

PARTIAL DISCHARGE EVALUATION OF 800KV HVDC THYRISTOR VALVE STRESS SHIELDS

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Abstract: The paper presents the investigation of partial discharge (PD) & corona behaviour of a typical stress/corona shields for $\pm 800\text{kV}$ thyristor valve arranged in a representative dummy stack with large air distances from grounded floor and side walls. As the only accessible grounded point was located on the suspension of the test object from the crane, a specially designed fibre optic analogue PD measuring system was deployed in the tests for the safety of both personnel and testing equipment. A high frequency current transformer (HFCT) and a transient earth voltage (TEV) sensor were placed on the ground return of the test object and a UHF antenna was positioned some safe distance away from the HV end of the test object. The paper describes the design of the instrumentation, the measurement methods, calibration set-up and some typical PD measurements results obtained under HVDC conditions for voltages in excess of 1MVdc . Some correlations were also made with corona observation carried out with a UV camera.

1 INTRODUCTIONS

Economic transmission of large quantities of power in the region of 6000MW , over long distances, is driving the need to develop HVDC technology up to 800kV and beyond, from the current levels of 500kV and 600kV . This significant increase in operating voltage presents some challenges in terms of converter and insulation design. Particular attention must be given to air clearance and to both optimisation and qualification test requirement to ensure that the valve structure is corona/partial discharge free in normal operation and to eliminate the risks of internal breakdown and external flashover under system and transient overvoltages.

To satisfy insulation coordination and determine the minimum acceptable and optimised air clearances, a comprehensive switching impulse (SI) and DC breakdown were conducted on representative shielded thyristor valve structures with air clearances from ground plane and side walls up to 9m . For an effective evaluation of stress/corona shield design under DC voltage, the partial discharge and corona behaviour were investigated on a typical structure at a given air clearance. In addition, the tests were also designed for the purpose of demonstrating the possibility of making PD measurements at high voltage DC, as a proving ground for tests in practical operation condition.

The test module was suspended from a crane, so that the air clearance from the grounded side walls and the floor could be varied. The high voltage was applied to lower module (stress shield), whilst upper stress shield was clamped to the lower potential by a resistive grading circuit, as discussed in another publication [1, 2]. Figure 1 shows the test module and arrangement in PD test under DC voltage.

HVPD Ltd had designed and built a special fibre optic analogue system for this test in which PD sensors would fix near to the high field area of the valve module, and allowing analogue signals to be measured remotely in a safe environment via the optical fibre link for the safety of personnel and testing instrument.

This paper presents the instrumentation, the test methods and PD results.

2 ANALOGUE FIBRE OPTIC PD DETECTION SYSTEM

The transmission of analogue signals from a high voltage area via fibre optics to a remote safe area is not new. However, it has not been widely used, largely due to the unavailability of commercially available equipment suitable for the task. As part of this project, HVPD Ltd developed a special, optic-isolation measurement system. Figure 2 shows the HVPD equipment which would be located at the high voltage (or remote) area.

A similar set of controllers and a two channel receiver is placed at the earth (or safe) end of the system. This end is mains powered, whereas the high field end is battery operated. The 12 Volt battery is designed to give a full working day (8 hours) between re-charges. The earth end and the high field end are connected with two pairs of fibre optic cables for controlling and analogue signal transmission respectively. The analogue bandwidth of the system is around 80MHz which is suitable of PD testing.



Figure 1, Valve Module attached to the DC test supply

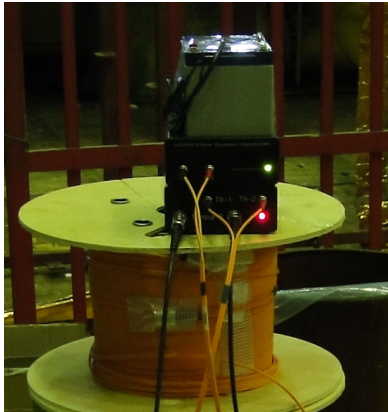


Figure 2, HVPD High Field Fibre Optic Analogue equipment (with battery)

The all working condition of the system at high field end, such as battery level, gain setting of the pre-amplifier and PD calibration could be monitored and controlled by the earth end system from safe area. The whole system has four gain settings, which cover a dynamic range of X40, i.e. around 30dB gain. The sensitivity of the system at the high field end, is around 1mV, and at the maximum gain, the noise floor is less than 2mV at the receiver. Figure 3 shows the schematic of the fibre system.

In the measurements, a transient earth voltage (TEV) capacitive coupler probe and a high frequency

current transformer (HFCT) were used for the two channels. The HFCT was placed on copper earth return from the top of the cage which shields the module. This is the only place where the earth return is clearly and singly brought out. Moreover, any large instantaneous rise in potential due to any flashovers of the main system, (something which is extremely difficult to protect against), will not result in large potential differences at the inputs to the high field end of the fibre system. This advantage comes from using floating systems such as the HVPD optical fibre isolation device.

