DEPLOYMENT OF AN ONLINE PARTIAL DISCHARGE MONITORING SYSTEM FOR POWER STATION WITH FOCUS ON GAS TURBINE GENERATORS.

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INTRODUCTION

Power station

This paper reports on the deployment of a continuous online partial discharge (OLPD) system to monitor a gas turbine generator at a combined cycle gas turbine (CCGT) power station. The site consists of two gas turbines rated at 250 MW and one steam turbine rated at 260 MW.
The station, initially commissioned in 1996 is located in North Lincolnshire (UK) and was mothballed for approximately 3 years. It was returned to service in the latter half of 2015.

Figure 1 Overview of the CCGT power station.

High Voltage Assets within the Power Station

Similar to any traditional CCGT site, the primary power train at the site includes generators, isolated phase busbars, generator circuit breakers, step up transformers, station supply transformers and outdoor HV switchyard equipment.
The generators at this site generate at 15 kV, whilst the transmission voltage is 400 kV. The generators have an indirect hydrogen cooling system and operate at a 3 bar gas pressure.

Power station condition monitoring strategies

Numerous condition monitoring (CM) techniques utilising both online and offline testing are deployed at the power station to guarantee a reliable running of the plant and help to implement condition based maintenance of the assets. All the generators are installed with several sensors to perform CM of relevant parameters such as rotor flux monitoring (for shorted turns detection within the rotors), generator stator core temperature, generator end winding vibration, partial discharge, etc..
To perform partial discharge (PD) testing a few systems are deployed. Each generator was installed with 80 pF high voltage coupling capacitors (HVCC). In the past these HVCC sensors have only been used to carry out online spot PD measurements. Recently, to show the advantage of performing online continuous monitoring over periodic spot tests, a continuous OLPD monitor has been deployed and connected to the HVCCs of one of the generators. The advantage of using continuous online monitoring is due to the fact that PD activity, especially in HV rotating machines, is influenced by several other stresses such as the well-known TEAM stresses [1]–[3], Figure 2 reports an example of how PD activity can be influenced by temperature. Consequently the ability to acquire and track PD data over prolonged periods can give a more accurate picture of the condition of the insulation of the asset under test compared to the picture that can be drawn from spot tests. In addition to the online monitoring equipment, offline maintenance testing and activities are carried out including insulation testing on the rotor and stators, static and dynamic recurrent surge oscillograph testing for rotor shorted turns, testing for stator core condition and visual inspections are carried out regularly.

ONLINE PARTIAL DISCHARGE SENSORS

There are several sensors that can be used to perform OLPD measurements. The selection of the sensors is based on the type of asset under test e.g. cable, transformer, generator, etc. and the restriction that may apply to the sensors installation (this is particularly true for retrofitting to existing HV assets). Sensor selection and placement choice can also be utilised to aid with analysis. This paper focuses on the OLPD sensors solution for direct on line rotating machines. Information on PD sensors for all HV assets can be found in [4].
The main sensor options currently used in the industry for OLPD measurements on rotating machines are HVCC and high frequency current transformer (HFCT) sensors.
HVCC sensors are best suited for at-asset detection where the frequency content of PD signals has not been attenuated and likely to be higher than any local source of noise. The HVCC sensors usually detect frequencies greater than ~10 MHz.
HFCTs are inductive wideband sensors [5] – typically 100 kHz – 30 MHz – and they can be installed at machine or at the switchgear end. If the sensors are installed at the switchgear end the measurements are performed using the remote OLPD monitoring technique [3], [6].

