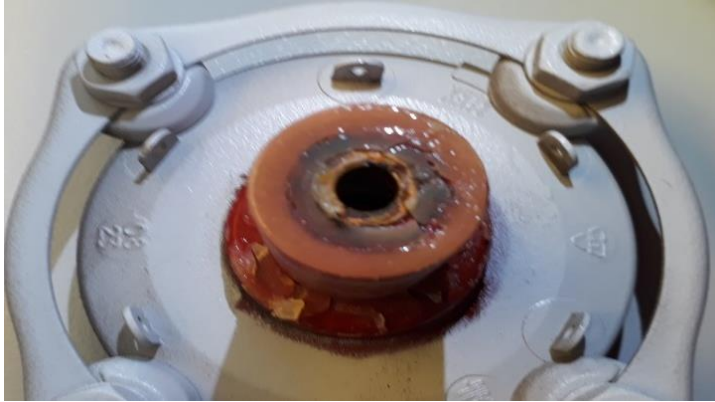


Phase Resolved HFCT

(After replacement of terminations on 07th Sept 2017)



Photos of PD during SDM



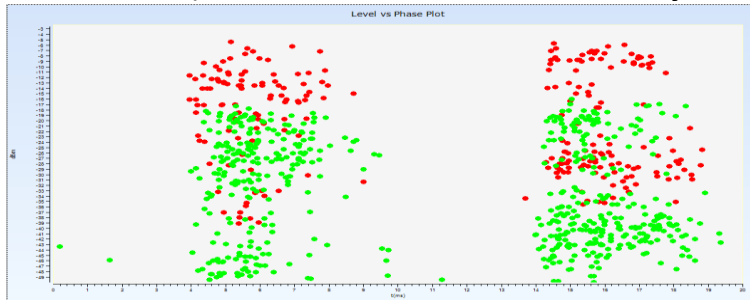
Observation : During Shutdown, Rust was found at the 22kV cable termination.

Case Studies 4:

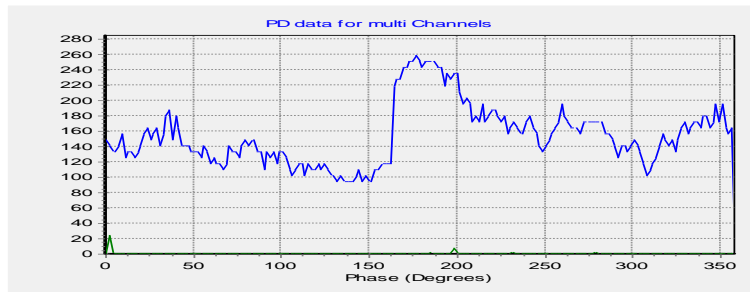
- Device Under Test (DUT):
 - **VT of 22kV Yorkshire, AIS Switchgear**
- Type of Partial Discharge Sensor Used:
 - **TEV sensor**
 - **Capacitive UHF sensor**
 - **HFCT sensor**
- Date:
 - **07th May 2018**

PD detection using TEV Sensor

Phase Resolved TEV
(BEFORE ISOLATING VT2 on May 2018)

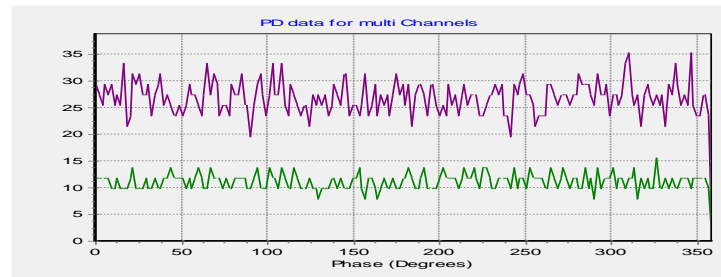
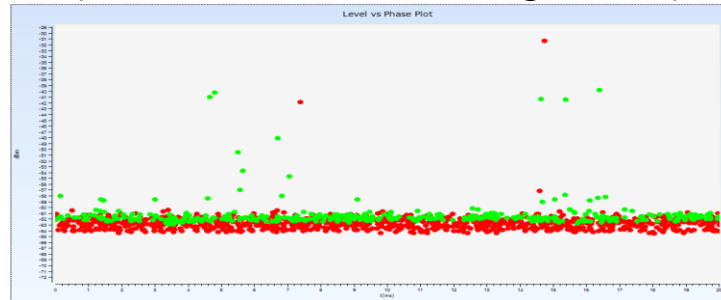


