Practical Application of On-line Partial Discharge Monitoring for the Improvement of Long-Term Power Network Reliability

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SUMMARY

Online Partial Discharge (PD) testing of new and aging switchgear and cable assets is a well-established condition assessment tool used by asset operators around the world to predict which assets are likely to fail. The majority of high voltage failures occur as a result of PD activity.

This paper focuses on permanently installed on-line PD monitoring and the practical application case studies of the deployment of integrated PD monitoring solutions across thousands of assets in different networks around the world including Hong Kong, United Kingdom, South Korea, and Canada.

The various unique challenges of these cases enable us to demonstrate the requirements of an effective on-line PD monitoring system and form a framework through which to assess the benefits of an on-line PD monitoring implementation across large networks.

Though the application case studies focus on PD as the main measurement tool, the infrastructure deployed and processes for analysis and interpretation can add insight to different applications for asset management, and we will explore these also.

1. Introduction

On-line PD testing is becoming a common tool for asset operators to detect and address network defects with minimal disruption of service. In order to implement a network of permanently installed, or 'fixed', installations there are many challenges to consider which must be overcome. In this paper we discuss the application of permanently installed on-line PD Monitoring technology on different network layouts on MV, HV and EHV cable and switchgear assets, learning what is needed for an effective implementation of such a scheme.

2. What is PD and PD Monitoring

Partial discharge is widely regarded as a predominant cause of long-term degradation and failure of high voltage (MV, HV and EHV) equipment. Partial discharge is a small discharge occurring between electrodes, specifically local to a defect in the insulation, Figure 1. Over time these small discharges, caused by disproportionate electrical stress across the defect site, will continually damage the insulation until it leads to a catastrophic failure. It is reported that 85% of disrupted failures are PD related.

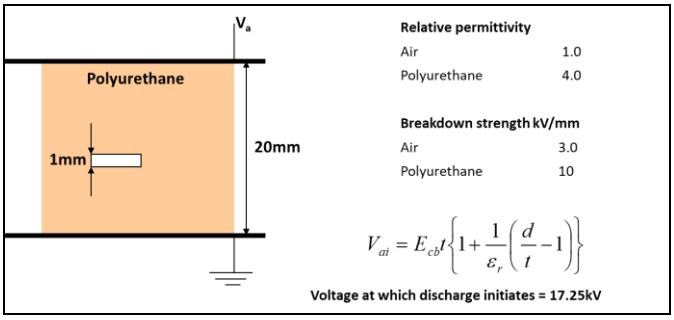

Figure 1: PD calculation example on simplified defect in polyurethane

Partial Discharge (PD) is a familiar phenomenon to many electrical engineers and asset operators worldwide. On-line PD testing is performed while the equipment is energised at normal operating voltages. The testing is conducted during normal operating conditions; thus, under typical temperature, voltage stresses, and vibration levels. It is a non-destructive test and does not use over voltages that could adversely affect the equipment. On-line Partial Discharge Testing is relatively inexpensive compared to off-line testing that requires interruption of service and production. For critical facilities that operate 24/7, this is an ideal solution for identifying insulation condition [1]

PD testing is conducted using a variety of equipment including handheld instruments, portable spot testing systems, and permanently installed monitoring systems. This assessment and analysis focus on the latter, deployed across many assets in a given network, bring data back to a central server which can then be analysed and assessed by network operators. PD On-Line Monitoring solutions help to address compliancy, regulatory, and health a safety initiative for our clients, reducing the need for resources to be sent to collect manual PD data within the sub-stations.

KEYWORDS

ASM (Advanced Substation Monitor) – The ASM is a Data Acquisition unit that collects up to 128 sensor channels from sub-station assets.

ISM (Intelligent Substation Monitor) – Data Analysis™ site is hosted by the server and accessed via the internet, or locally if installed on the customer’s private network or inside the substation. The iSM provides the analytic engine for the PD Monitoring system.