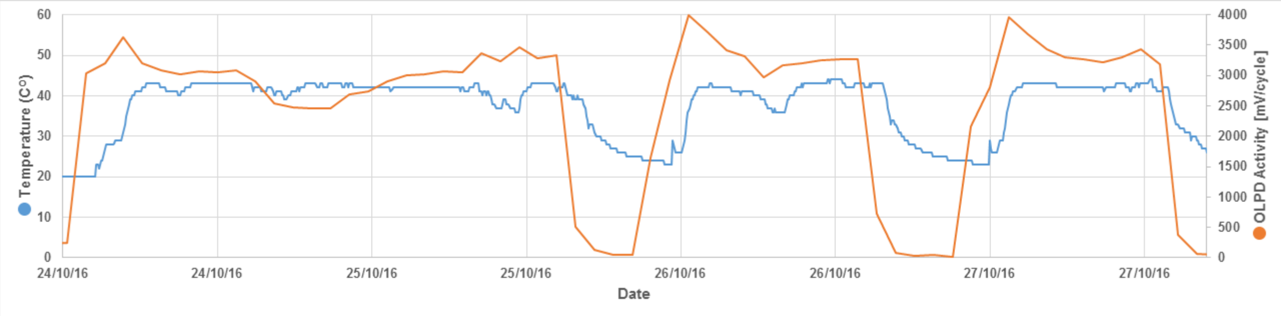

Figure 2 Correlation between temperature and OLPD Activity on a 15 kV generator over a 4-day period .

High Voltage Coupling Capacitor
HVCC are generally supplied in 80 pF, 500 pF and 1 nF ratings, the sensors are the only type of OLPD sensor to be galvanically connected to the HV asset under test. This gives them the highest sensitivity (above 10 MHz) of all the OLPD sensor options available [5]. Higher capacitance HVCCs are capable of the detection of PD pulses deeper into the HV windings, due to their wider bandwidth on the low frequency end of the band.

HVCC sensors are typically installed as close as possible to the asset under test, one sensor on each phase. Figure 3 shows an example of HVCCs installation within the termination box of a 15 kV, 45 MW generator.

In case of assets with high level of electromagnetic noise from the network, two HVCCs may be installed per phase to improve the signal to noise ratio of the measurements.

Figure 3 Example of 15 kV, 500 pF HVCCs installation on a 15 kV, 45 MW generator.

OLPD DATA ANALYSIS

Whichever sensor is used, it is crucial that any OLPD monitoring system employed is capable of effective de-noising of the data recorded as well as able to identify multiple PD sources in order that OLPD measurement results are reliable.

All recorded OLPD data must undergo some form of analysis to obtain any meaningful results. This analysis can either be done by specifically programmed intelligent software or an experienced operator. The largest obstacle to overcome during analysis is to reduce or eliminate any electromagnetic noise which is also captured during data acquisition therefore isolating the PD signals.

To achieve this a number of methods can be implemented. Both hardware and software filters can be applied however this can have also undesired effects. Depending on the point of test and PD source type/s, both the desired signals and noise can be found in overlapping frequency ranges so an alternative solution may be required. Each asset on a site may also be affected by different noise sources requiring multiple hardware filters to be carried and noise frequency content analysed by the operator to decide which filter(s) will be most suitable.

Where more than one source of noise exists, using hardware filters can become difficult to implement so software filters are used where more than one band of frequencies need to be removed from the recorded acquisitions. Software filtering enables the user to acquire raw data so no filtering is applied in the field. The raw data can be processed and reprocessed many times to achieve better noise reduction. Figure 4 (A) shows an unfiltered waveform captured over one 50 Hz power cycle. While high peak PD signals are easily detectable over the background noise, it does not allow for the easy identification and detection of smaller pulses and accurate calculation of OLPD cumulative activity.

The same 20 ms acquisition shown in Figure 4 (A) is reproduced in Figure 4 (B) after processing through a high pass software filter. The background noise has been significantly reduced from around 6 mV-pk to 2 mV-pk revealing a greater numbers of PD pulses for accurate calculation of OLPD activity. A PD phase resolved (PRPD) pattern also becomes more obvious after noise reduction.

An alternative to filtering frequencies from data is to look at individual event pulse properties within the waveforms. This must be done using intelligent software as PD data is usually derived from many power cycles each containing many pulses. This smart software utilises algorithms able to identify pulse parameters such as the rise time, fall time, pulse width, charge content, amplitude, pulse frequency, etc.. These parameters can be selected by the user to form customised rules for assets by plotting any pairs to form heat maps.