DFA300



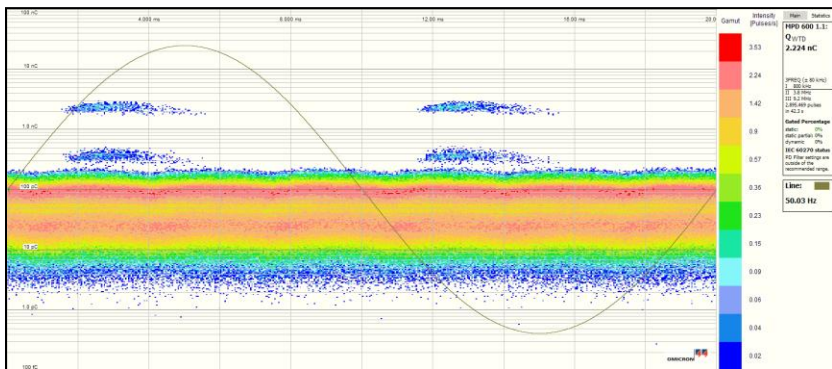
OSM-ST1

Phase Resolved TEV
(AFTER ISOLATING VT2 on August 2018)

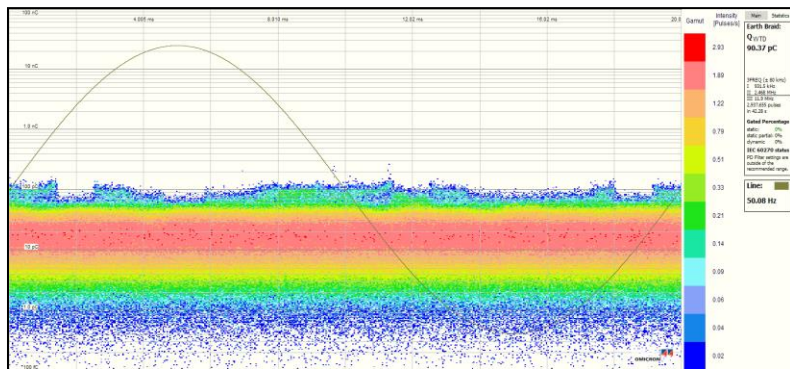


PD detection using HFCT Sensor

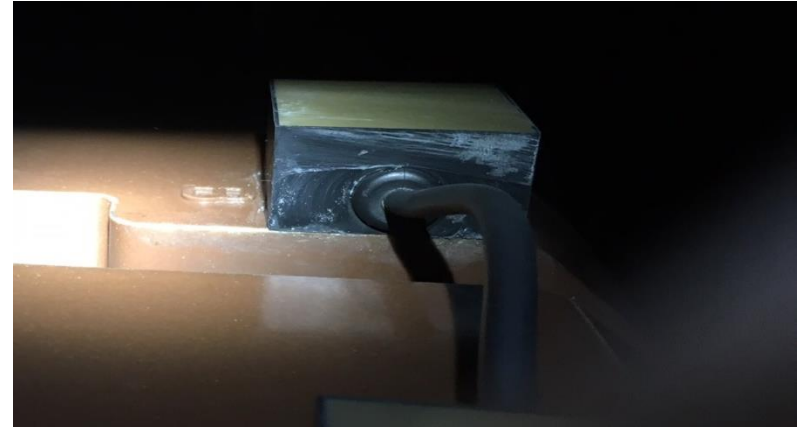
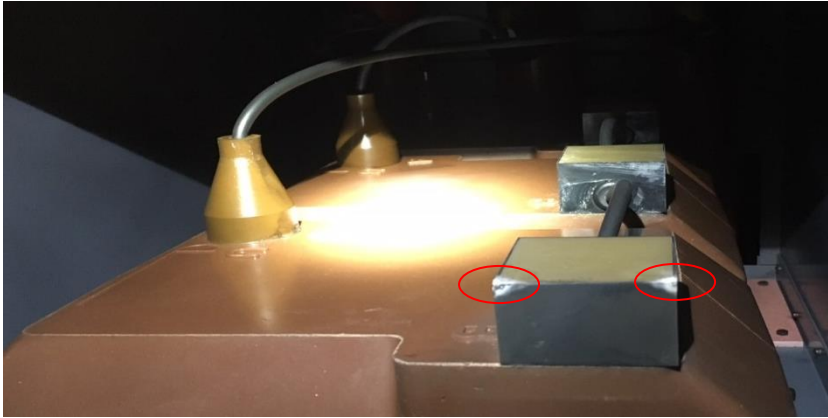
Phase Resolved HFCT
(BEFORE ISOLATING VT2 on May 2018)



