TechTalk

Switchgear Periodic Assessments and Permanent Monitoring

Compiled by John Sherriff | April 2021 | Rev 1

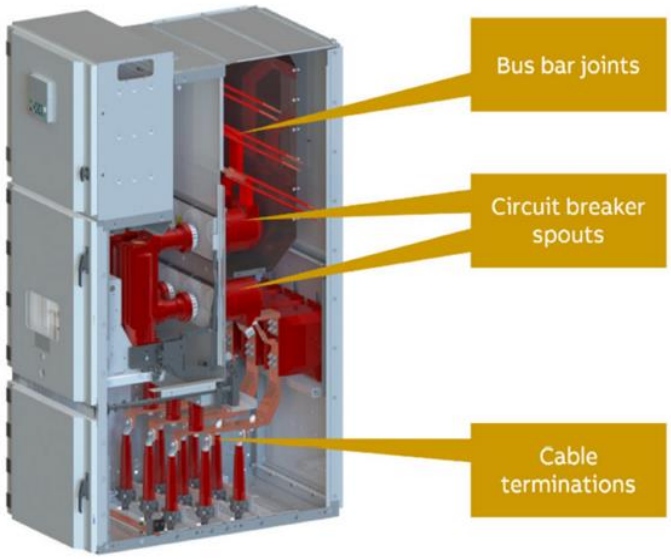
The scope

Condition-based assessments and monitoring form an integral part of the maintenance strategy for medium voltage switchgear. This TechTalk describes the best industry practice to adapting to Industry 4.0 IIoT (Industrial Internet of Things), which has become the automated approach in MV Switchgear condition monitoring.

MV switchgear is most often identified as part of the critical asset types when companies analyse operational risk at their facilities. Partial discharge (PD) is detected (as a symptom) in 85% of medium voltage (MV) switchgear faults. Thus, PD detection is a key technique to prevent switchgear failures attributed to insulation failures or dielectric failures of switchgear components.

The main functionality and requirements of medium voltage switchgear

- Segregation of electrical failures like arc flash is contained inside one switchgear panel. This guarantees safe operation by persons, serviceability and compactness, and the ability to disconnect and ground parts of the switchgear, resulting in the current-carrying parts' long-term operation and thermal stability. These aspects mainly dictate the fundamental design of modern MV switchgear.
- The entire electrical system is metal-enclosed, with doors often managed by interlock systems. The switchgear is protected from its neighbouring switchgear panels by segregation walls and may be equipped with a duct to vent hot gas from an arc flash via a chute integrated into the switchgear.
- Switchgear is typically divided into compartments such as the cable, breaker, and bus bar compartment for high voltage carrying components and a compartment for the low-voltage control equipment.



Electrical insulation systems naturally deteriorate over time. This is due to high operating temperatures, which accelerates insulation ageing, frequent switching activities impacting negatively on the insulation system and contamination, i.e. dust and chemical attack, which is significantly enhanced with high levels of humidity.

Electrical insulation systems naturally deteriorate over time and this is due to high TEAM stresses:

- **Thermal** – high operating temperatures accelerates insulation ageing.
- **Electrical** – frequent switching activities impacts negatively on the insulation system.
- **Ambient** - contamination i.e. dust and chemical attack which is significantly enhanced with high levels of humidity.
- **Mechanical** – Miss-alignment, loose support structures contribute to premature failures.

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PD Method and Defect Identification in Switchgear

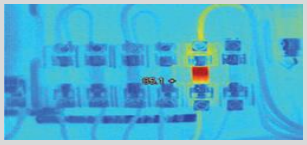
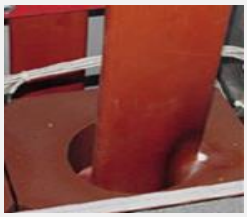
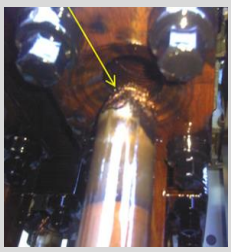
What method is used?

Unconventional PD measuring (IEC 62478) methods and systems can detect PD signals, identifying different physical characteristics and properties of the PD. In general, these methods are based on the measurements of electrical signals in the radio frequency (RF) ranges.

Unconventional PD measuring

This process is conducted on-site during the online condition assessment for the complete energised power circuit. This method highlighted high-risk areas within the feeder cable insulation system (joints), terminations, insulators, high resistance connections, bus bar connections, bus bar insulators, cables, current transformer and voltage transformers defects.

Breakdown process caused by partial discharges within switchgear

Section	Component	Defect type		Progression	End result
Low voltage	Control-gear contacts/wiring		High resistance connectors	Overheating	Eroded / burnt insulation
Bus bar	Connections		Contamination	Surface tracking	Erosion
	Insulators		Cracked/broken	Partial discharge	
	Cable to VT's		Loose connection	Overheating	
Voltage Transformers	Misaligned		Incorrect air gap	Partial discharge	Electrical treeing
	Connections		Poor contact	Overheating	Failure
Current Transformers	Misaligned		Incorrect air gap	Partial discharge	Fusing, welding or full arch flash
	Connections		Poor contact	Overheating	
	Earth wire		Incorrect air gap	Partial discharge	
Switchgear	Contacts		Poor contact	Overheating	
	SF6		Contamination, decomposition, SF6 loss	Sustained arcing	Explosion, toxic by-products
	Oil		Contamination / decomposition		Explosion, fire

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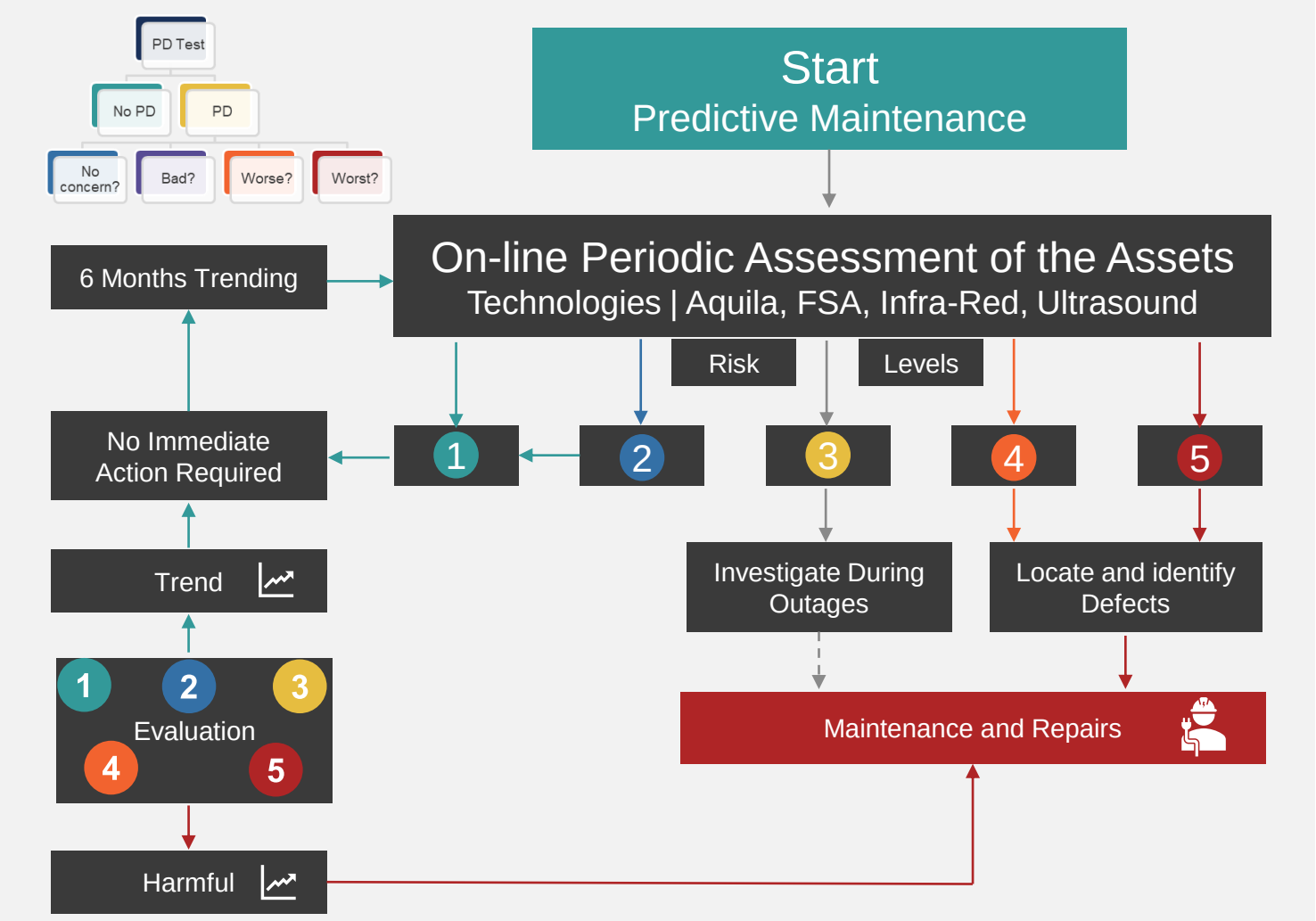
Condition Risk Interpretation Guidelines and Findings

Condition Risk Interpretation Guidelines

The levels given are meant as a guideline only, dependent on voltage levels, insulation material properties and operating conditions. They do nevertheless provide a basis for developing a risk indication for in-service HV and MV plant.