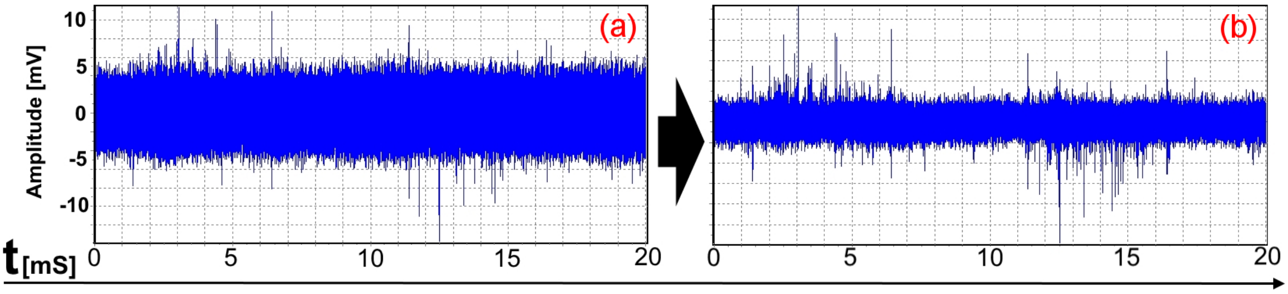

Figure 4 (a): Unfiltered 20 mS OLPD acquisition (b): Filtered 20 ms OLPD acquisition that shows PD peaks.

An example that utilises these rules to separate all noise sources from the PD signals in a rotating machine is reported later on in the case study. The production of a heat map using a pair of variables can assist in isolating noise from PD by making selections of regions of intensity (see Figure 6). This method can be used to not only isolate noise from a PD pulses but can be used to isolate multiple PD PRPD patterns from one another. This is particularly useful for rotating machines where it is common to have multiple sources of PD (i.e. in slot section or end winding) or when different assets within the same network are affected by PD. If the OLPD monitor deployed allows for implementation of custom rules for each asset, trending OLPD activity and PD peak can be undertaken for each asset and for each source of PD. This will allow less experienced operators to identify when action may need to be taken on an asset due to an increase in OLPD activity.

Once rules have been set the OLPD system will produce reliable results until there is a change in the network (i.e. network expansion, this may affects the network noise). At this point the rules have to be reviewed.

CASE STUDY: OLPD MONITORING ON A GAS TURBINE GENERATOR

This case study describes the temporary deployment of a continuous OLPD monitoring system on a gas turbine generator in an UK power station. The aim of the test campaign was to evaluate the generator insulation condition to perform informed condition based maintenance decisions.

OLPD Monitoring System

The OLPD monitor used at the power station was installed for a one month period. This was sufficient to capture variations in OLPD levels due to fluctuating load, winding temperatures and other stresses that affect the generator. Sensor installation was not necessary before the trial period as the monitor was connected to existing 80 pF twin-HVCC sensors. This formation uses six sensors in total. Two sensors are galvanically connected to each phase, one at the machine side and the other at the network side. The twin couplers allow for time of flight measurements to deduce the direction of propagation of any PD-like pulses and also help to reduce the electromagnetic noise transmitted by the network to the OLPD acquisition system.

Data Analysis

In this section the OLPD data for the U-Phase is presented an its analysis explained. The overall data results from all the phases and the machine insulation condition are reported later in the paper.

The phase pattern produced from the raw data containing all noise and PD pulses can be seen in Figure 5 (U-Phase). Six areas of very high intensity can be seen which are caused by the generator exciter pulses, these are considered to be noise and will be removed using custom made rules.

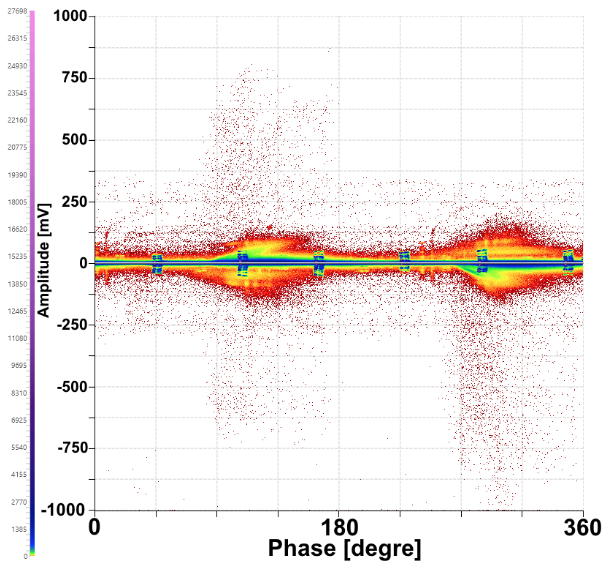

Figure 5 PRPD pattern produced from raw data before the de-noising process for U-Phase.

Exciter pulses: Noise. The exciter waveforms are sinusoidal and have a very narrow band of frequency content which is much lower than that any of the PD pulses (as measured using the HVCC sensors) and hence are easily removed.

