Experience with Directional Couplers in a High Noise Environment

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***Abstract*- Directional couplers have been used in Manitoba Hydro for on-line partial discharge measurements on rotating machines since 1981. This paper discusses experience with improved sensors and instrumentation in a high noise environment.**

***Index Terms* - Partial discharges, Monitoring, Insulation Testing**

I. Introduction

Detailed information on the application in Manitoba Hydro of directional couplers for on-line partial discharge measurements in rotating machines will be found in [1]. Nine hydrogen cooled synchronous condensers operate at an HVDC converter station which is an environment with high electrical noise. To improve sensitivity to partial discharge (PD) activity in the winding and to reduce vulnerability to noise three 80 pF capacitive couplers (one per phase) have been relocated inside the hydrogen seal. An additional set of couplers is installed in the isolated phase bus (IPB) approximately 2 m from those inside the machine housing. Most of the windings have also been equipped with stator slot couplers (SSCs) [2]. On-line PD measurements from all these sensors are made periodically using a TGA-SB analyzer manufactured by Iris Power.

II. Sensor Improvements

Outages to re-wedge stator windings or to carry out related maintenance have provided opportunities to install compact 80 pF epoxy mica capacitive couplers. Fig. 1 shows one such coupler installed at the line end terminal of the stator winding of a 300 MVA synchronous condenser. High frequency grounding of the shield of the signal cable at the coupler is provided by means of a capacitor as is discussed in [3]. With the rotor removed there has been the opportunity to install a SSC under the wedge adjacent to the first air gap side bar from the line end of each circuit. In each of the small 160 MVA 17 kV synchronous condensers 6 SSCs have been installed, while the 300 MVA 13.8 kV machines have 12 SSCs. A SSC installed in a 160 MVA machine with a polyester mica winding is shown in Fig. 2. Each 160 MVA synchronous condenser is connected to the tertiary winding of a HVDC converter transformer. Each 300 MVA synchronous condenser has a separate 13.8/230 kV step-up transformer.

Fig. 1. 80 pF capacitive coupler inside housing of 300 MVA machine

Fig. 2 Stator slot coupler installed under wedge in 160 MVA machine

III. On-Line Measurements

A. 160 MVA 17 kV unit with epoxy-mica insulation

Resin rich epoxy mica insulated stator bars cured in a heated press were installed in 1971. In 1974 the original 2-piece split wedges were removed and replaced with single piece slab wedges. In 1983 the unit was re-wedged with piggy back wedges fabricated from Micarta material. In 1988 the unit was re-wedged with Class F piggy back wedges. In 1999 the unit was re-wedged with a radial ripple spring system. Also in 1999 stator slot couplers were installed and the earlier 80 pF XLPE cable type machine terminal couplers were replaced with 80 pF epoxy mica couplers that were installed inside the housing of the machine.

On each occasion that the stator was re-wedged electromagnetic (TVA) probe readings [4] have been made at several locations along each slot with the winding energized at 10 kVrms 60 Hz. The May 1999 readings following re-wedging indicated a maximum of 10 mA peak pulse for stator bars near the line end of the circuit in which the Slot 28 SSC is installed. Readings as high as 980 mA were obtained for some bars at the neutral. The latter may reflect slot discharge during the off-line test as a result of loss of the outer semi-conducting coating. These stator bars do not have an armour tape.

In March 2000 with the machine running in air at 30 MVA 17.1 kV and a stator winding temperature of 72^{o}C on-line PD measurements were made. Fig. 3(a) shows the PD attributed by the TGA-S to Slot 28 at the line end of one of two circuits in B-phase by means of the SSC that had been installed at the opposite connection end of this slot. Fig. 3(b) shows the PD that was attributed to the end winding at the same slot. The TGA-B data from the directional couplers on B-phase are shown in Fig. 3(c) for the machine and in Fig. 3(d) for power system "noise" including PD associated with the isolated phase bus.