Level	Findings	Action	Trending Analysis
1	No PD	No immediate action	6 months trending analysis of the complete power circuit • Switchgear • Cables • Connected Equipment
2	Low PD		
3	Moderate PD	Investigate during outages	
4	High PD	Investigate immediately, maintain and repair	On completion of repairs, conduct assessments (Evaluate Findings) and trend every 6 months
5	Major PD		

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Condition Risk Interpretation Guidelines and Findings

Condition Risk Interpretation Guidelines for trending

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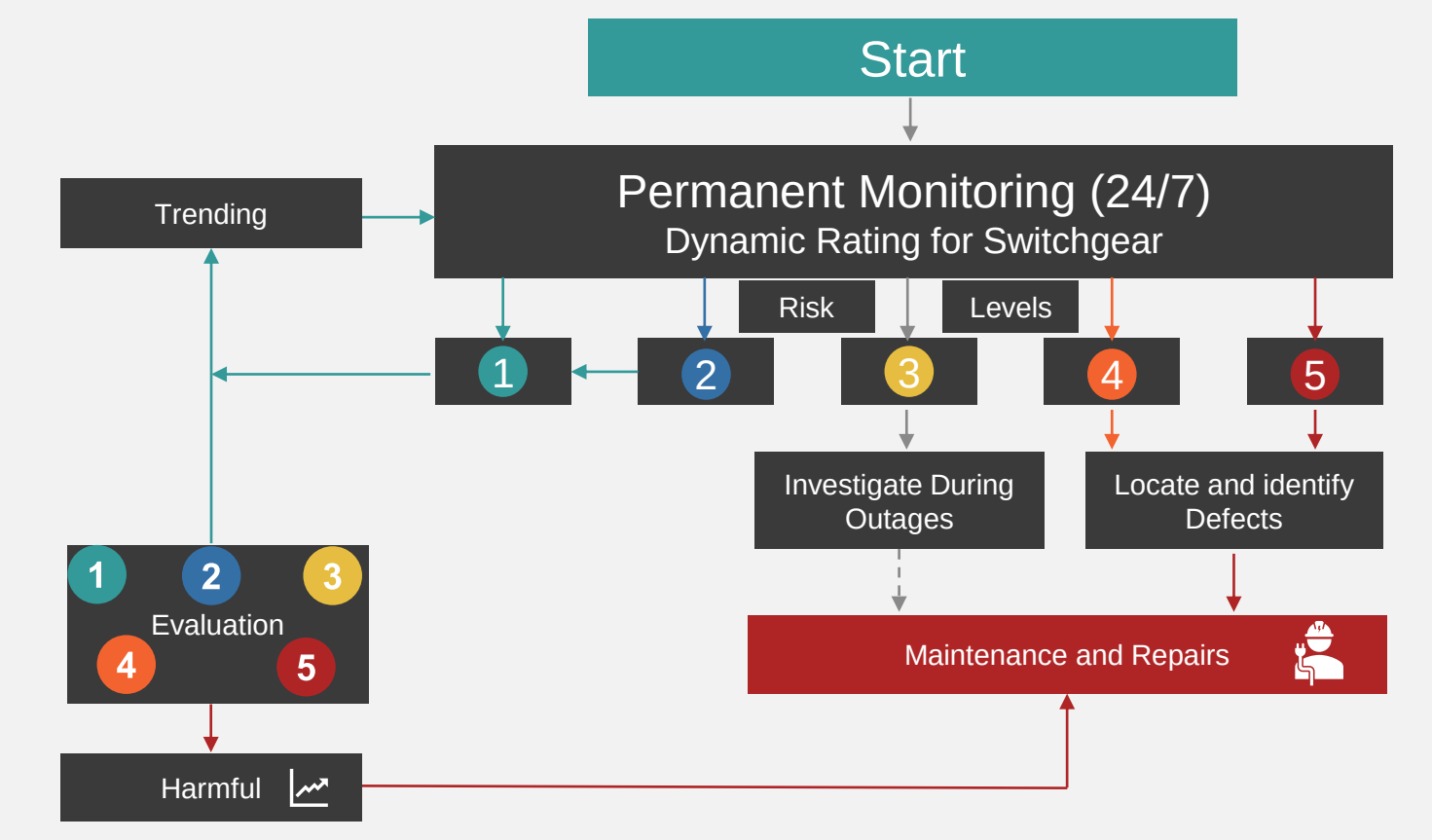

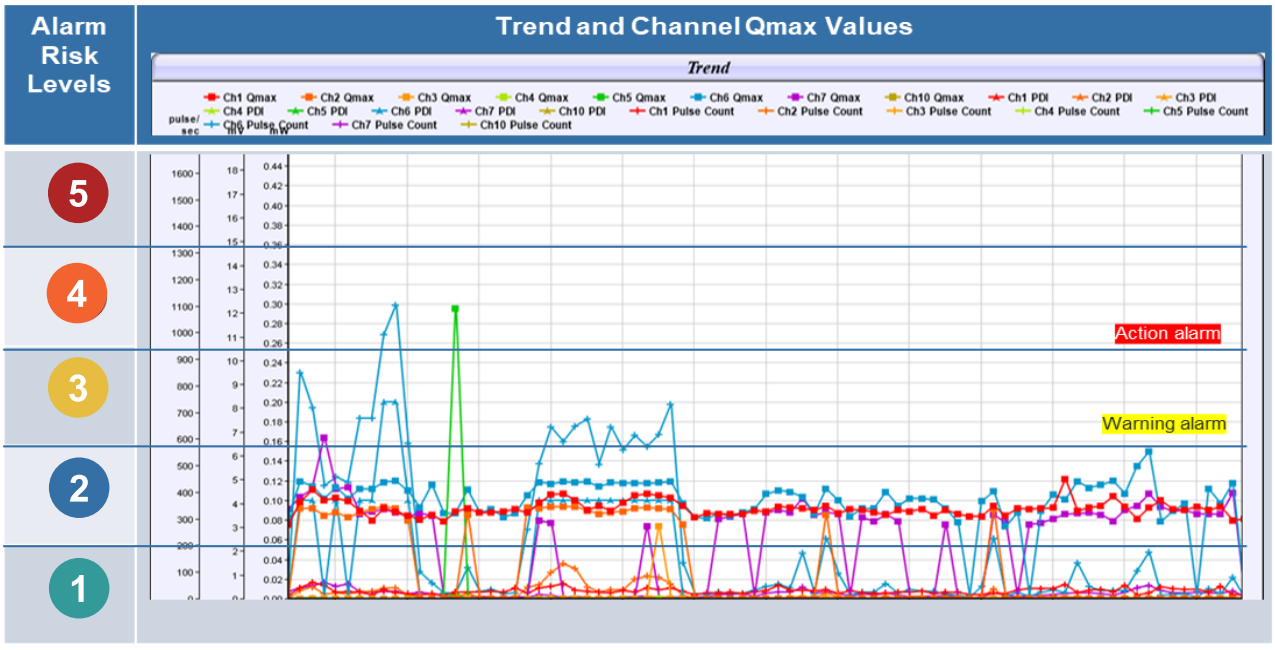

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Switchgear Monitoring System and References