Phase Resolved HFCT
(AFTER ISOLATING VT2 on August 2018)



Photos of PD during SDM



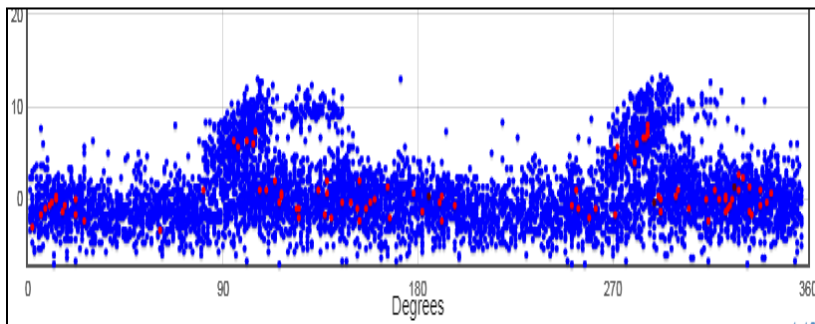
Observation : Visible crack at 22kV VT.

Case Studies 5:

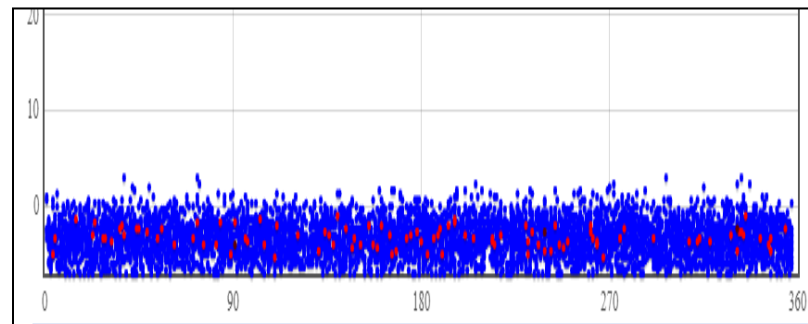
- Device Under Test (DUT):
 - **22kV Alstom GMA, GIS Switchgear**
- Type of Partial Discharge Sensor Used:
 - **Airborne Ultrasonic sensor**
 - **TEV sensor**
 - **Capacitive UHF sensor**
 - **HFCT sensor**
 - **Infra-Red scanning**
- Date:
 - **19th May 2018**

PD detection using Airborne Ultrasonic Sensor

Phase Resolved Ultrasound
(Partial Discharge in cable termination on 19th May 2018)

