IMPLEMENTATION OF INNOVATIVE MEASUREMENTS METHODS FOR ON-LINE DETECTION OF PARTIAL DISCHARGE AND HOT SPOTS IN MEDIUM VOLTAGE ASSETS

C SMITH, K TAVERNIER, C EASTHAM, S ROE

IPEC LTD, UNITED KINGDOM

1 INTRODUCTION

This paper explores novel methods for applying established condition monitoring techniques including partial discharge (PD) testing and infrared (IR) imaging on high voltage (HV) assets. Both PD and IR have well established methods for carrying out testing and can be applied to a wide range of HV assets, with the benefits of carrying out such testing well proven [1]. The first application assessed focusses on a market need for monitoring of downstream network components such as ring main units (RMU) with most current applications focusing on higher value assets. The paper introduces a novel system combining key condition based maintenance (CBM) technologies together, PD and IR, which allows for cost effective monitoring of downstream assets and evaluates the effectiveness of the technology. The second application evaluates a new technology for permanently monitoring medium voltage gas insulated switchgear (GIS) which historically has had limited monitoring options due to restrictions on viable sensor placements. The technology builds on the existing voltage detection system (VDS) / voltage presence indication system (VPIS) method of detection and advances it from a spot testing tool into a permanent monitoring option.

2 ON-LINE PD DETECTION

Partial discharge is an electrical discharge that occurs inside or on the surface of insulation under normal operating conditions. The PD will occur due to contamination, defects, voids, or degradation of insulation, resulting in a non-uniform stress distribution of the electrical field. PD occurs within operating voltages and over time causes further exacerbation of the defect, such as electrical treeing or surface tracking, which over time often leads to complete breakdown of the insulation, and HV failure.
As well as being commonly tested offline or in factory, PD can be tested online (whilst asset is live)
Partial Discharge sensors for detecting defects in HV assets utilize one of three primary methods of signal detection;

2.1 Current Pulse

Detection of a current pulse which propagates along metallic surfaces, often referred to as Transient Earth Voltages (TEVs) when applicable to medium voltage (MV) switchgear. These signals are high frequency but low in energy, propagating via the skin effect on the equipment surface. Air gaps between panels on Air Insulated Switchgear allow for the TEV signals to escape to the outside of the equipment where a capacitively couple sensor (CC or CC-TEV) can be placed to detect the signal. High frequency current transformer (HFCT) sensors also detect current pulses, those which propagate along a cables length to a point where earth and core separate. These sensors have long been established as the primary method for detecting current pulses in online PD testing [2].

2.2 Direct Electromagnetic Radiation

From a PD perspective, Electromagnetic Radiation (EMR) is the high-frequency energy released instantly during a discharge event. This results in a broadband signal spanning radio frequencies. Direct EMR detection utilizes specialized sensors: Ultra-High Frequency (UHF) antennas (300 MHz to 3 GHz) are deployed inside shielded assets like GIS to capture internal radio waves, offering excellent sensitivity; conversely, Ultraviolet (UV) cameras focus on the optical band (200-400 nm) to detect the faint light (corona) emitted by PD in open air environments.

2.3 Ultrasonic And Sound

Ultrasonic sensors detect acoustic energy generated by a PD event. Typically in the ultrasonic range of 40kHz, this is the method of detection for surface-level faults, such as surface tracking or corona on exposed assets. Most commonly the sensors are permanently installed inside cable terminations. Contact acoustic sensors can be used, though airborne acoustic sensors installed inside the cable box are much more sensitive [3].

2.4 Application Of Sensors

The PD sensor that is used depends upon the asset being tested, and practicalities of a sensor that can be physically applied. Some assets pose limitations to sensor installation due to their design and operation. In these cases, specialist sensors may be needed, or alterative designs. This paper will explore some of these innovations recently being deployed.

3 INFRARED TESTING OF HV ASSETS

Sensors which operate in the Infrared frequency range are particularly effective at detection of temperature differentials of assets under test [4].
In HV electrical assets, hot spots can be caused by increased electrical resistance, essentially caused by poor contact between conductors carrying current. A common and particularly concerning example involves cable terminations on MV feeders. Where the cable conductor connects to the circuit breaker, the termination must be tightened to the specified torque and made with an even, secure contact. If the contact surface between the conductors is uneven or incomplete, the connection resistance increases, leading to localised heating at the points of highest resistance. Heating caused by this increased resistance can raise conductor temperatures above normal operating levels and beyond design limits. This reduces the asset's service life and, under certain conditions, can lead to failure.