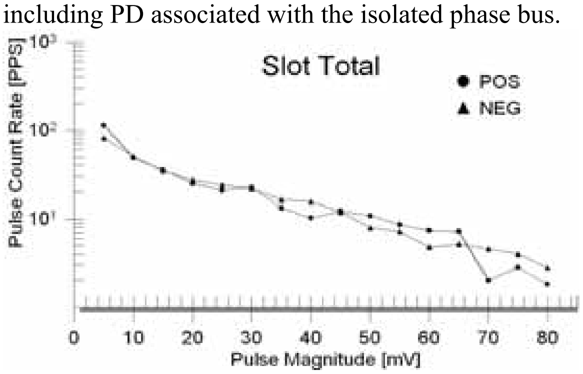

Fig. 3(a) SSC – PD Attributed to Slot 28 B-phase line end in air

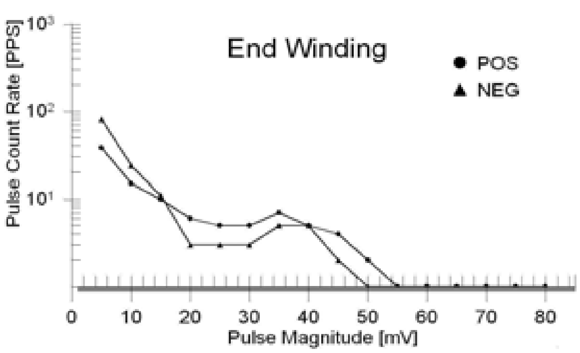

Fig. 3(b) SSC – PD Attributed to end winding at Slot 28 B-phase in air

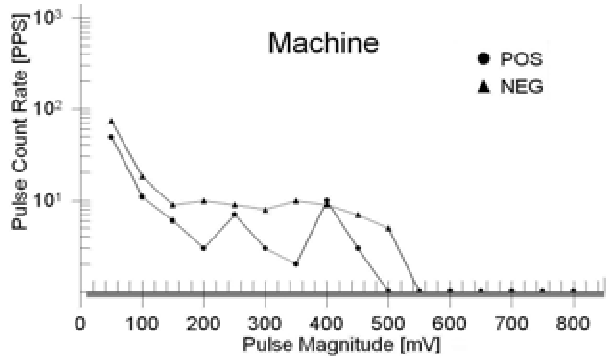

Fig. 3(c) 80 pF couplers – PD attributed to B-phase of machine in air

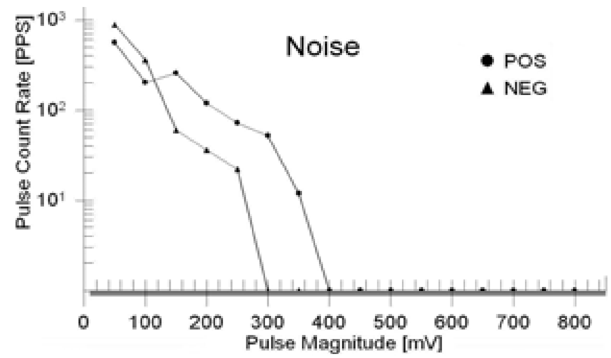

Fig. 3(d) 80 pF couplers – B-phase power system noise & IPB PD

In January 2001 with the machine running in hydrogen at 207 kPa (gauge), loading at 38 MVA 17.0 kV and a stator winding temperature of 39^{o}C, on-line PD measurements were made. The data will be found in Fig. 4(a) – Fig. 4(d). It will be noted that the PD measured from the sensors was reduced from that measured in air, with the exception of the power system "noise".