CC-TEV Sensors – Measurement of electrical transients generated by internal PD. Used to detect Trans Earth Voltages in Switch Gear.

AA-Ultrasound Sensors– The AA Ultrasonic acoustic probe is designed for use on air insulated terminations where a clear sound path between the electrically stressed insulation and the probe is present.

HFCT Sensors– High Frequency Current Transformers user to detect PD in cabling.

UHF Sensors– Used to monitor PD in GIS switch gear.

T&H Sensors – Used to provide environmental monitoring of Temperature and Humidity and references for the ASM system in substations.

3. PD Monitoring Projects

PD Monitoring on smaller scales, say for one or two critical sites in a network, or temporary testing following high PD detection, is common amongst many networks around the world. Some network operators, however, take permanent online PD monitoring a level further, by deploying systems on a larger scale, across significant portions of their networks in order to implement overall improved network management. IPEC's PD monitoring process is shown in Figure 2 below.

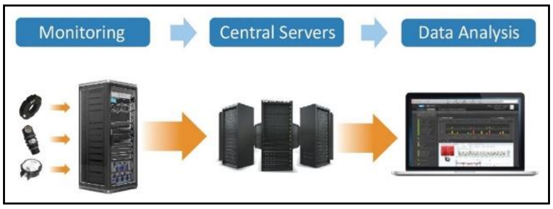

Figure 2: IPEC PD Monitoring Process – The ASM Monitoring System

IPEC have assisted companies around the world to deploy such large condition monitoring implementations, in this paper we will take some varied case applications which to analyse, a brief overview is given below for each;

London: Starting in 2001, but with major roll-out from 2007, the project in London involved significant PD monitoring installation on MV Air Insulated Switchgear and underground cables, or both PILC and XLPE type. The system covers over 90 substations in the inner city (over 2,500 assets), outer city and associated private networks such as key airports. Data is communicated from the systems back to a central cloud server, hosted by IPEC, where it can be accessed via a secure web front end for data interpretation across the network.

Hong Kong: From 2014 the client implemented a large deployment of monitoring systems to cover every feeder and switchgear at the major primary substations on Hong Kong Island. Involving over 50 systems looking at 11kV assets (over 3,000). The systems communicate data on the private customer operated operational network to the central server, thus the system operates completely autonomously with no access from the outside world. Operational Engineers in Hong Kong manage the system.

Republic of Korea (South Korea): Beginning in 2009, IPEC's partner in Korea has worked with multiple private chemical processing and high technology manufacturing plants to implement a country wide solution of On-line PD Monitoring, both standalone and remotely monitored, in order to provide best in class fault prevention on these critical MV and EHV assets. Standalone installations show data on site/substation only whereas remote sites bring data back to IPEC's cloud server in the UK and access is available via a secure web front end.

Canadian Oil Sands / Northern Alberta Canada: From 2021 a Canadian Energy company has deployed On-Line PD Monitoring for managing their Electrical Generation requirements, in a standalone deployment with Remote Access for PD analytics. This solution monitors MV switch gear and cable assets with customized Integration to SCADA monitoring solutions. This includes 5-minute sample rates, PD Magnitude, Phase Angle, and others that allows for establishing their own PRPD analysis. Operational engineers locally review and analyse the raw data within their SCADA system, with access to the main PD server remotely for Client and IPEC remote analytic services. This system is expanding to include additional sub-stations for their main plant and they are also expanding their PD On-Line monitoring into multiple refinery locations.

4. Challenges and Requirements for an Effective Large-Scale Deployment

Deploying systems on a large scale is not easy, it poses particular challenges to both the manufacturer (in this case IPEC Ltd) and the client, as well as the local territory partners and 3rd party contractors. No power network or application of technology is the same, and so with each different type of project, we come across unique challenges to overcome. That said, some key common challenges and accomplishments exist, and we will consider these.