Referring to the heat map in Figure 6 (Peak PD vs PD-frequency) the exciter pulses are highlighted by the green box. PRPD of this pulses is reported alongside an example of exciter pulse waveform. It is interesting to notice how wide is the waveform of an exciter pulse if compared with any of the PD waveforms (see right hand side of Figure 6). Once the exciter pulses and noise has been removed the partial discharge sources can be resolved. This requires knowledge of the PRPD patterns caused by damage in rotating machines [7].

Gap Discharge PD. The PRPD pattern generated by gap type discharges (high frequency pulses) is reported at the bottom of Figure 6. It is suspected these pulses do not originate from deep within the windings but somewhere near the point of test.

Delamination Discharges. The PRPD pattern shown in the middle of Figure 6 was resolved by setting rules based upon the frequency and peak width of the pulses acquired. The resolved PRPD pattern shows discharges caused by delamination in the insulation on U-Phase. The pulses caused by this defect contain a lower frequency content with a wider pulse than the gap discharge as shown in Figure 6 (middle right).

Overall machine insulation condition. The analysis was performed for all three phases on the generator.

It was found that V and W phases displayed only small values of Peak PD discharge and are categorised in the "Good" and "Excellent" condition categories according to the OLPD guideline for HV rotating machines [8]. These phases also had a low repetition rate so the overall OLPD activity is considered very low.

U phase displayed higher Peak PD and higher OLPD activity, although the values are in the "Still Acceptable" category accordingly to the OLPD guidelines [8]. Results are summarised in TABLE 1.

TABLE 1 Machine insulation conditions based on OLPD data and OLPD guideline [8].

Generator Phase	PeakPD [mV]	OLPD Activity [mV/Cycle]	Machine Insulation Condition Category
U	142	655	Still Acceptable
V	25	402	Good
W	14	224	Excellent

These OLPD measurements can now be used as baseline PD trend for this generator and all future testing and monitoring should refer back to them.

Any deviations from these OLPD measurement trends may indicate a worsening condition where intervention is required.

Testing Outcomes

The monitoring of the generator using existing HVCCs was successful and provided useful baseline measurements for site engineers and asset managers:

- It was shown that the OLPD continuous monitoring system is able to identify PD from different sources and remove the noise signals to provide reliable OLPD measurements for this generator.
- Low levels of OLPD Activity was detected on phases V and W – No action required.