3.1 Ir Testing Technologies

Handheld devices are the most common IR tools used on equipment. They offer flexibility, allowing multiple assets to be tested with a single device, but they are limited to intermittent spot checks.
Less commonly, continuous IR monitoring cameras can be installed. These systems are generally more expensive to deploy because a large number of cameras may be needed to cover a given set of assets.
When either technology is applied to MV switchgear, modifications are required as IR cameras need a direct line of sight to MV terminations.

4 COMBINING THE TWO INTO ONE SENSOR

To provide a strong value proposition for asset managers, integrating IR and PD into a single sensor offers a more cost-effective way to monitor key degradation indicators on RMU terminations than existing solutions. Secondary substations and sites are typically lower value than primary substations, so the allowable condition-monitoring budget per unit is also lower. Any system designed for this application must reflect that constraint.
Accordingly, the proposed system's electronics have been designed to deliver the required functionality at minimum cost. This includes the sensor design, which uses a lower-resolution IR camera than typical handheld products. The selected resolution provides visibility of the individual phases within a termination and enables hot-spot identification, but it does not offer the same measurement accuracy as current spot-testing methods.

Figure 1 – Images of sensor installed in trial sites

For the sensor to be effective, it must be installed inside the cable termination box. This can be done either by the OEM during manufacture or as a retrofit, provided an outage can be taken on the relevant RMU. The sensor has a 75° × 110° field of view and an effective range of up to 1 m between the sensor and the temperature source. This allows it to be mounted well outside minimum safety clearances and as far as practicable from exposed HV components, minimising potential safety and reliability risks.
By integrating the technologies, a single RJ45 cable connects the sensor to the controller and carries PD, IR, and ambient temperature and humidity data, reducing cabling requirements and minimising installation risk.

Figure 2 – Images of sensor installation at trial sites

5 CONTROLLER / INTERFACE

Sensors in each cable termination box are linked to a central controller. The controller collates data together from each sensor to be transferred to a centralized system covering all RMU's on the network. Each controller is designed to cover a single 3 or 4 panel RMU. Data is transferred either directly to the remote terminal unit (RTU) via a Modbus connection or can be sent via modem to a custom online platform for further data analysis.
Data available from the sensors includes, PD level, PD frequency, phase resolved partial discharge (PRPD), average IR, peak IR, Full IR image, ambient temperature, humidity. This data can be polled by the RMU at any interval required by the user. A general recommendation

would be saving data once every 30 minutes based on previous experience of PD monitoring. Basic parameters such as PD level and peak IR can be used to create threshold triggers to give warnings of abnormal measurements however the data resolution given by these variables alone is not sufficient to diagnose either a hotspot or PD issue. It is highly recommended to analyze full PRPD graphs and IR images over time before going to site or taking further action. By looking at the more detailed data false positives can be significantly reduced.
The detailed data produced by the system is often too information-rich for standard RTU interfaces, which typically accept only single-value parameters. While basic values can be communicated to the local RTU via Modbus, the full dataset can be transmitted over a TCP/IP connection to a central server. A customised user interface can then present the detailed information clearly for analysis and further processing.

6 TECHNOLOGY ROLLOUT STATUS

The system is currently at the beginning of technology readiness level (TRL) 7 stage and undergoing field demonstrations in the Middle East. The data acquired to date has shown fluctuations in temperature and partial discharge with a demonstrated ability to identify the presence of hot spots and partial discharge events.
Trending data over time shows daily and seasonal fluctuations in temperature and humidity.

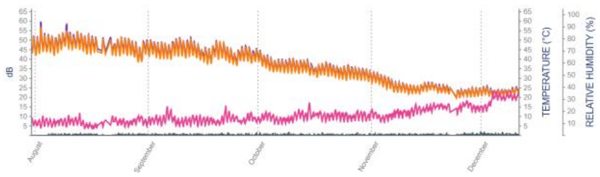


Figure 3 – Temperature, humidity & Acoustic PD measurements from August to December 2025.