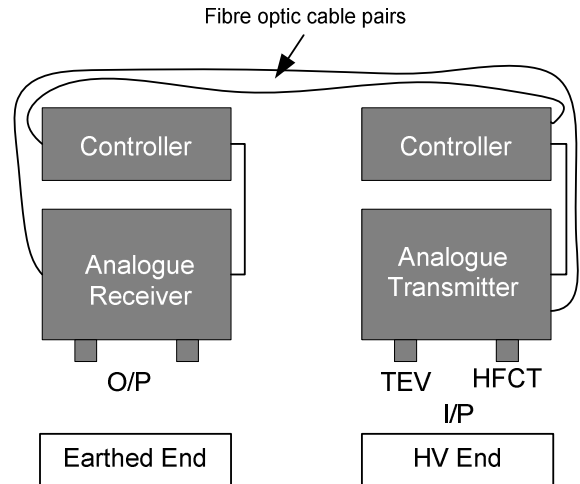


Figure 3, Schematic of the 2 channel analogue fibre equipment

3 CALIBRATION

To calibrate the system for PD activity measurement, the standard method was used. The system was calibrated using a pulse generator through a nominal injection capacitor of 1000pF (actual value 1020pF). Figure 4 shows the simple schematic of the calibration procedure.

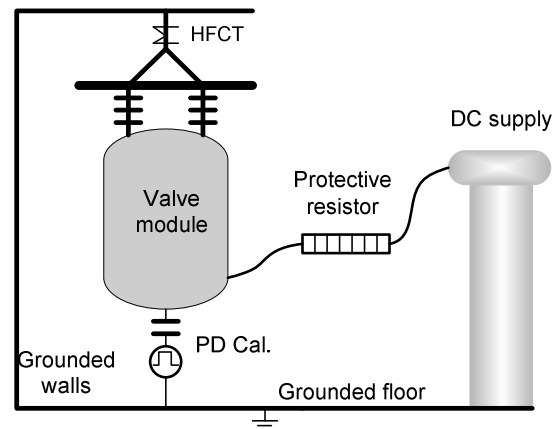


Figure 4, PD Calibration of the Valve Module

The calibrations were carried out at the air clearance of 6m on Gain 4 for the HFCT, and two calibration values were tried, namely 2000pC and 600pC. The results are listed in Table 1, which is 10pC/mV, or 0.1mV/pC. Figure 5 shows the calibration signal on the HFCT.

The noise floor on this basis was around 6mV on Gain 4, giving a PD detection level of around 60pC. In practice, the minimum levels will be smaller than this as the rms noise is measured over a long period (920mSec), and local PDs will give much smaller noise figures.

Table 1, PD calibration results

Calibration Magnitude	Signal on HFCT at gain 4
600pC	60.8mV
2000pC	199mV

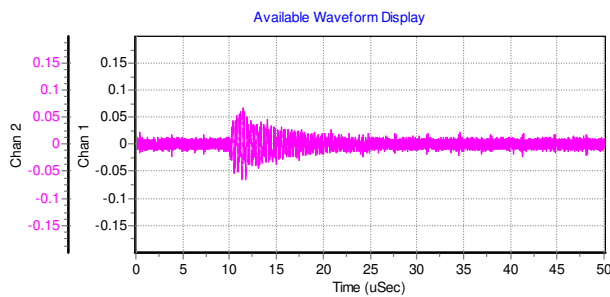


Figure 5, Calibration signal on the HFCT of 600pC

It needs to be pointed out that the test object structure may be of an extended set of circuit components, similar to cables and windings in machines and transformers. Thus PDs being of identical size which arise in different parts of the structure, will show different magnitudes at the detection point. In the present case, there are discrete parts of the module, linked by large (in size and value) resistors. Hence it should be borne in mind, that the calibration given above may not always represent the PD magnitudes from all parts of the module in the same way.

4 PD MEASUREMENT

4.1 Positive DC testing

Three sensors were used in the test, they were: TEV probe on top of the screen of the module, mounted below the crane; HFCT on top of the module, clamped round the earth connection to the top shield; and wideband Aerial placed about 12m from the module near floor level.

PD measurements were made on all sensors outside the screen of the module cage under positive DC voltage. Figure 6 shows the measurement equipment in the laboratory, outside the earthed screened cage of the test module.



Figure 6, Control cage outside the high voltage screen

Figure 7 shows a PD data at a voltage of 1.3MV. Notice the frequency of the PD pulses on the HFCT sensor (Ch2) is greater than that of TEV and aerial sensor.

