# Comparison of UHF Antenna and VHF Capacitor PD Detection Measurements from Turbine Generator Stator Windings

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***Abstract*—On-line partial discharge (PD) measurements are widely used to detect stator winding insulation problems. The most widely applied measurement method uses 80 pF capacitors to detect the PD in the VHF (30-300 MHz) frequency range. However, there are more than 1000 large turbine generators equipped with a UHF antenna called the stator slot coupler (SSC). The SSC method operates in the frequency range 10 – 1000 MHz. In several cases both PD measuring systems were installed on the same generator. This paper compares the results from 13 generators that have both the VHF and UHF PD measurement systems. In some cases the correlation between the systems is good. However, there are some situations where one system indicates high PD is present and the other does not. This is presumably caused by the differences in pulse attenuation that occur in the two frequency ranges and the influence of high level sparking noise at the machine terminals, to which the capacitive sensors are preferentially sensitive.**

***Keywords—partial discharge, stator winding, VHF and UHF detections***

## I. Introduction

On-line partial discharge testing to detect deterioration of stator winding insulation has been in widespread use for almost 20 years. As described in IEEE 1434 and IEC 60034-27-2, various methods have been developed, with the most popular including:

- Capacitive couplers and instrumentation that work in the low frequency range (< 3 MHz) or high frequency (3-30 MHz) range, similar to the IEC 60270 detection, where human experts determine what is PD and what is a pulse-like disturbance.
- Capacitive couplers and instrumentation that work in the VHF (30-300 MHz) range, where "time-of-flight" methods are used to suppress disturbances from the power system.
- Antennae-based approaches that work in the VHF and/or UHF (300-3000 MHz) range, which suppress disturbances based on pulse shape.

Over 12,000 machines have been equipped with either the antenna or VHF capacitive coupling methods. A very small proportion of these machines have both methods installed. This paper reviews the results from 13 turbine generators that have both PD measuring systems. In particular, we compare the efficacy of the disturbance rejection methods and the ability to rank the PD severity for both detection methods. Most of the machines compared were hydrogen-cooled turbine generators, as shown in Table I. A description of both measurement methods is first presented.

## II. VHF Capacitive Coupler Method

In this method, two 80 pF capacitive couplers per phase were installed on the isolated phase output bus (IPB). One coupler was installed as close as possible to the generator output bushing. The other was installed at least 2 m along the IPB (towards the power system). Figure 1 shows a schematic of the installation of the couplers on one phase. Since the PD normally has a risetime of a few nanoseconds, and the velocity of an electrical pulse along the air-insulated IPB is 0.3 m/ns, a PD pulse will arrive at coupler 2 at least 6 ns before it is detected at coupler 3. Conversely, a disturbance pulse (for example a corona pulse) from the power system will arrive at sensor 3 at least 6 ns before it arrives at sensor 2. Digital logic in the detector decodes from which direction the pulses come, based on the relative time of arrival [1]. If the pulses are detected <6 ns apart (assuming 2 m between the sensors), then the disturbance (PD or a poor electrical connection on the IPB) is occurring between the couplers. This PD detection method has been installed on over 3000 turbine generators since 1990.

## III. VHF/UHF Antennae Method

As discussed in [1], the time of arrival method using two capacitive sensors per phase was found to sometimes produce false indications of high stator winding insulation PD. Research showed this was caused by sparking that occurred between the stator winding and the PD sensor at the generator terminals (Sensor 2 in Fig. 1). The most common cause of this type of disturbance is sparking from poor electrical contacts at the flexible links connecting the generator terminals to the IPB. Although sparking from this source has a phase-resolved pattern that is quite different from stator insulation PD, a non-PD expert may misdiagnose a good stator insulation system as deteriorated if these disturbances are occurring.