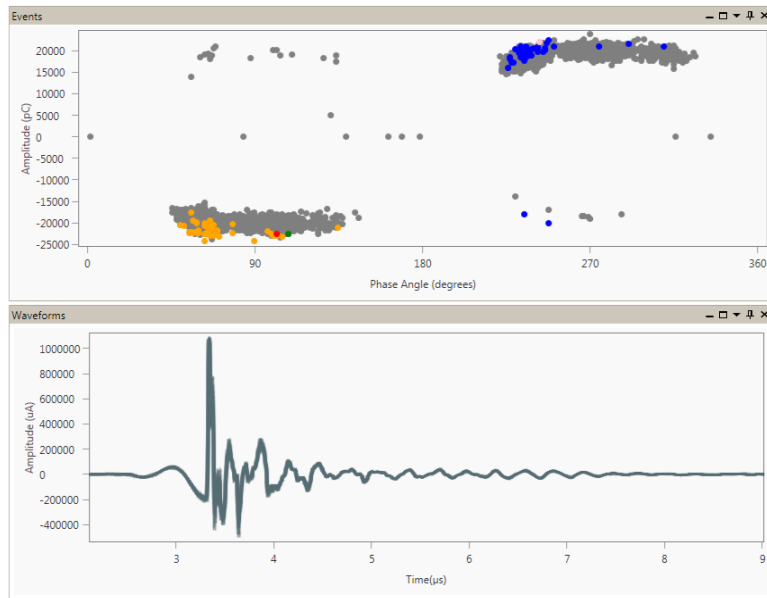


Phase Resolved Ultrasound
(AFTER Rectification on 26th May 2018)

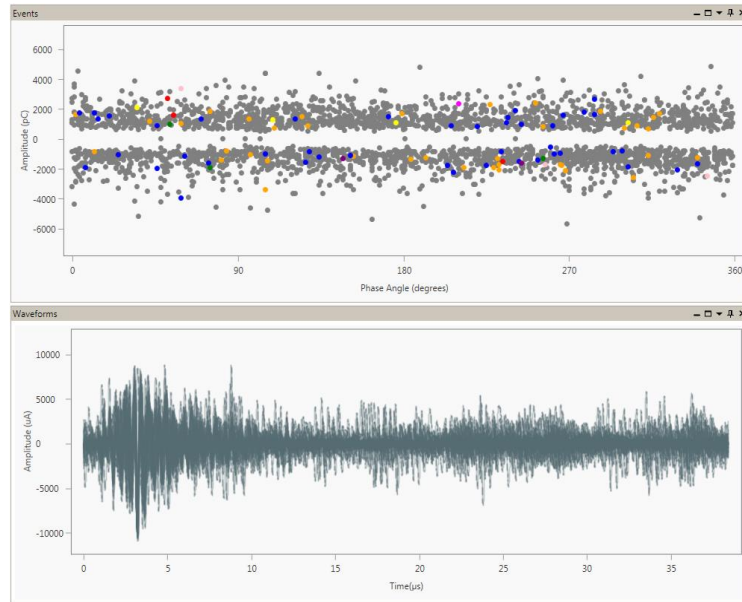


PD detection using HFCT Sensor

Phase Resolved HFCT
(Partial Discharge in cable termination on 19th May 2018)

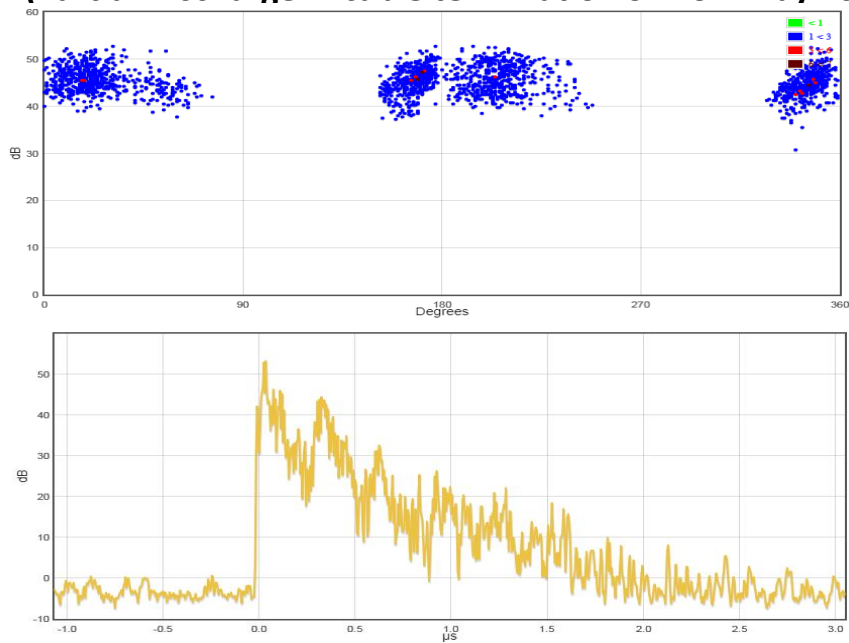


Phase Resolved HFCT
(AFTER Rectification on 26th May 2018)