Normative References

[1] ISO 13373 - Condition monitoring and diagnostics of machines - measurements
[2] ISO 13374 - Condition monitoring and diagnostics of machines – data processing
[3] ISO 17359 - Condition monitoring and diagnostics of machines -- General guidelines
[4] IEC 60270 - Partial Discharge Measurements
[5] SANS 10198-13:2016 Edition 2 - Conditions of MV Cable test
[6] IEC 62478 High voltage test techniques – Measurement of partial discharges by electromagnetic and acoustic methods

Informative References

[1] “Modbus Tutorial from Control Solutions.” [Online]. Available: https://www.csimn.com/CSI_pages/Modbus101.html. [Accessed: 23-Mar-2020].
[2] “RS485 Protocol Basics | RS485 Cable & Wiring - B&B Electronics.” [Online]. Available: http://www.bb-elec.com/Learning-Center/All-White-Papers/Serial/Basics-of-the-RS-485-Standard.aspx.[Accessed:23-3-2020].
[3] “Advantages of RS485 | disadvantages of RS485.” [Online]. Available: https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-RS485.html. [Accessed: 23-Mar-2020].
[4] “Serial Communications RS232, RS485, RS422.” [Online]. Available: https://www.raveon.com/wpcontent/uploads/2019/01/AN236SerialComm.pdf. [Accessed: 23-Mar-2020].

Switchgear Monitoring System

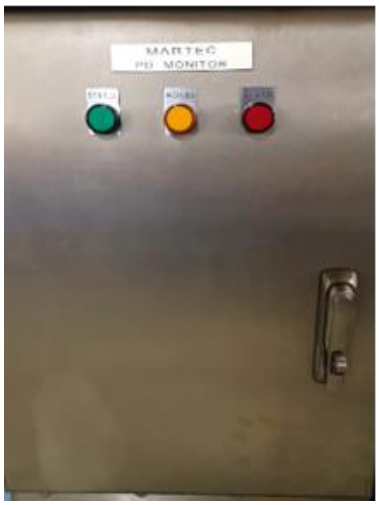
The monitoring system can be configured to have up to 60 PD inputs (four PD modules). Each module features fifteen independent (concurrently monitored), highly sensitive, user-configurable input channels that deliver the industry’s best signal-to-noise ratio and connect to a wide variety of PD sensors. The PD monitor should ideally be able to utilise the most commercially available PD sensors such as PD coupling capacitors, HFCT’s, Regowski Coils, radio Frequency coupling capacitors, ground path current sensors, and more.

Basic components

- Power supply
- Main monitor
- PD modules
- PD sensors (HFCT’s and coupler sensors)
- Environmental sensors (temperature and humidity)
- Current Transformers (load measurements)
- DNP 3 and Modbus communications

Process and Deliverables

The monitoring system, including the main monitor with the required PD modules, is fit into a mild steel enclosure that is powder-coated (Rating IP 65). The system uses coaxial connections and a power pack fitted in the steel enclosure (15 to 30 channel or 45 to 60 channel enclosures) that need to be factory acceptance tested before site delivery.



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Defects identified during sensor installation

Visual findings identified during this process

The below photograph is the layout of the feeder cables with permanent sensors installed. Termination number 4 is at the back of the switchgear panel and termination number 1 in the front standing behind the panel.

Black heat-shrinkable medium wall insulating tube with adhesive.

These tubes must not be used on 33kV terminations.

The terminations are sleeved with a Black heat-shrinkable medium wall insulating tube with adhesive. These tubes are for low voltage application and MV zip sleeving to repair the outer PVC to avoid moisture and water increase.

Description and Application	Technical Characteristics
Heat-shrinkable medium wall insulating tube with adhesive. GT3 is a medium wall co extruded tubing with adhesive. Provides excellent adhesion to a variety of cable substrates and various metals. Ideal for LV joints and termination as core insulation. Cable sheath (PVC) replacement in LV and MV cables. The adhesive layer ensure a watertight seal and eliminate moisture ingress.	Material: Crosslinked polyolefin Colour: Black Continuous operating temp.: -40°C to +135°C Minimum shrink temp.: 125°C Density: 1,1 g/cm^3±10% — ASTM D-1505 / ISO R1183 Tensile strength: 20÷25 N/mm^2 — ASTM D-412 / ISO 37 Ultimate elongation: 500%÷600% — ASTM D-412 / ISO 37 Dielectric constant: <5 — IEC 250 Volume resistivity: >1x10^{13}Ohm.cm — IEC 93 Dielectric strength: >15 kV/mm — IEC 243 Water absorption: <0,2% — DIN 53495 / ISO 92 Fungus and mildew resistance: gl0 — ASTM G 21 Contents of carbon black: >2,5% — ASTM 2671 Chemical resistance: (Treatment with 0,1NNa2SO4, H2SO4, NAoH, NaCl)

Why not use the tube on 33kV (MV) terminations

The content of carbon black (>2.5%) in the tube could lead to tracking type discharges between the connection lug (bus) and termination earth strap.

The anti-tracking (red tube) in this case under the black tube cannot perform to the design parameters.

Voids between the black tube and anti-tracking tube can form, leading to void ionization and deterioration of the insulation system of the termination.

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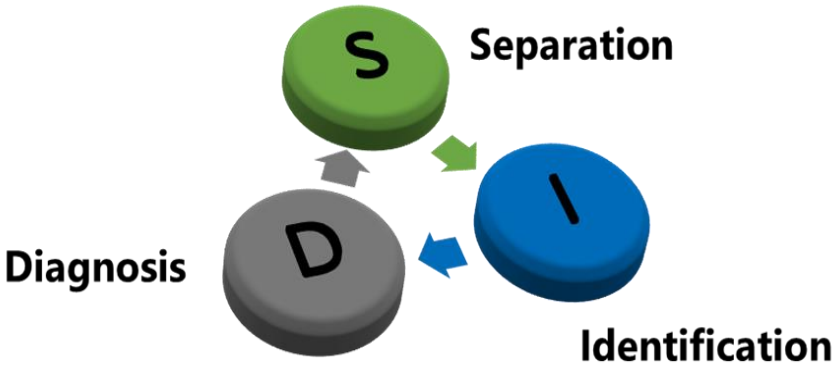
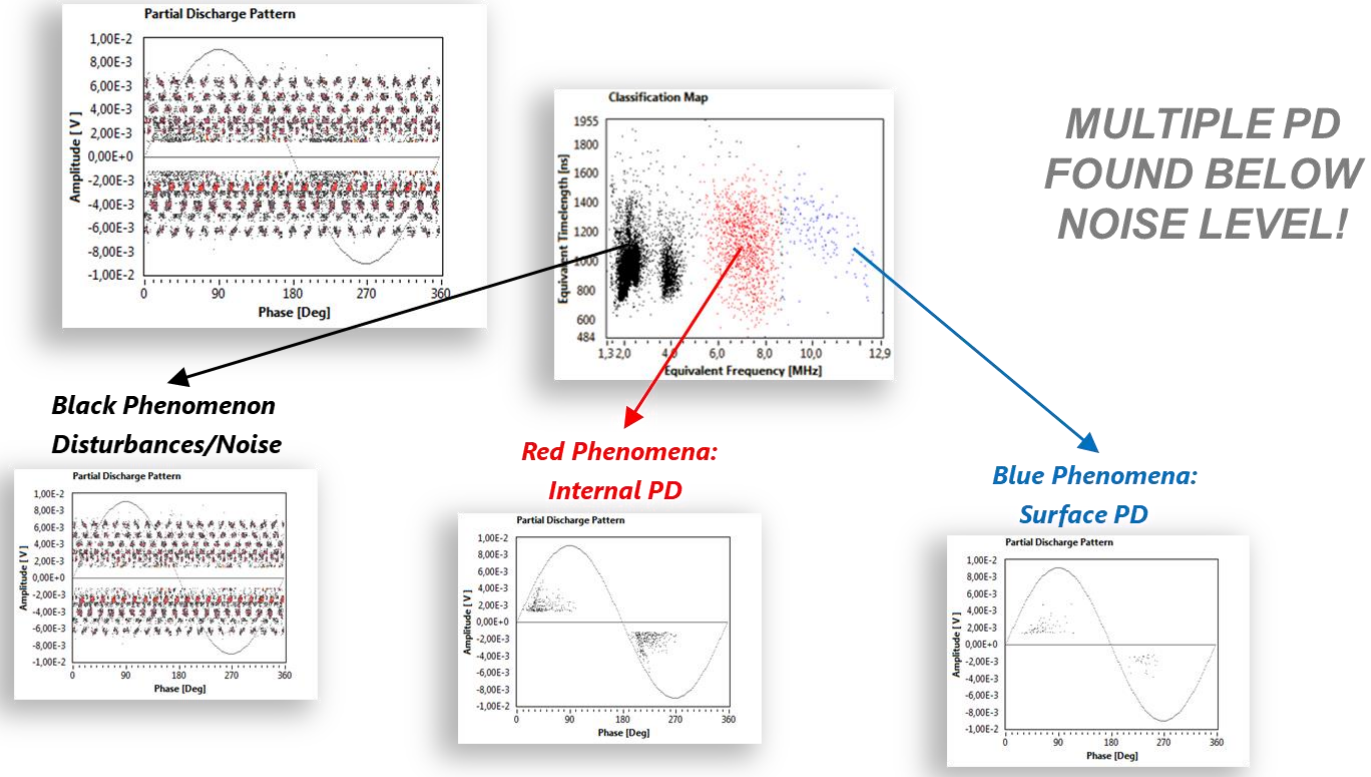
Aquila Advance Diagnostic Process used by Martec