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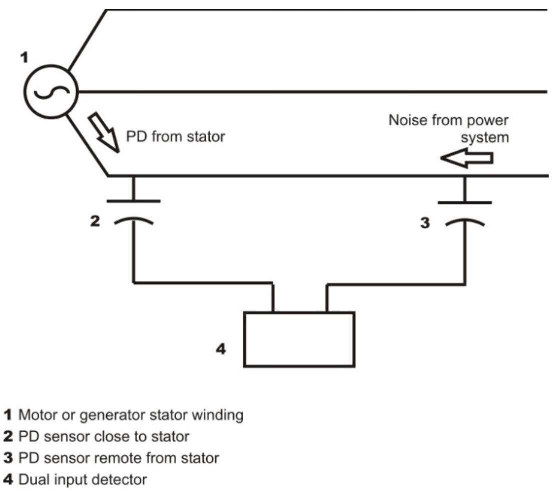


Fig 1: VHF capacitive coupler method to separate PD from the stator winding from disturbances from either between the sensors or from the power system.

To address this issue, a directional electromagnetic coupler called the SSC was developed. The SSC is an antenna that is installed in the stator slots containing stator bars operating at the highest voltage in the winding. Both simulation and practical experiments indicated that PD in the stator slot containing the antenna had a unidirectional nature, and a pulse width less than 8 ns [1]. In contrast, disturbances from the power system, and in particular pulses due to sparking from poor connections at the terminals, were oscillatory and had a pulse width greater than 8 ns. Figure 2 shows an example of an antenna installed in a hydrogen-cooled turbine generator. A limitation of the antenna type of PD sensor is that it is not sensitive to PD occurring in other slots [1]. Over 1000 large turbine generators have been equipped with 6 or more antennae of this type.

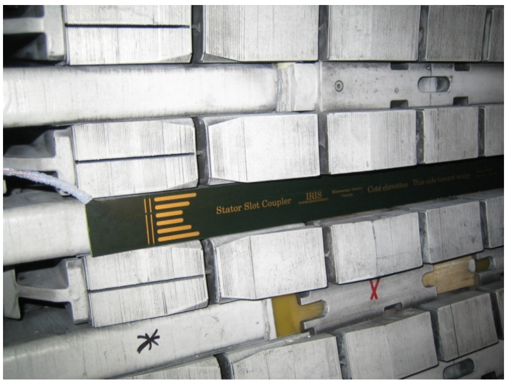


Fig 2: An SSC antenna in the process of being installed on a large generator. A stator wedge is inserted over the antenna.

## IV. Summary of Test Results

Table I shows a compilation of generator ratings and PD data with both sensing systems. Eleven of the 13 generators were hydrogen-cooled with ratings ranging from 167 MVA to 1000 MVA. Only two are air-cooled, since SSCs are rarely applied to air-cooled machines. Most of the PD measurements occurred in the past 2 years. For each phase of a machine, the peak PD magnitude for each pulse polarity is listed, using the definition of Qm in IEC 60034-27-2 (i.e. the PD magnitude at a pulse repetition rate of 10 pps). There may be 2 or 3 SSCs per phase. The data presented is the Qm from the SSC with the highest activity in the phase.

It is well known that the operating voltage of the machine and the hydrogen pressure can have a strong impact on the PD magnitude for the same amount of insulation degradation [2, 3]. Analysis of a database from tests on thousands of machines has enabled a relative ranking of PD severity, corrected for hydrogen pressure and voltage class [2, 3]. Therefore, Table I also shows a relative ranking of the Qm that is based on categorization in [3], using the hydrogen pressure and operating voltage at the time of measurement.

The descriptive rankings used in Table I are based on the statistical distribution of Qm levels from hundreds of similar machines (i.e. similar voltage and pressure):

- Negligible (**Neg.**), i.e. the Qm is lower than 75% of similar machines [3]
- **Low**, Qm is less than 50% of similar machines
- **Typical**, Qm is less than 25% of similar machines
- Moderate (**Mod.**), Qm is less than 10% of similar machines
- **High**, Qm is less than only 10% of similar machines
- **Very High**, the Qm is higher than 95% of all similar machines, (or only 5% of machines have a higher Qm).

Generally, if the Qm is higher than 90% of similar machines, a visual inspection of the winding will show significant insulation deterioration.