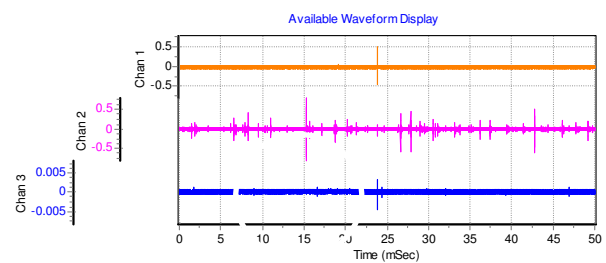


Figure 7, PD signals across a 50mSec recording, (1.3MV), Chan 1 TEV down fibre (Gain 4), Chan 2 CT down fibre (Gain 4), Chan 3 Aerial measured directly

In fact if one looks at both the repetition rate, and the magnitude of the pulses, they show a clear variation with applied voltage. Using the average size of the largest 5 pulses in a 20mSec period, and the repetition rate, the Table 2 can be constructed

Table 2, PD test magnitude and repetition at different voltages

VOLTAGE (MV)	Largest 5 pulses average (mV)	Largest 5 pulses average (pC)	Repetition rate (No /Sec)
0.9	277	2778	200
1.1	396	3971	650
1.3	662	6640	1950
1.34	278 (Gain 3)	8810	2950

The PD inception voltage for the system was around 0.7MV. At 1.34MV there were occasional streamers which were much larger than the PD signals shown in Figure 9. The most common PD signal occurred only on the HFCT's and looked very much like the calibration signal shown previously in Figure 5.

There were some examples of streamer activity recorded. Figure 8 shows such an event recorded at 1.34MV. The amplitude of this event is much larger, and the other sensors also show some synchronous signals. The magnitude of this event is around 25000pC.

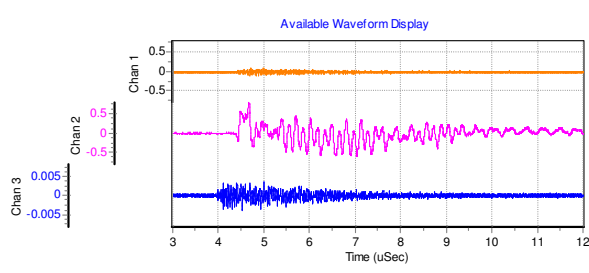


Figure 8, Large PD Event at 1.34MV (Magnitude is 25,300pC), Chan 1 TEV down fibre (Gain 3), Chan 2 CT down fibre (Gain 3), Chan 3 Aerial measured directly

Figure 9 shows a photograph of streamers originating from one of the module stress shields. Notice that there are in fact two streamers occurring during the time when the camera shutter remained open. This would be entirely consistent with the repetition rate of pulses recorded during the tests.

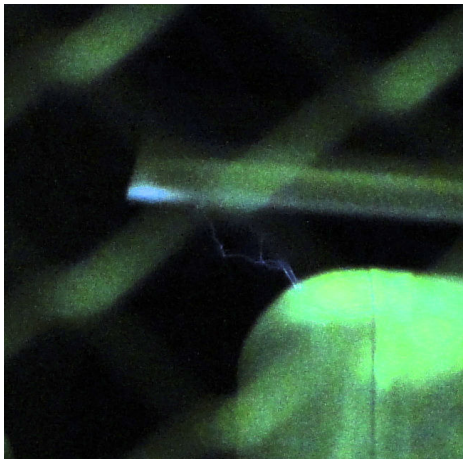


Figure 9, Photograph of streamers taken at 1.34MV

4.2 Negative DC testing

The polarity of the DC set was reversed for the following set of measurements. During the ramp up process, HVPD's PD monitoring software (PDGold©)

was used to monitor the PD activity during the increasing voltage ramp.



Figure 10, PD Activity vs Time during DC Ramp Up in Voltage, Chan 1 TEV down fibre (Gain 3), Chan 2 CT down fibre (Gain 3 means full scale =12600pC), Chan 3 Aerial measured directly

Figure 10 shows the three recorded sensors in time during the DC ramp activity. Channel 2 shows the CT sensor information, which contains virtually all of the PD data. Notice the noise at the start of the ramp which later disappears. This occurs mainly in the first 3 minutes, and intermittently for the first 5 minutes. Following the first 5 minutes, the activity is almost all PD data. Notice that for the most part, only intermittent signals appear on the TEV and antenna channels. In the later part of the recording, there are several large streamer events, and some of these streamers will appear on both the TEV and antenna channels. The background peak PD levels are in the region of 2000pC to 3000pC with occasional events up to the full scale of 12500pC. Later, the volts were increased to 1.35MV where larger streamers were observed.