On-line condition assessment of the switchgear power circuit

The 1st online condition assessment with advanced PD detection technology must be conducted to identify existing defects that can be repaired during the installation process of the PD sensors. Data acquisition of the complete switchgear power circuit must be assessed. This includes switchgear components, switchgear termination, feeder cables, connected equipment terminations and connected equipment. The technology must conform to the required standards as per the Normative References.



- Separation of any multiple PD sources and noise rejection
- Identification PD Type based on the PD Pattern and resulting harmfulness
- Knowing number and type of defects, the resulting Diagnosis is more accurate and effective



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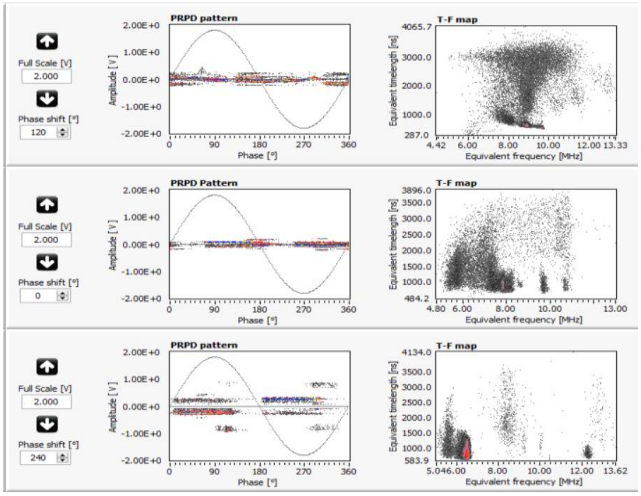
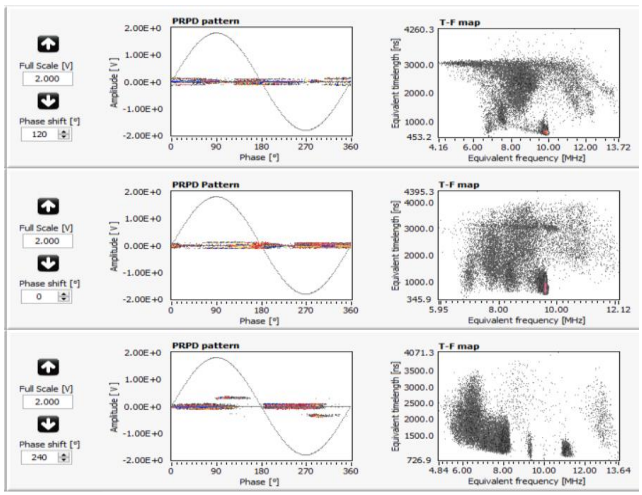
Aquila Raw Data Findings of Termination Defects

The reference is set at 2000 mV. Coupler sensor Yellow 3 is indicating the highest discharges (highlighted in red) and Red 3 indicates activity, but it could be cross talking from yellow 3.