A column for each measurement method is devoted to the disturbance level. Each method does not discard the disturbance pulses, but in fact records the number and magnitude of the disturbances. The disturbance columns show the level of disturbance as classified by the time-of-pulse-arrival method (for capacitive couplers) and the pulse shape method (for SSCs).

Six of the 13 (46%) machines had the same severity classification. In all these cases, there were no sources of disturbances detected by either type of PD sensor.

Two generators had similar classifications, although in machine A, the capacitive coupler was exposed to considerably more disturbance from the generator output bus, which may have corrupted the stator PD. Similarly there were two other machines with capacitive couplers that were classified to exhibit higher PD activity than the SSCs, although this was likely caused by the high level disturbances on the terminals or the IPB. Thus a total of 4 machines with capacitive couplers (31%) were not correctly diagnosed due to disturbances.

Three generators (23%) had higher severity indicated with the SSCs than with the capacitive couplers (C, J, and K). The cause for the discrepancy can only be speculated upon. In C, there were very high levels of disturbances from the IPB, which may have reduced sensitivity to the capacitive coupler PD due to the dead time effect (when a pulse of any sort is

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detected, the instrument stops looking for pulses for 2 microseconds). For J and K, it might be that the SSCs were just exceptionally close to the PD sites, and thus exhibited higher sensitivity. This is certainly the case for generator J, since the PD is directly below the SSC.

In general, if there is a low level of disturbance, the severity of the PD detected is similar, or the SSC is more sensitive. If the noise from the machine terminals or the IPB is high, then the capacitive coupler Qm values tend to be erroneous.

## V. CASE STUDY - MACHINE E

This generator has very high noise as is apparent from the antenna sensor in Fig. 3b. However, there is no disturbance detected using the time of arrival principle with the capacitive sensors (Fig. 4b). Thus it seems there are no disturbances caused by PD or contact sparking from the capacitive sensors from the IPB or the power system. Instead the “Machine PD” plot in Fig. 4a seems to be corrupted by very high magnitude pulses, positioned around the AC voltage zero crossings. Therefore, the disturbance pulses seen with the SSCs seem to be from the generator terminals, likely one or more poorly-torqued bolts on the flexible leads between the generator terminals and the IPB. Indeed, the pulse pattern for the disturbances in Fig. 3b and the high level activity classed as Machine PD (Fig. 4a), is typical of sparking due to poor contacts, since the activity is occurring near the voltage zero crossings of the AC cycle. This is an example of the antenna sensor being able to prevent the stator insulation PD from being confused with relatively harmless terminal sparking. It is apparent that once the signals are correctly identified by the antenna, the actual stator insulation PD is minor, and the insulation is in good condition.

## VI. CONCLUSION

1. In the absence of significant disturbances from the generator terminal or from the power system, both the capacitive and antenna-type PD sensors usually agree on the severity of the PD measured in the stator winding. Thus either sensor can be used effectively when disturbances are minimal.
2. Both types of sensors are effective in suppressing disturbances from the IPB and power system.
3. The capacitive sensors are shown to be ineffective in suppressing disturbances that originate from the machine terminals.