4.1 . Autonomous and Accurate Analysis

PD in on-line applications, particularly those of underground cables is often much smaller than surrounding background noise, the differentiation of PD and noise is a complex task [2]. Therefore, On-line PD monitoring and testing is often conducted as two distinct phases; acquisition of data and analysis of data. Often different acquisition tools are used, as different engineers or experts to assist with interpretation of data and noise rejection. This application is suitable for small scale deployment of PD monitoring, but if thousands of cables and thousands of Switchgears are monitoring 24/7, as in our cases, then this method is not cost effective nor practical.

In order to effectively deploy networks of such scale, the systems need to be completely autonomous, in order to not require external data analysis, and extremely accurate, in order to reduce false positives to a miniscule level.

In the case of the London network, where data is centralised at IPEC's head office in Manchester, UK, the ability to post analyse data exists, if it were needed. However, with the Hong Kong network, as mentioned, the system is isolated from the outside world. In order to effectively operate for such a large network with no external 'PD expert' analysis possible, the system needs to be extremely effective at automatically differentiating PD from noise, and, incorrect system conclusions need to be rare.

For our Canadian deployment, standalone LTE connectivity is utilized for accessing the local servers with future database mirroring to enable safe and secure remote access to PD data for Client and IPEC remote analytics.

The ASM PD Monitoring system, deployed in our case studies, acquires data at an extremely high resolution (100Mega-samples/second, 14-bit resolution). High resolution digital data enables advanced software algorithms, in our case the wavelet based DeCIFer™ algorithm, to detect small PD pulses in often large background electrical noise – which is detected by any PD sensor.

4.2 Infrastructure and Resilience

The data acquisition, processing and identification of PD happens within the substation, close to the assets. It is relatively straight forward to display data locally and connect the systems to local SCADA and substation alarm infrastructure (for basic alarm communication). In larger network/city/country-wide roll-out of technology it is often critical that condition monitoring engineers and operators can remotely assess system results and make decisions without having to visit site.

Further, one of the key benefits of continuous PD monitoring over spot testing is the ability of the operator to see PD activity trends over time, noting if PD level is constant/increasing/decreasing or maybe has a relationship with load or environmental conditions. Being able to remotely view data from across the many thousands of assets allows the operators to more effectively deploy resource to sites with concerning data trends.

Central Servers are key to the ability to collate data from substations, but network operators have different requirements for such centralised data collection.

In South Korea, many PD monitoring systems operate completely standalone with local-only data assessment (in site/substation), this is generally most required in secure sites with 24-hour engineer presence in order to manage the site, along with the PD system.

In the case of Hong Kong, the substations are linked on a private and secure operational fibre network with no access to the outside world. Although this offer high speed communication from substations to the central server, it means the system needs to operate without external access for data management and maintenance, a high level of resilience and auto-recovery is required.

London PD monitoring systems send data back to IPEC in Manchester, so data communications and systems can be remotely managed and diagnosed. The challenge of this type of set-up is the communication method itself. Many sites are underground, have no phonelines, and few fibre connections. In this scenario a variety of communication methods need to be deployed, whilst all working together to bring data back to a common interface for analysis.

Similarly, to the Hong Kong example, the Canadian deployment has all substation connected to the customers OT network with the PD server in isolation from the outside world (NIRC-CIP compliance). Future efforts will enable access to databases remotely, however system management and maintenance will still be isolated and manageable with LTE connectivity.

The ASM's deployed in our case examples are designed to operate three ways; locally only, connected to a central server on the customer network, or via a VPN and the internet to a central server at an IPEC base. Additionally, the communication methods are any TCP/IP link, 3G/4G, ADSL, Fibre optic (in the past even GSM and dial-up) – allowing for flexibility depending on the network requirements and site limitations.

4.3 . 3 Phase Implementation – The PWR Cycle™

Collection of data, analysis and centralisation onto a data analysis interface must be complete autonomous and resilient, as discussed. And though this is the largest part of any deployment of continuous condition monitoring network, it is only part of the story.

It is critical with any technology deployment like this, to ensure that there is a clear asset management and diagnosis program in place with which to effectively and correctly deal with potential network failures before they occur, and as highlighted by the system.