By further analyzing these trends across both single and multiple sensors there is scope to develop effective and accurate thresholding and alerting systems to accurately identify hotspots. This work will continue as part of the development of the device.
Currently to identify a hotspot, individual IR images must be analyzed. Although the resolution of the IR images is lower than used on modern spot testing tools it is sufficient to clearly identify the phases on a termination and consequently any hot spot arising in these locations.

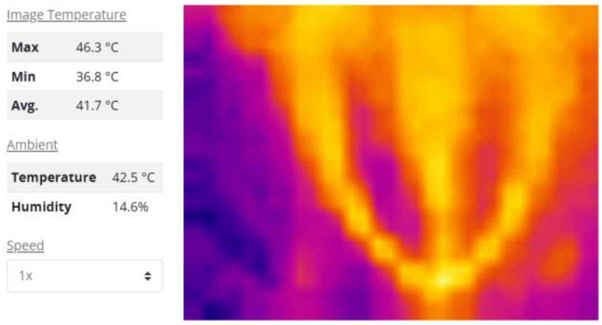


Figure 4 – IR data showing a termination during operation at trial site

By adjusting visulisation parameters, the images using the built in tools it is easy to identify hot spots in the images.

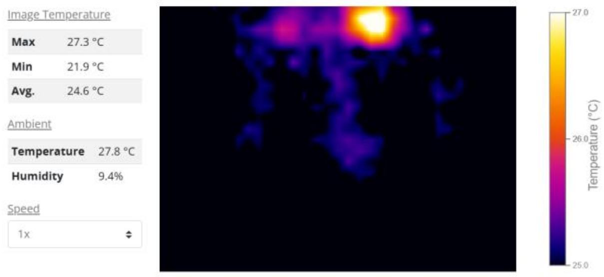
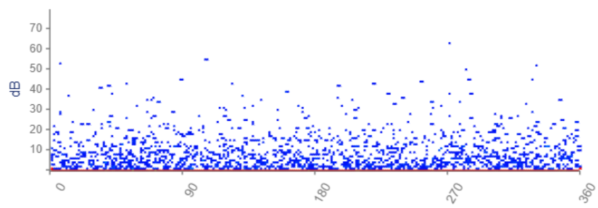


Figure 5 – Example of a hot spot detected using IR camera on trial site.

Significant further work is still required on the system in hot spot identification, stabalising IR imaging settings across a wider range of environments and automating the process of identification.
Although no genuine PD activity has been detected on the system during the trial phase the device is effectively picking up background signals and plotting PRPD graphs. In this case high activity levels have been detected with values in excess of 60dB however by analyzing the PRPD it can clearly be seen that the activity in this case is noise.



Sensor Name	AE
Detected Value	63 dB
Lowest Value	17 dB
Highest Value	63 dB

Figure 6 – PRPD of acoustic PD data collected at trial site.

The field trials conducted to date have demonstrated that the system is a stable, reliable, and effective data logger, with sufficient resolution to identify key parameters.

Further work is now required to refine the system and incorporate more intelligent analysis tools.

7 MEDIUM VOLTAGE GIS

Medium voltage GIS has typically been a difficult asset type to test for PD. This is because the gas filled chambers are hermitically sealed and this does not allow TEV signals to escape as is commonly used to detect PD on air insulated switchgear (AIS). At extra high voltage (EHV), GIS has insulating spacers or built in UHF sensors where PD can be detected. These are not accessible or available at the medium voltage level making sensor placement difficult. PD has been measured in MV GIS using TEV sensors located by the cable glands where some signal can escape the gassed chambers however the signal is often highly attenuated and can sometimes be undetectable within background noise due to the longer propagation paths from PD source to sensor. HFCT's coupled around the feeder cable earths have also sometimes been used for PD measurements on MV switchgear. These measurements have been proven to show reasonable results [5] however this method relies on the cable earths to be accessible and outside of the cable termination box to avoid shutting the asset down.