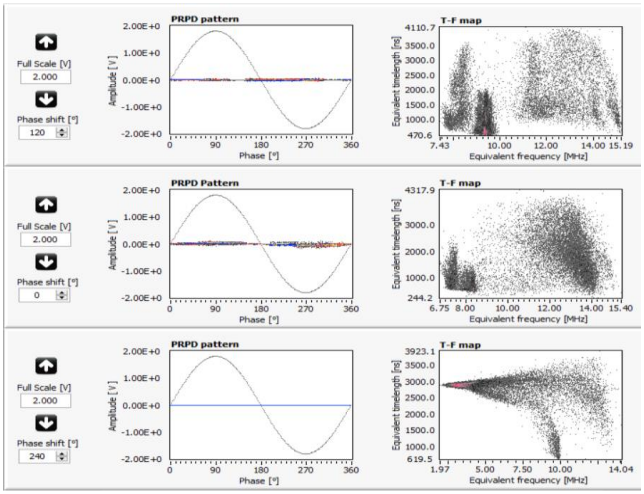
HFCT 1 Red ½ – Yellow ½ - Blue ½



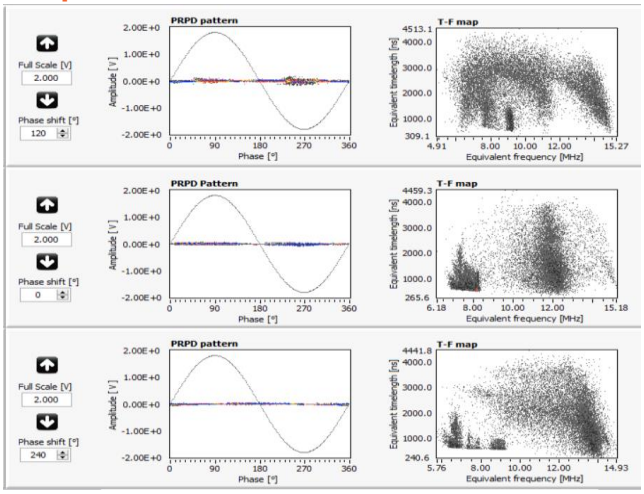
HFCT 1 Red ¾ – Yellow ¾ - Blue ¾



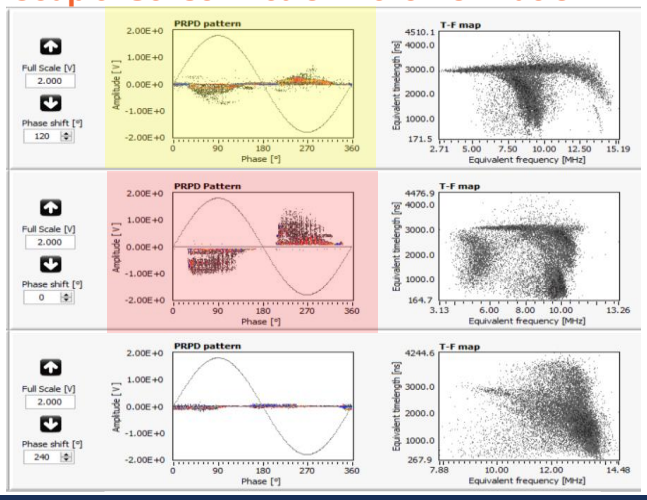
Coupler Sensor Red 1 – Yellow 1- Blue 1



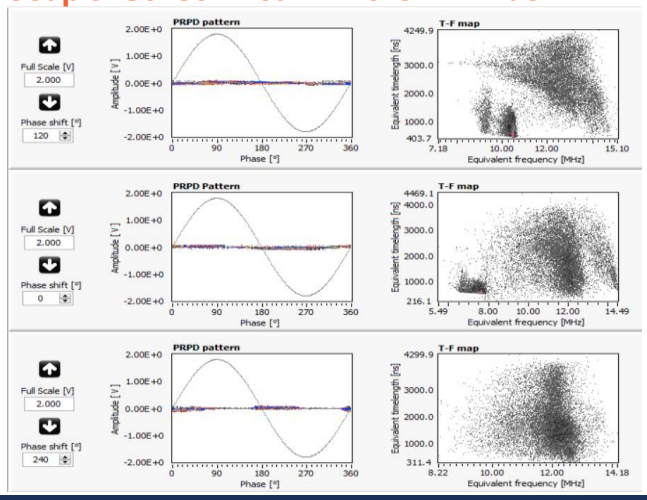
Coupler Sensor Red 2 – Yellow 2- Blue 2



Coupler Sensor Red 3 – Yellow 3- Blue 3



Coupler Sensor Red 4 – Yellow 4- Blue 4



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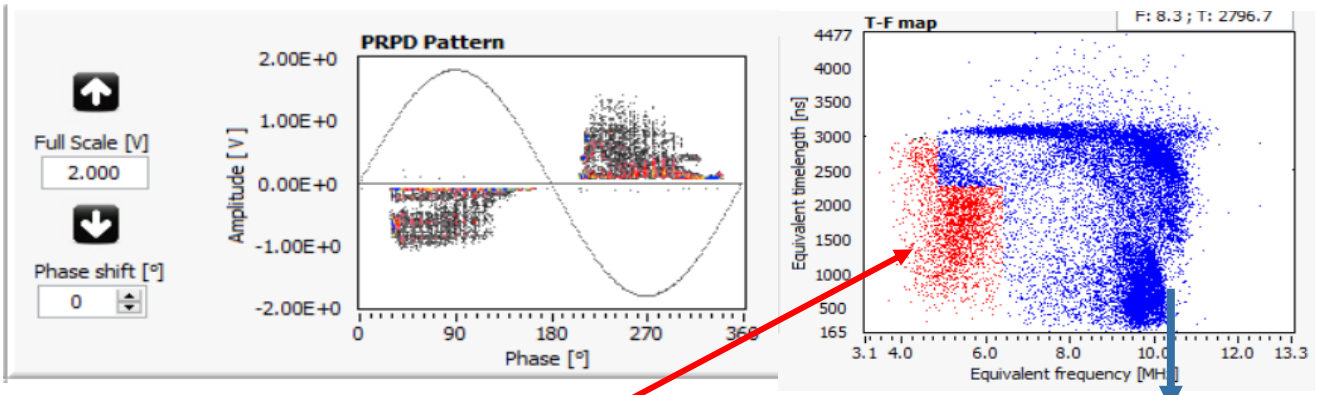
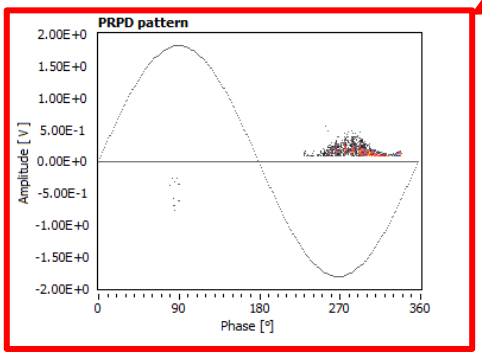
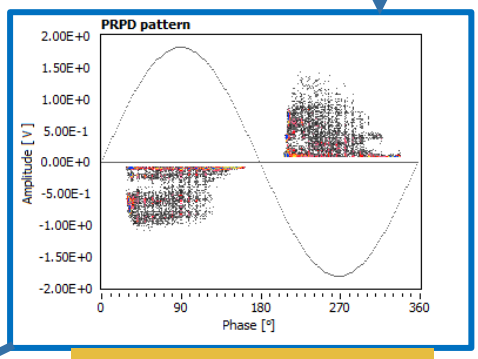
Aquila - Findings of Termination Yellow 3 (Level 5)

The raw data is analysed and each pulse coded in the TF map (Red pulses – Cross Talk, Blue pulses PD in the termination).

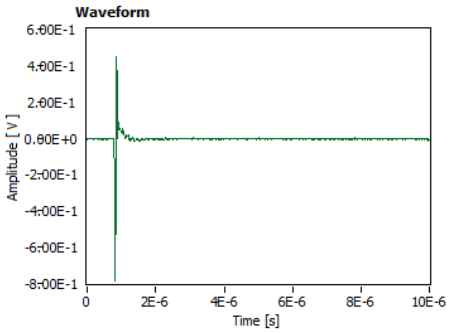






PD in the termination of Yellow 3

Positive	Parameter	Negative
0.341	Alfa [V]	0.394
1.088	Beta	1.380
1.062	QMax [V]	1.422
0.844	QMax95% [V]	0.828
0.338	QMean [V]	0.366
0.062	QMin [V]	0.078
0.739	NQN	0.616
862.892	N/s [1/s]	673.496
9800	N	7649
1285.709	Nw	1003.509



*The **Qmax 95% = 844 mV** which is very high for terminations.*

*The Nw factor is the pulses per cycle and indicates the PD activity per cycle **Nw = 1285.71** pulses per cycle that is very high for termination defects.*

The wave form have a very fast rise and fall time that indicates that the defect is close to the assessment point (sensor)

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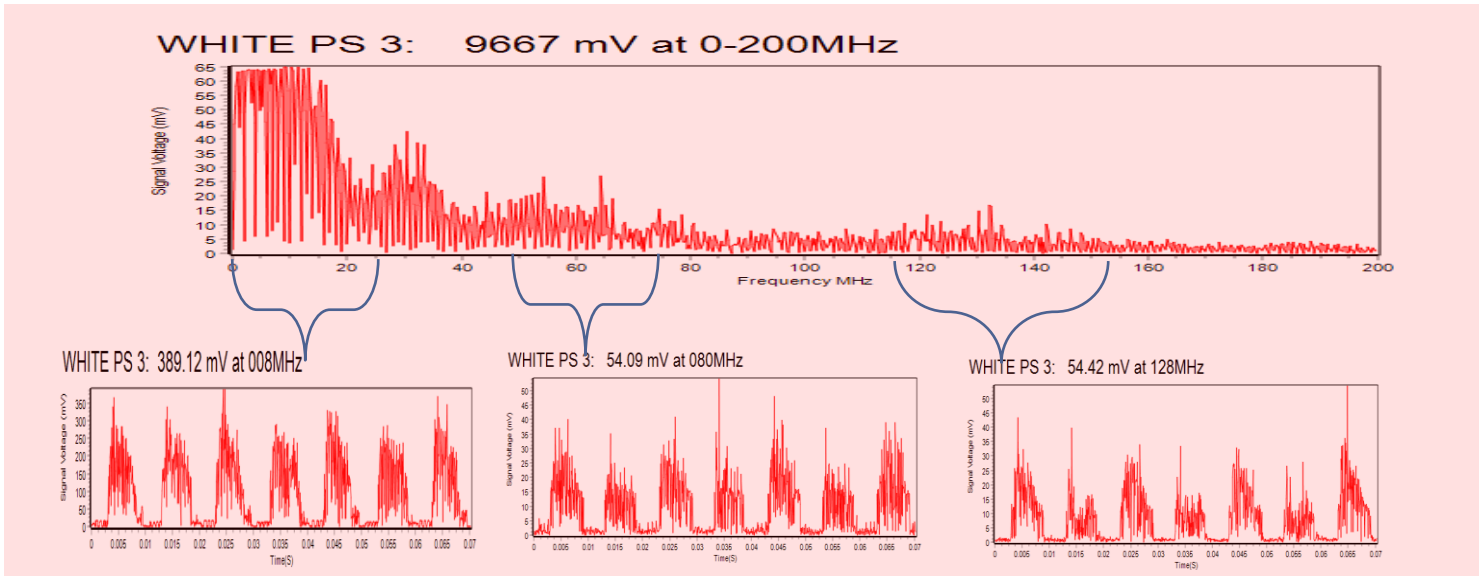
Frequency System Analyser – Comparison Findings

The below FSA findings are taken in the frequency domain from 0 to 200 MHz. The amplitude is set between 1 and 25 mV with PD pulses between 106 to 4633 mV. The yellow phase termination number 3 amplitude was set at 65 mV to avoid clipping of the signals and the PD pulses were detected at 9667 mV.