The process can vary depending on network procedures, but generally once a PD is highlighted by the system the next stage would be to view the data and verify a correct conclusion by the system, produce a recommendation, conduct on-site verification and on-line PD location, post-site visit reporting and recommendations, on-site switching and intrusive investigation to pin-pint/repair defective component, post-process results analysis and case study generation.

Ownership of the process is the first thing to consider, and each network is different depending on their resources, business model and security considerations. And so, the management of a system and process like this must be flexible.

For example, with the London case, IPEC manage the full process up to the point of intrusive repair and defect rectification. This helps the client maximise their resource on their areas of expertise – fixing problems – whilst IPEC takes care in our area of expertise – PD analysis and on-site on-line PD location.

On the contrary to this in Hong Kong, the customer owns the full process. Meaning planning had to be considered at an early phase in order to effectively schedule training and knowledge transfer, to allow the client to affect the fault prevention without external 3rd party assistance.

In Korea, we take a varied approach to process management. A challenge, however, is language barrier. Though IPEC produce reports and recommendations for many clients in Korea the end users often require the report to be written in Korean. To solve this challenge IPEC conducted detailed training with our local partners, in order for them to be able to pass on IPEC's message and accurately communicate our recommendations during translation of reports issued to end users.

In Canada, a blended approach has been established providing local resources with theoretical training and on-site system management training with remote analytic services being delivered by IPEC.

With the IPEC ASM Monitoring system, IPEC works with clients to implement The PWR Cycle™. A framework designed to help organise, manage and implement CBM technologies.

Plan
The first step is the Planning phase, carrying out an assessment of all assets.

It is important to consider multiple angles, such as:

- Existing condition assessment information
- Assets at the end of design life
- Company priorities and Critical infrastructure

Using the available data, to then decide on which solutions to implement on which parts of the network.

Watch
With testing and monitoring solutions implemented, Watching and monitoring the results is key. Incoming test results and data is used to inform asset managers on network condition, critical levels and where action needs to be taken.

Repair
Locating problems, repairing assets and maintaining your network is efficient and optimised, removing defects before they lead to bigger problems for you or your customers. The PWR Cycle™ is designed to combine a variety of solutions that complement each other. Form a complete framework to maximise the performance of your network, for now and for the future.

5. Technology Applications

Once overcome, and with a reliable and accurate on-line PD monitoring solution, and management process, in place, operators can then begin to realise the benefits.

The most obvious benefit of on-line PD monitoring is defect detection, and the ability to detect problems with network assets before it leads to a catastrophic failure. There are many case studies and statistics for different networks, where defects are successfully removed, and with continuous monitoring we can expect more defects to be addressed.

Additional benefits are often over-looked, such as the ability to extend the life of ‘good’ assets through installation of a monitoring system to track asset condition beyond its normal life, freeing up asset replacement funds for more critical infrastructure. Another ‘over-looked’ benefit is the ability to help with network operational management, optimising loading and switching operations to components of known ‘good’ condition through PD monitoring, and avoiding overloading known assets with PD present.

With a variety of drivers and network operator concerns, it’s clear that the applications need to be flexible, and highlighted how this can be achieved and what is needed to allow this. IPEC have deployed technology globally for both large and small, private and public network operators, and solutions can be customised to overcome particular network conditions.

6. Canadian Oil and Gas Sector PD Monitoring Solution

In 2020 a Canadian Energy Company operating in Northern Alberta’s Oil Sands requested IPEC provide a response to an RFP for Partial Discharge Monitoring to monitor their plants Electrical Generation environment. The client operates an electrical generation environment supporting their internal operations and providing surplus electricity to the local electrical grid. IPEC with their local distributor Phoenix Monitoring Technologies Inc. (Phoenix Monitoring) responded to the RFP securing it in the fall of 2020 with the first Proof of Concept (POC) being delivered in August 2021.