When the voltage was at 1.35MV, streamers were captured using a sequence method. In this way many triggers can be captured in sequence. Figure 11 shows 20 PD events captured in a sequence. This method ensures that during the capture time, no events are missed. It is a classic way of gathering

data which can be collected by using a trigger, and are potentially intermittent.

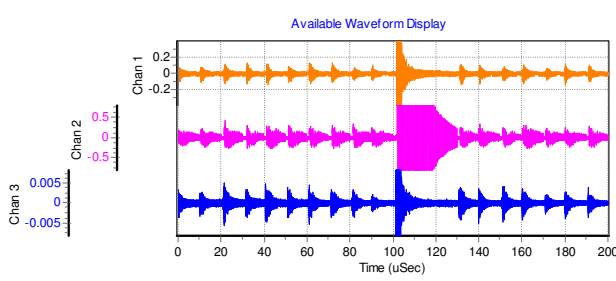


Figure 11, Large PD events captured as a sequence at 1.35MV (negative), Chan 1 TEV down fibre (Gain 3), Chan 2 CT down fibre (Gain 2 means full scale = 75000pC), Chan 3 Aerial measured directly

The streamer PD events in figure 11 show an average size of around 20000pC to 25000pC. Note that the large streamer event which is clearly off scale, indicates a discharge well in excess of 100000pC. However, such events are the exception rather than the routinely average size.

With the large streamers, the signals received from the other sensors (TEV and antenna) also show a coincident waveform. This would show that for the antenna placed at 12m from the module, the minimum discharge measurable would be around 6000pC. The same calculation shows that the TEV channel has a minimum measurable PD level of 2280pC using the same calculation. This was on TEV channel with Gain 3, and if Gain 4 had been used, this may be improved by a further factor of up to x3. This might lead to a minimum detectable signal in this case for the TEV sensor of just under 1000pC, but notice that no signals were detected on this channel during the calibration test when a 2000pC calibration pulse was injected. This may well be due to variations in the calibration factors depending on where geographically on the module the calibration signal was launched. No time was available to investigate this effect.

Several photographs were taken of streamers during this time. Figure 12 shows a typical streamer at the largest test voltage (1.35MV).

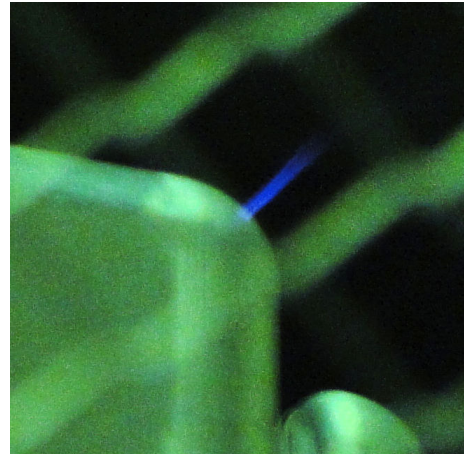


Figure 12, Photographs of streamers on the module stress relieving shields

The photo shows the streamer originating on one of the stress control shields of the module. There may be several streamers in the photograph.

5 CONCLUSIONS

Specially-designed analogue fibre-optic PD detection system allows signals to be detected at high voltage, and transmitted over an optical fibre to the detector at earth potential area. The system has been successfully deployed in Alstom Grid 800kV thyristor valve stress/corona shield development programme for PD evaluation. Following conclusions can be drawn from the tests:

- PD measurements can be successfully made using fibre optic analogue link as a detector coupled to HFCT, TEV sensor and UHF antenna for UHVDC thyristor valve structures for voltages higher than 1MV.
- Detection sensitivity of less than 100pC could be achieved for this method.
- The inception of low level discharges could also be measured and verified using a UV Camera.
- Streamers of average size around 30,000pC could be correlated with the PD measurements using a UV camera. Intermittent streamers could also be measured with magnitudes well in excess of 100,000pC.
- The TEV sensor, which was placed on the metalwork near the ground end of the test object suspension point, showed a detection sensitivity of around 2000pC.
- The repetition rate of PD events was measured near a maximum of 3000 PD pulses/second at 1.34MVdc.

6 REFERENCES

- [1] J. Sturgess, A. Baker, N. MacLeod and F. Perrot, "Development of Insulation Structure for Thyristor Valves for Use on 800kV HVDC Transmission Schemes", IEEE POWERCON 2008, Delhi, India, 12~15 Oct. 2008
- [2] M. Fu, J-L. Rasolonjanahary and F. Perrot, "The Effect of Stray Capacitances on a Representative UHVDC 800kV Corona Shield Structure", 11th International Electrical Insulation Conference, (INSUCON 2009), pp.234-240, 26th~28th May 2009, Birmingham, UK