Red Phase	Yellow Phase	Blue Phase
RED PS 1: 2338 mV at 0-200MHz	WHITE PS 1: 2672 mV at 0-200MHz	BLUE PS 1: 106 mV at 0-200MHz
RED PS 2: 3471 mV at 0-200MHz	WHITE PS 2: 2171 mV at 0-200MHz	BLUE PS 2: 2594 mV at 0-200MHz
RED PS 3: 4633 mV at 0-200MHz	WHITE PS 3: 9667 mV at 0-200MHz	BLUE PS 3: 1898 mV at 0-200MHz
RED PS 4: 2643 mV at 0-200MHz	WHITE PS 4: 2889 mV at 0-200MHz	BLUE PS 4: 2884 mV at 0-200MHz



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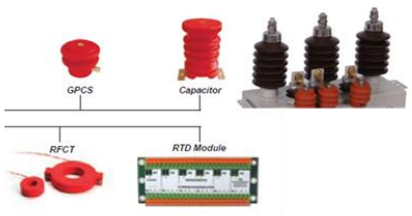
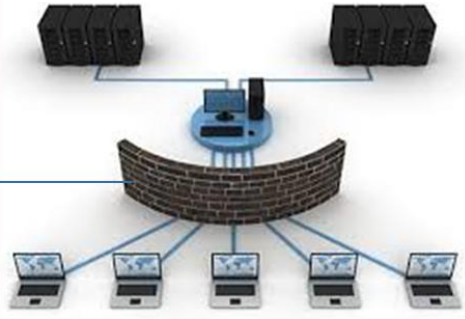
Dynamic Ratings In-Time Monitor for Switchgear

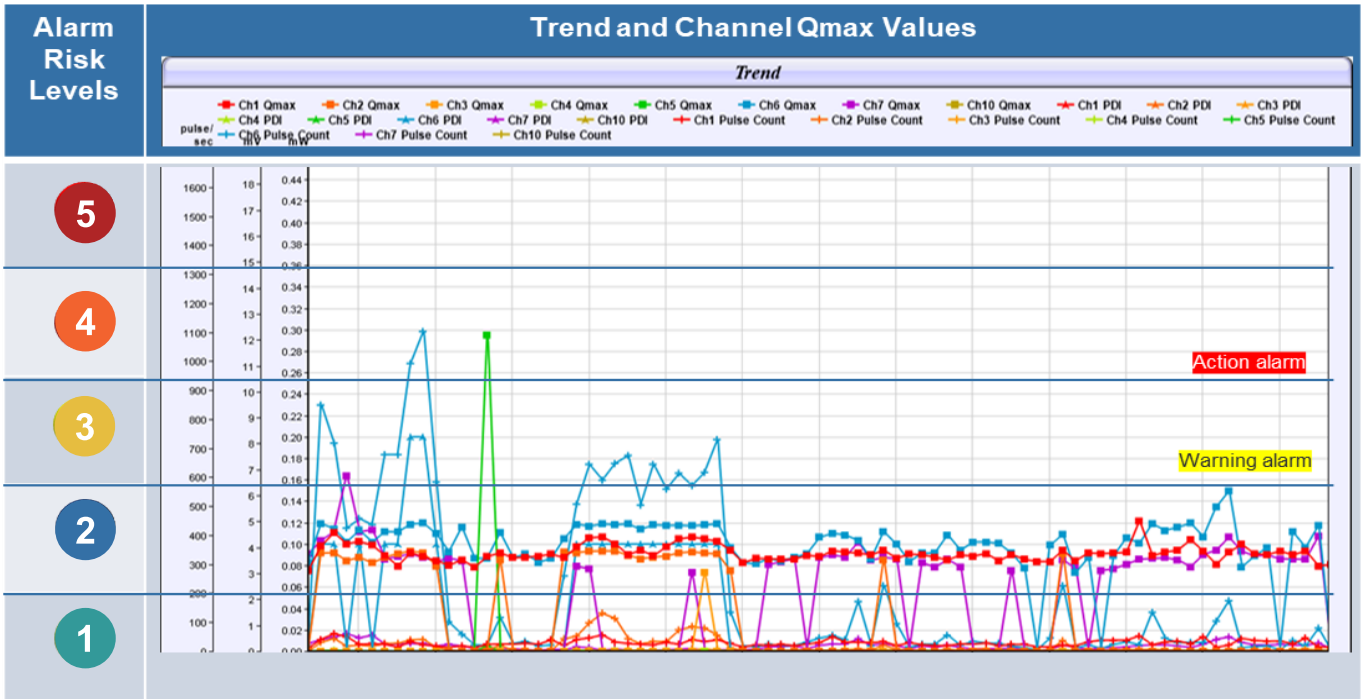


Identify Required Sensors and Technologies

Implement Communication Platform

Commander Dashboard





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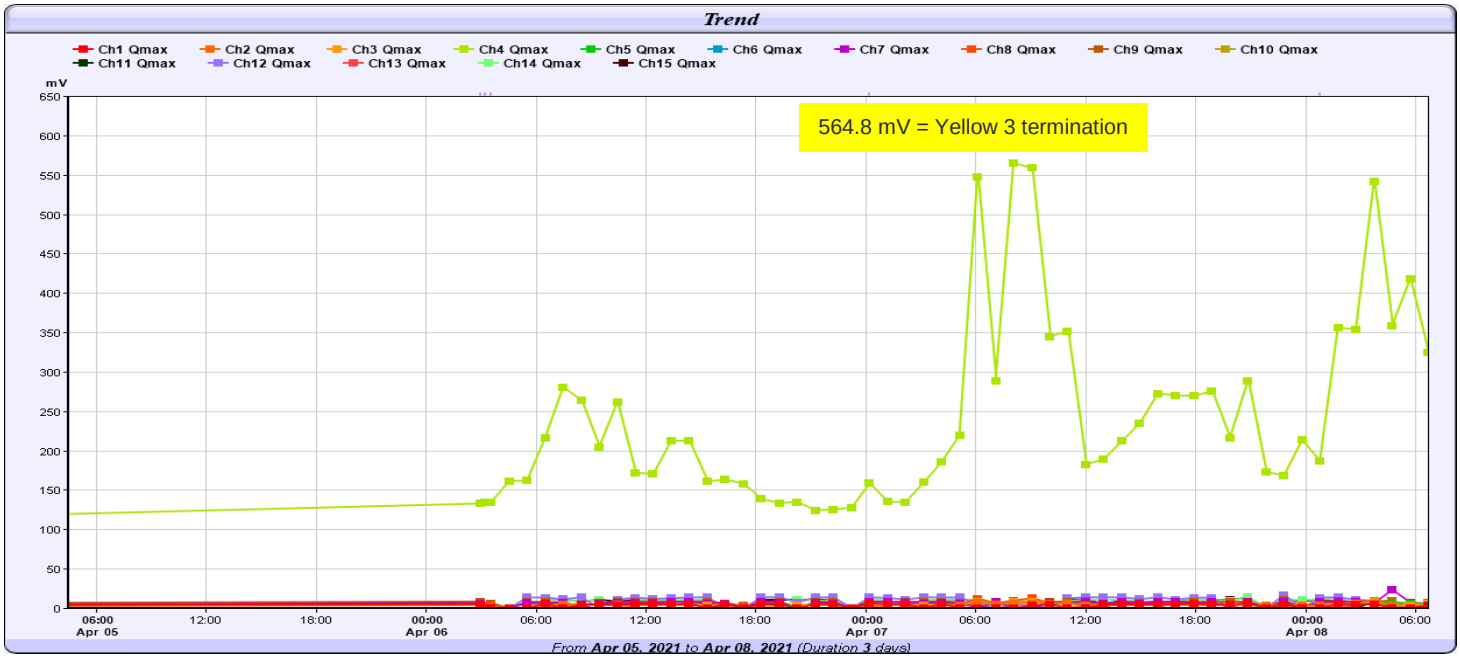
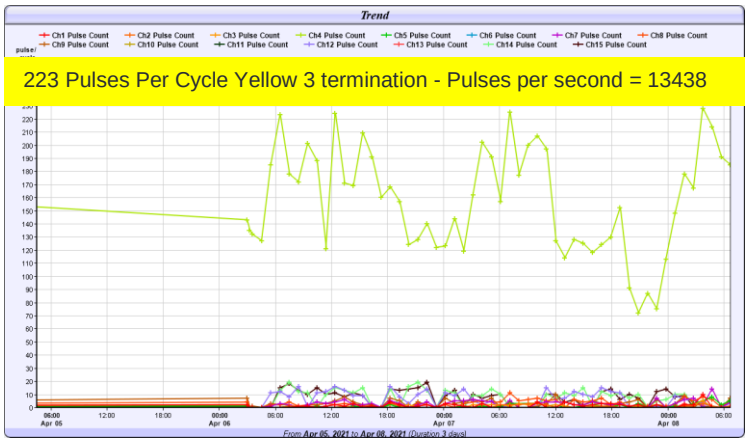
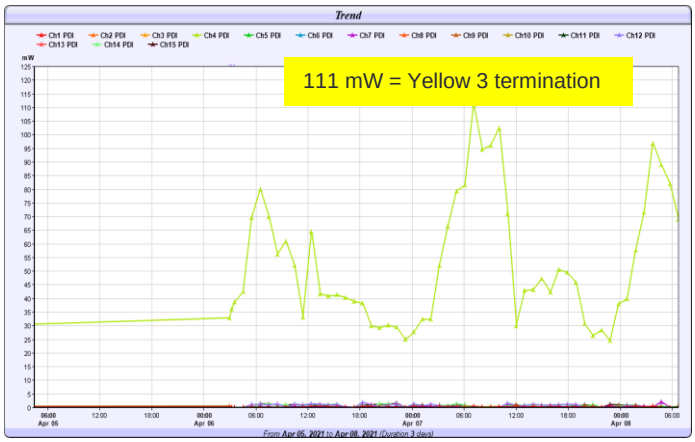
Dynamic Ratings On-line Condition Monitor Findings