Details

The POC was to be delivered into their Oil Sands plant in Northern Alberta into 2 – Substations. The key elements that were specified in the RFP include the following:

The solution included the following key elements:

- 1 – IPEC ASM-C solution with 16 – Channels to Monitor Switch Gear and Cables.
- Proof of Concept request for 2 substations with further plant wide expansions planned.
- PD Monitoring Switchgear and Cables / 15kV to 25kV.
- TEV Monitoring / PD Magnitude to Convert dBmV to apparent charge pC.
- Capable of storing PD data locally and integrating to their SCADA solution.
- 5-minute data sample of PD magnitude and phase angle.
- Ability for client models to run their own PRPD analysis.
- Customize SCADA integration format for in-house Asset Management system.
- Due to Covid remote delivery was required including system commissioning.
- Established a standalone solution for OT network with a capability to utilize LTE connectivity for testing. Commissioning, and day 2 operations including remote analytics.

With a successful POC, the system has been expanded since August 2021 to include:

- 4 – Additional ASM-C systems all supporting 64 sensor monitoring channels per ASM.
- Integration with 3rd party Cable sensors was established to enable the system to re-use client previous purchases.
- 21 – Switch Gear sensors and 48 – Cable sensors currently and to expend to 108 / 37.
- 2 – New refinery locations with full standalone systems.

Canadian Oil and Gas Sector PD Monitoring Solution Conclusion

The true value of PD Monitoring can only be realized if you can get the systems in and operational in what tends to be a very complex environment. Being fully capable of managing the challenges that are faced in establishing PD monitoring in any environment ensures a successful delivery of product and is 50% of the equation for any IIoT product deployment. Once these systems are in place clients can rest assure that PD On-Line monitoring will protect their critical assets health for many years to come.

Other key points include:

- Canadian standards are very stringent.
    - Flexibility to manage these standards delivers huge value to the customer.
- Strong data security requirements
    - Being flexible and finding creative ways to address these restrictions is key benefit that is required in and PD Monitoring solution.
    - Strong security practises and services are needed today more than ever as we look to bring the value of the Cloud to our customers.
    - Alternative Cloud / LTE-5G solution need to be obtainable in any solution.
- Adapting to the changing circumstances and finding innovative ways to address them.
    - With COVID and customers on-site requirements, managing remote commissioning was key.
    - Remote solutions for system installation and commissioning are table stakes in today's IIoT environment.
    - Planning for custom SCADA or other interfaces is a requirement.
    - *Integration with Third*-Party Sensors being open to managing 3rd party sensors brings customer value that extends past the sale of sensors and differentiates your business from others that are not as flexible.

7. Other Cases

IPEC have deployed PD monitoring across the globe. Whilst the Canadian Oil and Gas Sector PD monitoring solution is in early stages to show significant results, other cases can be discussed. Figure 3 shows Partial Discharge activity detected over a period of 4 weeks by a PDM system, and the associated discovered defect on the insulator. This defect is the presence of Nitric Acid, by product of partial discharge, which forms in high humid environments. In this case the system is installed in Saudi Arabia and this type of defect is commonly detected by PD monitoring systems.

Figure 3: PD Trend over time and discovered PD activity. Nitric acid will damage the insulator.

8. Future

Further advancement of the solutions and systems used in the market will likely take advantage of the advancements in processing power and the physically smaller and more cost-effective monitoring that can take advantage of this. Resulting in PD monitoring technology that is more applicable for smaller and more cost sensitive sights, whilst maintaining the accuracy and effectiveness described in the paper.

9. Conclusions

The application of permanently installed on-line PD Monitoring on a large scale allows network operators to realise increased performance and operation of their networks. To implement such a system, there are many challenges and requirements which must be overcome and achieved in order to smoothly integrate with the networks and end user requirements. On-line PD monitoring demand and requirements is increasing with the increased capability of systems on the market. Recent market research shows the market growth between 2019 and 2023 from 235million USD to 465million USD [3]. Adoption of this type of technology will increase, and new challenges likely lie ahead.

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