## REFERENCES


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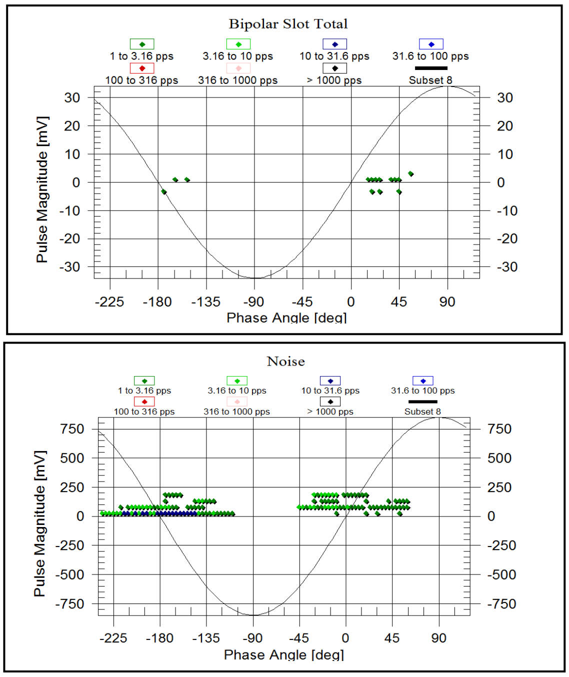
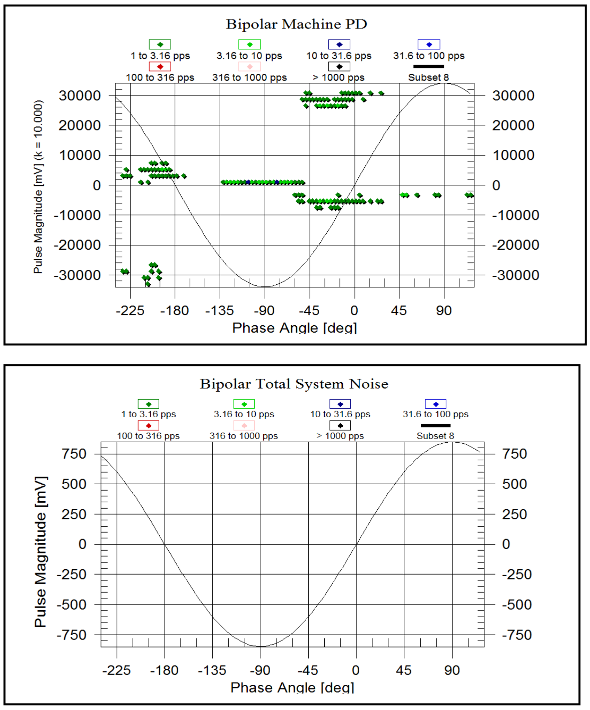



(a)

(b)

Fig. 3: Slot PD (a) and disturbances (b) from C phase, SSC 41. Machine E. The vertical scale is the pulse magnitude and the horizontal scale is the phase angle of the 50/60 Hz AC cycle. The color indicates the pulse repetition rate. Note the difference in scales.




(a)

(b)

Fig. 4: PD (a) and power system disturbances (b) from C phase capacitive coupler for Machine E. There are no pulses occurring from the output bus beyond the machine capacitive coupler. Note the difference in scales between the plots.