The below graph show the mV intensity of the 15 channels with channel 4 (green = Yellow Phase Termination number 3) the highest at 564.8 mV.

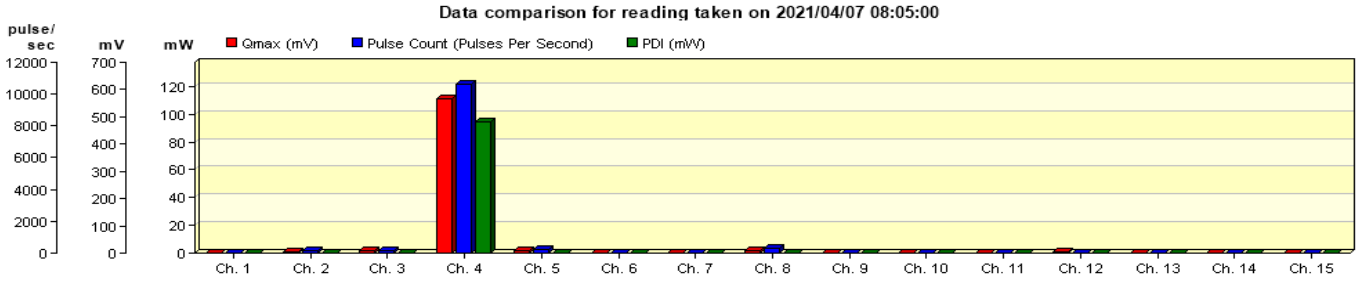


The below graph on the left side shows the pulses per cycle of 15 channels with channel 4 (green = Yellow Phase Termination number 3) the highest at 223 PPC or Pulses per second at 13438.
The graph on the right side shows the PDI (Partial Discharge Intensity) of 15 channels with channel 4 (green = Yellow Phase Termination number 3) the highest at 111 mW.





The below data comparison show channel 4 (Yellow 3) data taken on the 2021/04/07 (08H05) to be the highest of the 15 channels.



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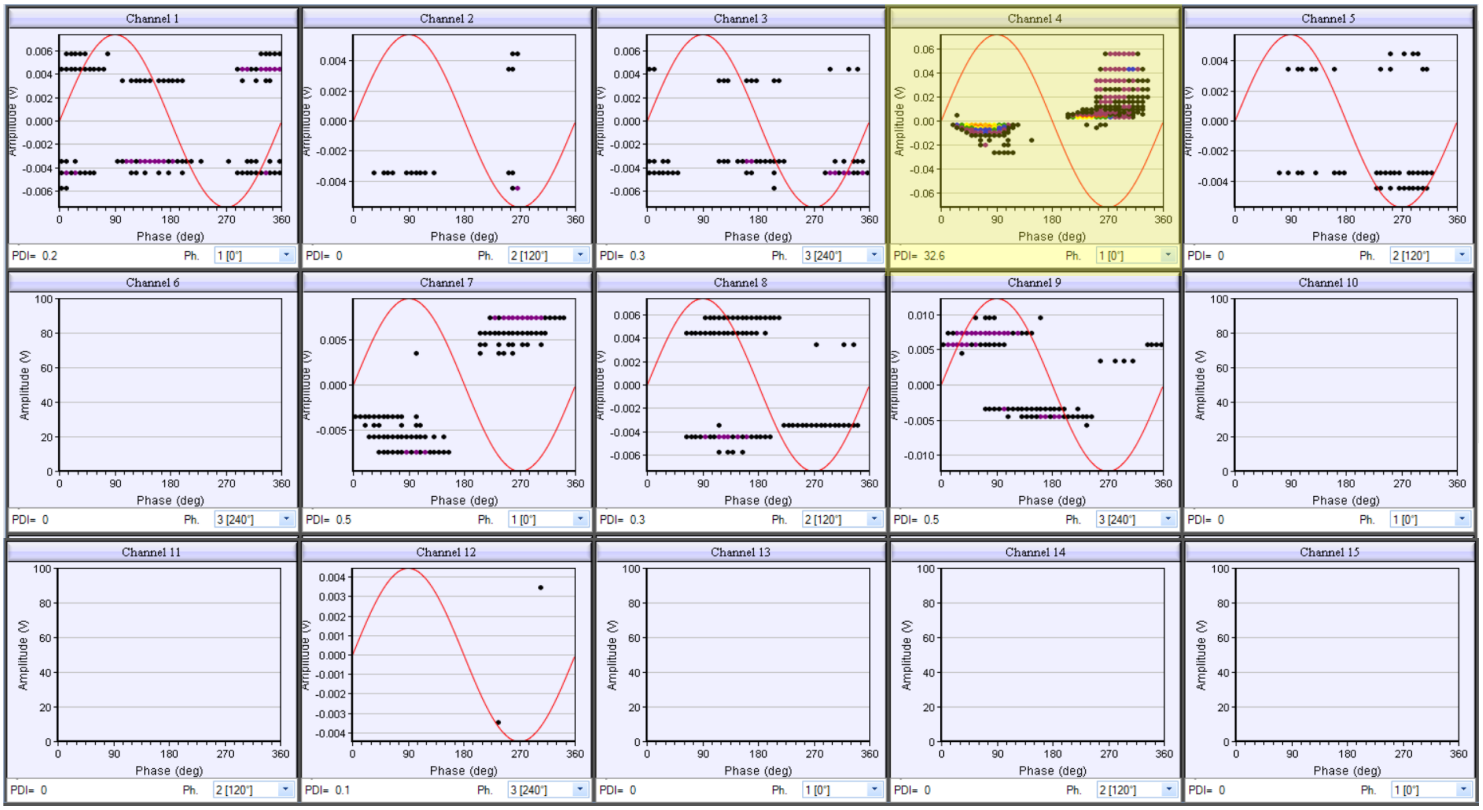
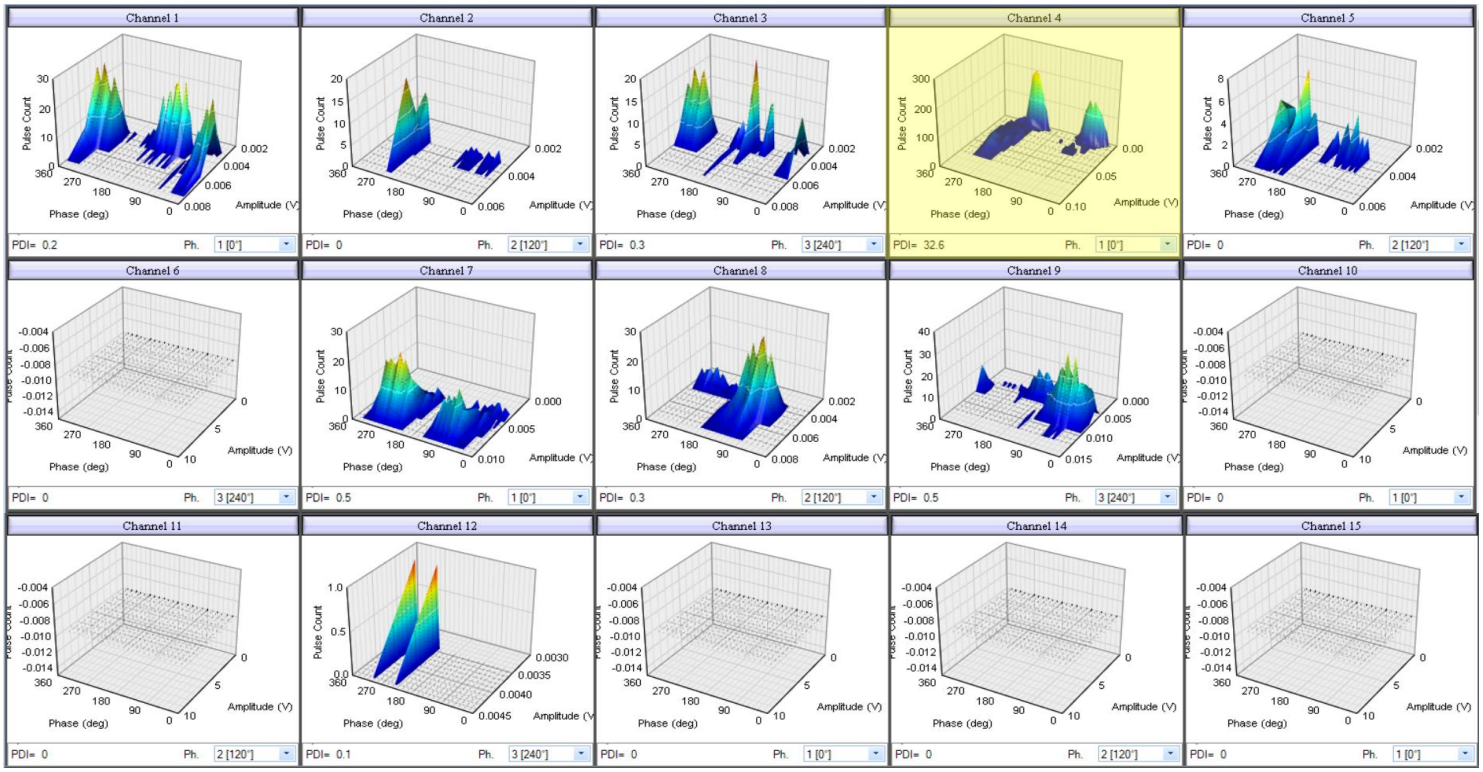
Dynamic Ratings On-line Condition Monitor Findings