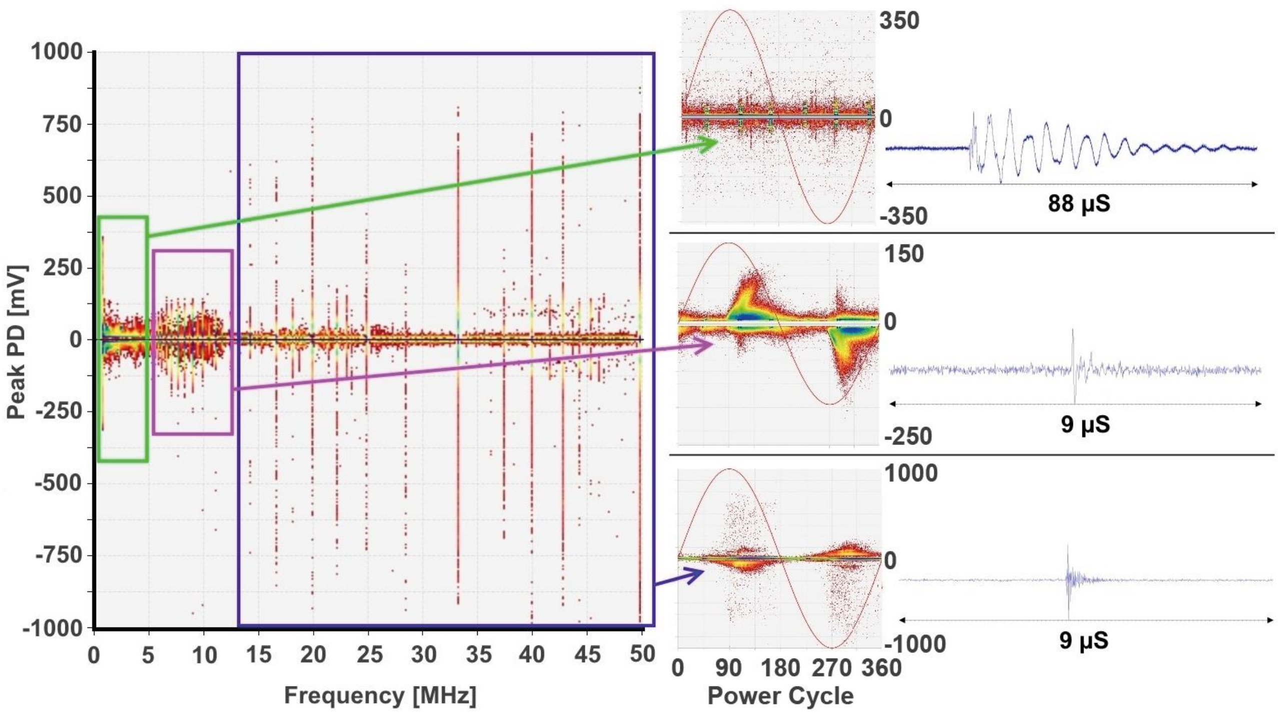

Figure 6 OLPD data de-noising process. On the left the heat map of the raw data from the monitoring on the generator (plotted according to Peak PD vs PD-Frequency) is reported. The different types of PD and the noise pulses are then separated on the bases of their frequency contents. In the middle of the picture the PRPD data of the removed noise pulses, the gap discharge pulses and the delamination discharges are respectively reported. On the right examples of each pulse type waveform are presented next to each respective PRPDs.

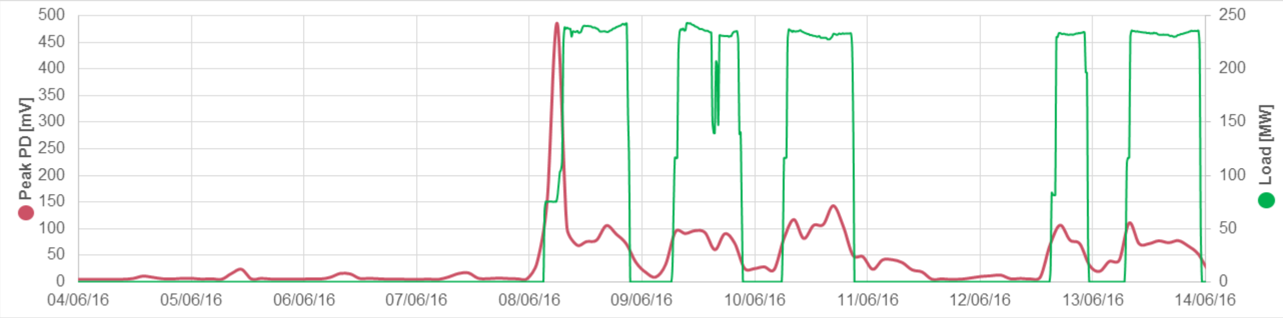

Figure 7 Peaks PD vs Load trends over a 10-day period.

- Higher levels of OLPD Activity was detected on U phase however, according to guidelines, the machine is placed in the "Still Acceptable" category – It is recommended to repeat the measurements again within 12 months.
- Continuous monitoring with portable or permanent system should be considered for continued assessment of the generator condition.

Lesson learnt

Continuous OLPD monitoring was proven to be useful for producing baseline PD measurements that can be used to asses future PD measurements and OLPD trends of the asset.

The monitoring outlined in the case study has also shown how the PD peaks and other PD parameters vary considerably during the 1-month monitoring period due to multiple factors (temperature, start-up cycles, etc.). For example PD peaks can be as ~10 times larger at the machine start-up (especially when the start-up occurs after several days of downtime) as reported in Figure 7 over a 10-day period. This shows that, in the case of this generator that operates only to support the network on period of peak demand OLPD measurement campaigns should be performed with continuous monitoring over prolonged times (i.e. 1-month) rather than with short duration periodic spot tests.

CONCLUSION

This paper has shown how OLPD measurements can be effectively de-noised to produce reliable condition data of rotating machines. This data can then be used to implement an informed condition based maintenance campaign to increase asset reliability.

The case study presented has also highlighted how, in the case of rotating machines that are typically affected by varying operating stresses (load cycles and so on), continuous monitoring is preferred.

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