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TABLE I. SUMMARY OF PD AND NOISE DATA FROM THE VHF AND UHF SENSORS

| *ID* | Ratings | | | Year* | Phase | Capacitive Coupler Results | | | | SSC Results** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *MVA* | *kV* | *H2 Press (kPag)* | | | *Qm+ (mv)* | *Qm- (mV)* | *Severity* | *Disturbance (mV)+* | *Qm+ (mV)* | *Qm- (mV)* | *Severity* | *Disturbance (mV)^* |
| *A* | 176 | 18 | 300 | 1963 | A | 26 | 28 | Mod. | >3400, from bus | 25 | 21 | Neg. | 250 |
| | | | | | B | 21 | 21 | Mod. | >3400, from bus | 8 | 11 | Neg. | 50 |
| | | | | | C | 19 | 19 | Mod. | >3400, from bus | 5 | 4 | Neg. | 0 |
| *B* | 350 | 20 | 270 | 1972 | A | 9 | 0 | Neg. | 0 | 0 | 0 | Neg. | 0 |
| | | | | | B | 0 | 0 | Neg. | 0 | 0 | 0 | Neg. | 0 |
| | | | | | C | 28 | 23 | Low | 0 | 3 | 0 | Neg. | 0 |
| *C* | 690 | 20 | 290 | 1999 | A | - | - | - | - | 72 | 0 | High | 320 |
| | | | | | B | 3 | 3 | Neg. | 300 from bus | 97 | 94 | High | 200 |
| | | | | | C | 4 | 3 | Neg. | >3400 from bus | 197 | 207 | High | 300 |
| *D* | 1000 | 25 | 400 | 2003 | A | 2 | 0 | Neg. | 0 | 0 | 0 | Neg. | 0 |
| | | | | | B | 15 | 2 | Low | 0 | 0 | 0 | Neg. | 0 |
| | | | | | C | 6 | 3 | Neg. | 0 | 0 | 0 | Neg. | 0 |
| *E* | 550 | 22 | 385 | 2004 | A | 769 | 1233 | Very High | 50 | 5 | 6 | Neg. | 50 |
| | | | | | B | 1700 | 900 | Very High | 50 | 5 | 4 | Neg. | 100 |
| | | | | | C | 8330 | 6360 | Very High | 50 | 1 | 0 | Neg. | 200 |
| *F* | 400 | 21 | 330 | 2004 | A | 16 | 24 | Low | 27 mV | 3 | 3 | Low | 0 |
| | | | | | B | 17 | 19 | Low | 29 mV | 3 | 2 | Low | 0 |
| | | | | | C | 16 | 18 | Low | 25 mV | 3 | 0 | Low | 0 |
| *G* | 640 | 24 | 400 | 2004 | A | 145 | 96 | High | 0 | 9 | 8 | typical | 5 |
| | | | | | B | 1394 | 1235 | Very High | 0 | 7 | 5 | typical | 2 |
| | | | | | C | 55 | 68 | Low | 0 | 7 | 5 | typical | 10 |
| *H* | 496 | 22 | 220 | 2005 | A | 4 | 0 | Low | 1477 | 3 | 2 | Low | 10 |
| | | | | | B | 10 | 7 | Low | 2250 | 5 | 5 | Low | 45 |
| | | | | | C | 0 | 0 | Neg. | 10810 | 3 | 3 | Low | 30 |
| *I* | 1000 | 25 | 380 | 2006 | A | <5 | <7 | Neg. | <5 | 0 | 0 | Neg. | 0 |
| | | | | | B | <9 | <8 | Neg. | <5 | 0 | 0 | Neg. | 0 |
| | | | | | C | 0 | 2 | Neg. | <5 | 0 | 0 | Neg. | 0 |
| *J* | 167 | 16 | 210 | 2007 | A | 13 | 14 | Neg. | 95 | 98 | 89 | Very High | 0 |
| | | | | | B | 60 | 36 | Low | 39 | 93 | 99 | Very High | 0 |
| | | | | | C | 30 | 28 | Neg. | 33 | 150 | 260 | Very High | 0 |
| *K* | 205 | 15 | Air cooled | 2007 | A | 0 | 26 | Neg. | - | 123 | 130 | High | 50 |
| | | | | | B | 22 | 19 | Neg. | - | 19 | 14 | Low | 50 |
| | | | | | C | 0 | 32 | Neg | - | 750 | 750 | Very High | 2000 |
| *L* | 200 | 18 | Air cooled | 2010 | A | 17 | 24 | Neg. | 12 mV | 11 | 12 | Typ. | 12 |
| | | | | | B | 12 | 9 | Neg. | 7 mV | 4 | 2 | Low | 12 |
| | | | | | C | 18 | 15 | Neg. | 49 mV | 4 | 6 | Low | 8 |
| *M* | 700 | 24 | 390 | ? | A | 8 | 6 | Neg. | 24 mV | 7 | 8 | Typical | - |
| | | | | | B | 9 | 9 | Neg. | 12 mV | 9 | 9 | Typical | - |
| | | | | | C | 8 | 9 | Neg. | 17 mV | 18 | 9 | Low | - |

*YEAR OF WINDING MANUFACTURE OR REWIND
**USING HIGHEST SSC READINGS FROM A PHASE. ONLY INCLUDED SLOT PD RESULTS
+ BASED ON TIME OF ARRIVAL, FROM THE POWER SYSTEM, UNLESS OTHERWISE NOTED
^ BASED ON PULSE WIDTH, UNLESS OTHERWISE NOTED

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