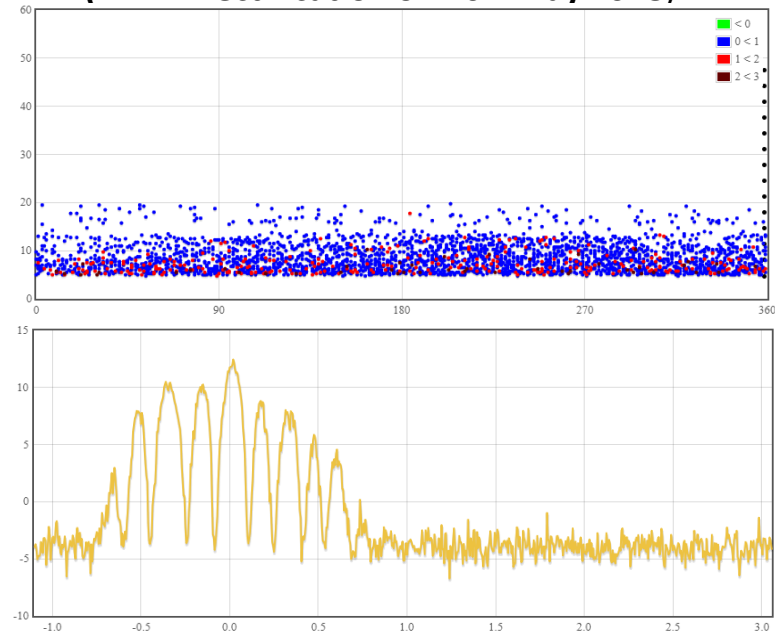


PD detection using TEV Sensor

Phase Resolved TEV
(Partial Discharge in cable termination on 19th May 2018)

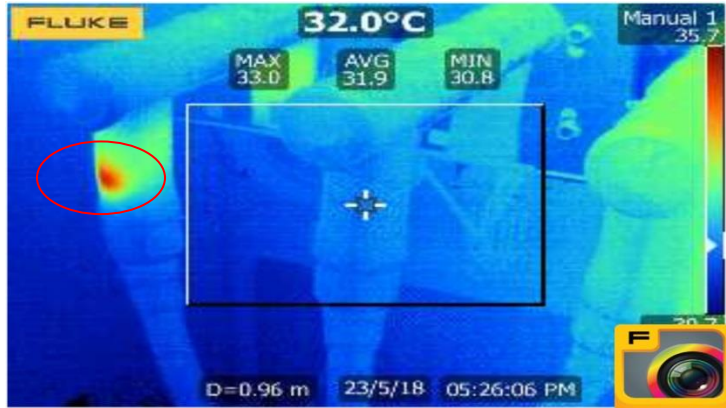


Phase Resolved TEV
(AFTER rectification on 26th May 2018)

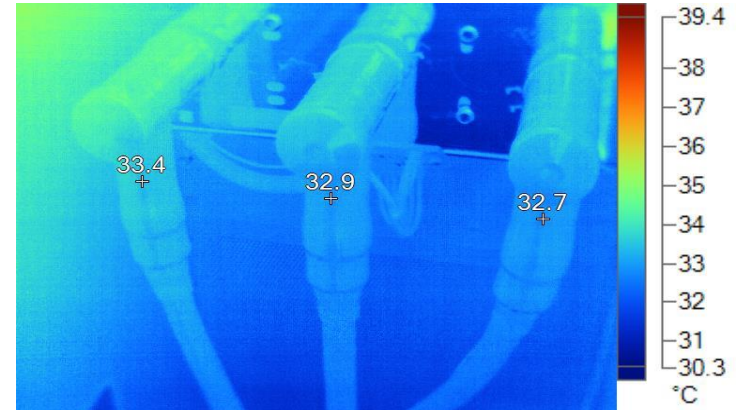


PD detection using Infra-Red

Phase Resolved HFCT
(Partial Discharge in cable termination on 19th May 2018)



Phase Resolved HFCT
(AFTER Rectification on 26th May 2018)



Photos of PD during SDM



Observation : Partial discharge was found at the cable lug of L3 with green discoloration.

Q & A

Thank you.