The below phase resolved partial discharge pattens from channel 1 to channel 15 – Note channel 4 PDI = 32.6 mV with the rest of the channels from 0 to 0.5 mV.



The below 3D phase resolved partial discharge pattens from channel 1 to channel 15 – Note channel 4 PDI = 32.6 mV with the rest of the channels from 0 to 0.5 mV.



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Partial Discharge Failure in MV Switchgear

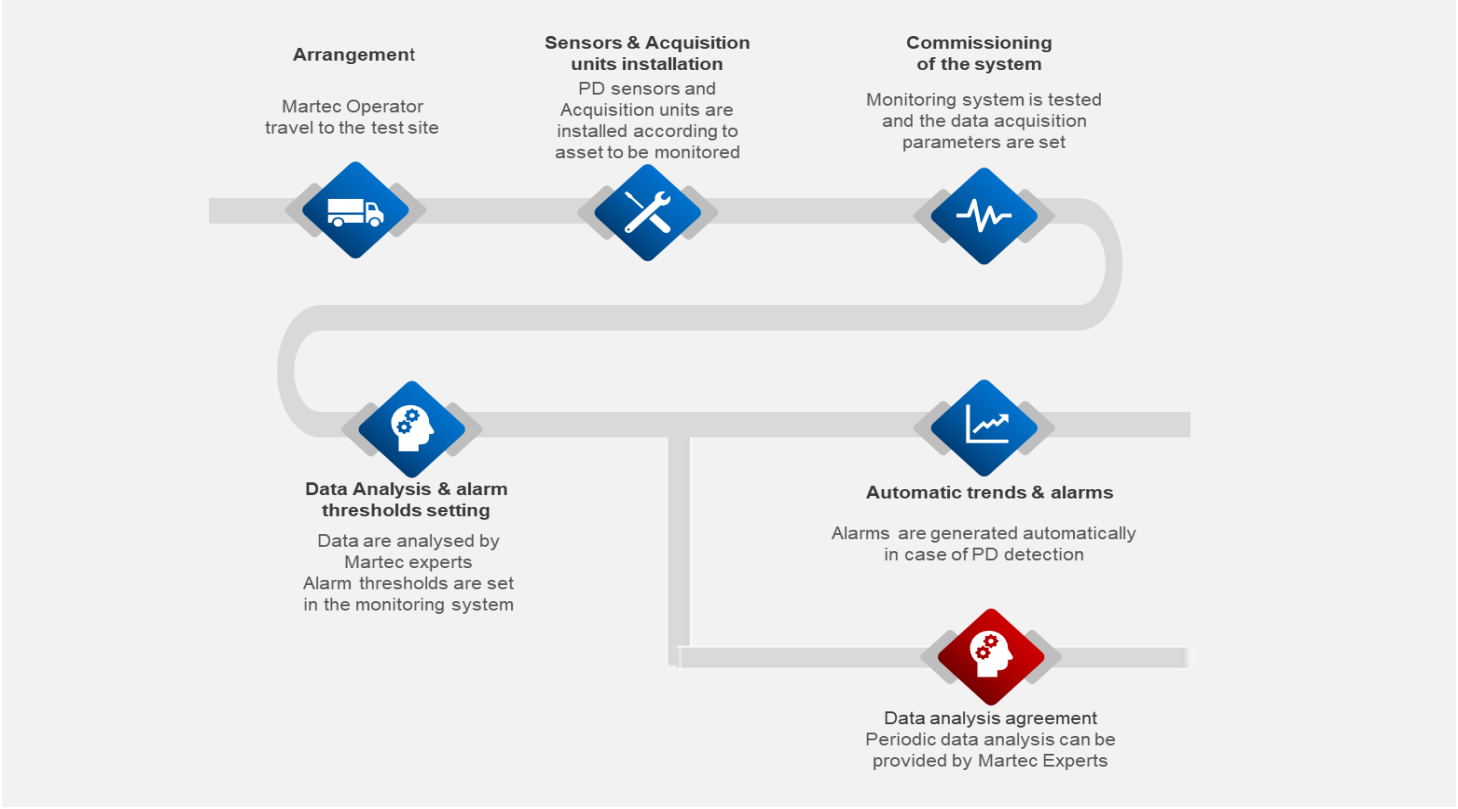
Maintenance and Engineering Decisions

Good maintenance begins with a **proactive approach** to maintain, keep, preserve and protect the equipment. The most fundamental proactive system to achieve this, is a comprehensive predictive maintenance programme.

What does that mean? Predictive maintenance (PM) consists of many parts. Let's break it down into two primary components:

- **Essential Care -** Essential care is preventive maintenance that relates to the prevention of failures. This is analogous to checking the air pressure in the tires on your car or changing the engine oil on a routine basis. In industry, these tasks are generally noted as lubrication, cleaning, adjusting, operating, and more.

- **Condition Monitoring -** Condition monitoring (periodic assessments) is the part of predictive maintenance relating to the detection of failures. It is like checking the wear profile of your car's tires. The tires' wear profile can be how you detect failures (i.e., problems). In industry, these tasks are generally noted as inspection (identify defects), investigation (locate defects), root cause (prevent defects), quality assurance (record findings), and monitoring (trending).



Conclusion

Electrical insulation is one of the essential sources of unexpected failures in electrical equipment. Voltages should not exceed rated values (during operation) to avoid electrical breakdown of insulation systems. However, even rated voltages can create Partial Discharge (PD) in power cables and electrical machines whereby environmental conditions and installation methods have influence.

Partial discharge does not cause immediate failures but contributes to degrading insulation systems through a chemical and physical attack of the main solid dielectric's surroundings. This leads to premature electrical equipment failures because partial discharges take place several times per power frequency cycle.

Identifying the type of PD phenomena is the key prerequisite to carry out effective maintenance since different partial discharge activities lead to different degradation rates within an insulation system.