7.1 VDS Ports

VDS / VPIS ports are safety systems installed in switchgear to detect the presence of voltage before doing maintenance on the system. They consist of a capacitively coupled connection to the high voltage on each phase with plugs or push buttons to show the presence or absence of voltage on the switchgear. These capacitively coupled connections provide a path through which the high frequency transient signals induced by PD can propagate and be detected.
VDS / VPIS ports have previously been investigated as a method for detecting high frequency transients related to PD and have proved effective [6]. Use of these sensors to date is not widespread and almost exclusively used for spot testing. For comprehensive monitoring of MV GIS, a permanent monitoring solution is recommended.
The high frequency transients recorded via the VDS ports are in the frequency range 50 to 200MHz this is typically faster than commercial PD monitoring acquisition systems can effectively and reliably detect. It is therefore required to use an envelope detector to accurately capture the magnitude of the PD signals.
The VDS sensor first applies a high pass filter to the incoming signal, getting rid of lower frequency noise, and subsequently applies a bandstop filter to suppress external noise. An envelope detector is applied to the filtered signal which then gets digitally sampled by the PD monitor. The envelope amplifier rectifies the signal, so polarity of the events is lost.
These signals can then be processed by standard commercial PD monitoring systems.
As with all on-line PD applications, background noise is a significant issue when permanently monitoring using VDS sensors. Similar methods for removing background noise as applied on established sensors such as CC-TEV and HFCT have been used to process the VDS sensor data. Examples of results are shown below.

Typical signal acquired by the sensor:

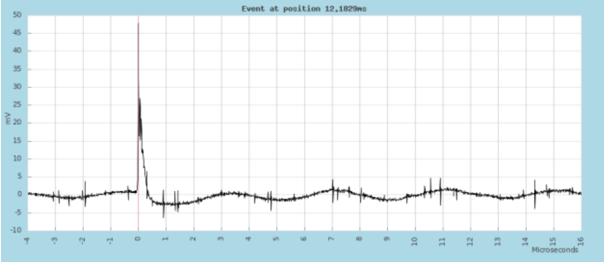


Figure 7 – PD waveform from VDS sensor after passing though filters and envelope detector

Monitoring over time allows PRPD patterns to be captured, similar to the ones obtained by CC_TEV and HFCT sensors:

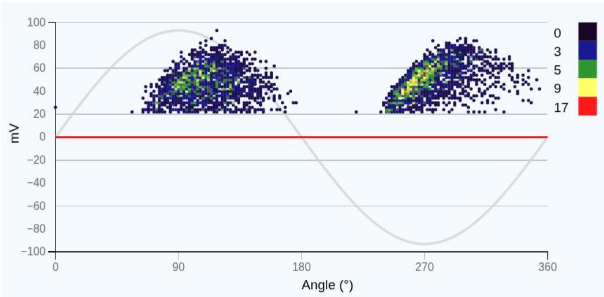


Figure 8 – PRPD from data collected using VDS sensor on permanent monitoring device following denoising post processing

Noise signals coming from these sensors are slightly different from other sensor types due to the high frequency components of the signal recorded by the signal and the use of the peak hold amplifier. This means denoising techniques commonly used on cables for example are harder to implement.
As the VDS sensor envelopes the high frequency signal, the original waveshape of the captured event is lost, however the amplitude and pulse width of the acquisition are a good indication of the magnitude and duration of the original event. These initial parameters allow for a simple level of denoising. Clustering and other PRPD analytical techniques are used for further levels of noise suppression.

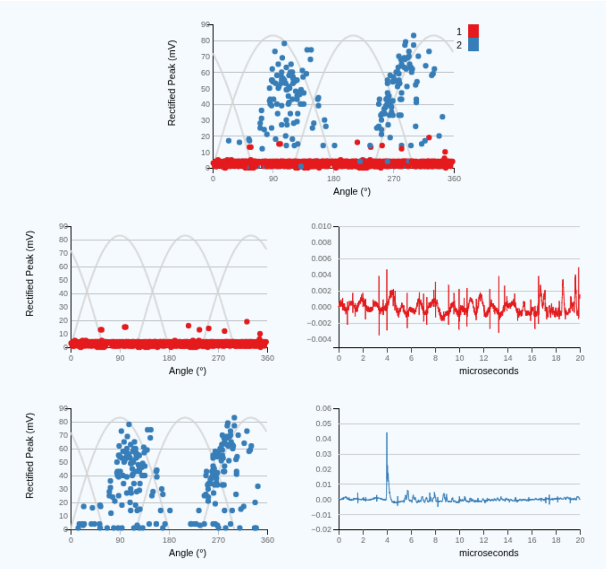


Figure 9 – Clustering of signals received from VDS sensor on PD monitoring system highlighinting the differences between noise and PD waveforms

Within the data shown there are clear waveform differences between the lower magnitude (red) signal and the higher magnitude (blue) signal. The lower magnitude signal in red displays a PRPD pattern consistent with noise and can therefore be rejected. The blue signal waveforms display a PRPD pattern consistent with PD and are therefore kept by the denoising algorithms. These algorithms can therefore be used to effectively denoise VDS signals resulting in a system that can automatically process data from this sensor type.

8 CONCLUSION

On-line partial discharge (PD) monitoring is becoming an increasingly important condition-based maintenance (CBM) tool for medium-voltage (MV) networks, but practical limitations still restrict widespread use—particularly on secondary assets where budgets and installation opportunities are constrained. This paper has presented measurement approaches intended to overcome these barriers by improving accessibility and reducing cost. For RMU cable terminations, an integrated PD and infrared (IR) sensor concept provides a single installation capable of monitoring two dominant degradation indicators: PD activity and thermal hot spots. Field demonstrations have shown the system to be stable and reliable as a data logger over extended periods, with sufficient resolution to identify phase locations and detect abnormal temperature rises. The data architecture also supports operational deployment by sending summary parameters to local RTUs while making richer datasets (e.g., PRPD and IR imagery) available to central systems for deeper analysis.

Further development is now required to convert these measurements into robust, automated decision support. Key priorities include stabilising IR imaging across a broader range of environmental conditions, automating hot-spot detection and trending, improving PD noise discrimination and feature extraction, and validating alarm thresholds to reduce false positives while maintaining sensitivity to early-stage defects.

The paper has also addressed the long-standing challenge of on-line PD measurement on MV GIS, where sealed chambers can significantly attenuate signals available to conventional external sensors. Using VDS/VPIS ports as an access path, combined with suitable filtering, envelope detection and post-processing, the approach has been shown to capture PD-related transients and produce usable phase-resolved patterns. Initial clustering and PRPD-based denoising indicate strong potential for separating noise from PD-like activity; however, additional datasets and continued refinement are required before the method can be considered fully mature for broad commercial deployment.

REFERENCES

1. *Nazarychev A, Iliev I, Manukian D, Beloev H, Suslov K, Beloev I, "Review of Operating Conditions, Diagnostic Methods, and Technical Condition Assessment to Improve Reliability and Develop a Maintenance Strategy for Electrical Equipment" Energies , 18(21):5832, 2025*

2. *C. M. Walton, "Detecting and locating MV failure before it occurs. Experience with live line partial discharge detection on underground paper insulated 11 kV cables in London," 16th International Conference and Exhibition on Electricity Distribution, Part 1: Contributions. CIRED. 482, Amsterdam, Netherlands, pp. 5 pp. vol.1, 2001*

3. *J. Morris, C Smith, K Tavernier, Improved Condition Monitoring Using Internally Mounted PD Sensors Within Network Components And Switchgear Enclosures, 27th International Conference on Electricity Distribution, Rome, paper no 11486, 2023*

4. *A.S. Nazmul Huda, Soib Taib, Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment, Applied Thermal Engineering, 61, Issue 2, Pages 220-227, 2013*

5. *K. X. Lai, C. S. Yiong, N. F. Affandi, C. X. Wong, K. K. Wong and T. Ranjan, "A Practical Approach to Benchmark the Relationships between On-Line Measurement Versus Off-Line IEC60270 Measurement for Singapore Distribution Network Switchgear," INSUCON - 14th International Electrical Insulation Conference (INSUCON), Birmingham, United Kingdom, pp. 157-162, 2023*

6. *Tao S, Zhang X, Cai H, Li P, Feng Y, Zhang T, Li J, Wang W, Zhang X, "On-line Monitoring Device for High-voltage Switch Cabinet Partial Discharge Based on Pulse Current Method", IOP Conference Series: Materials Science and Engineering, 281, 2017*