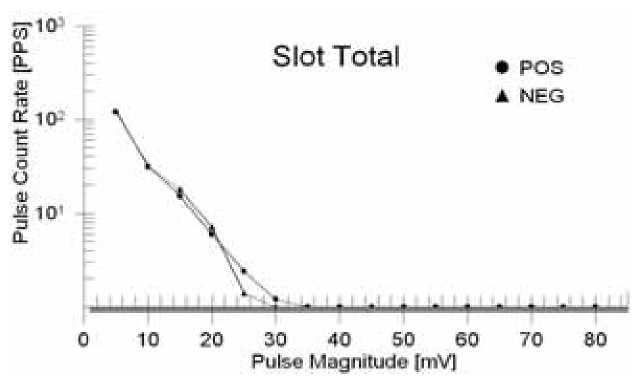

Fig.4(a) SSC – PD Attributed to Slot 28 B-phase line end in hydrogen

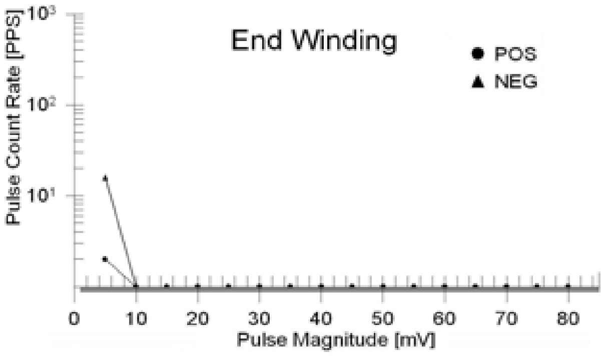

Fig. 4(b) SSC – PD Attributed to Slot 28 B-ph end winding in hydrogen

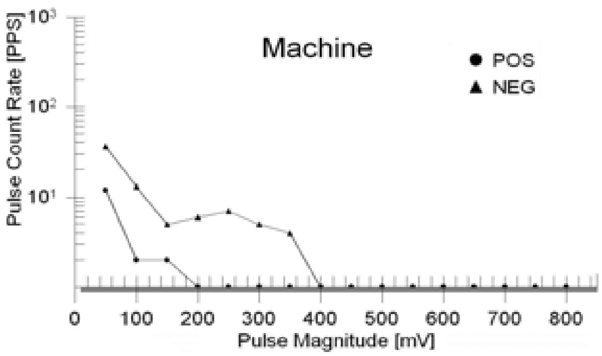

Fig. 4(c) 80 pF couplers – PD attributed to B-ph of machine in hydrogen

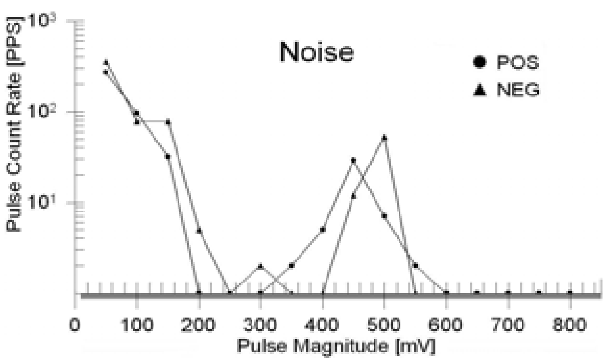

Fig. 4(d) 80 pF couplers – B-phase power system noise & IPB PD

B. 160 MVA 17 kV unit with polyester mica insulation

In 1987 the original stator winding and core were severely damaged as a result of a metal object that had entered the air gap while the machine was in operation. Both the winding and the core had to be replaced. The new stator bars were insulated with polyester bonded mica using the VPI process. Class F piggy back wedges were installed. In 1996 the stator winding was re-wedged with a radial ripple spring system. At the same time six stator slot couplers were installed and 80 pF epoxy mica terminal couplers were installed inside the machine housing.

In June 1996 electromagnetic (TVA) probe measurements were made with the winding energized at 10 kVrms 60 Hz. A maximum of 30 mA peak pulse was measured for stator bars near the line end of the same circuit in which the SSC is installed in Slot 13.

In October 1996 with the machine running in air at 26 MVA 17.0 kV and a stator winding temperature of 72°C, on-line PD measurements were made. Fig. 5(a) shows the PD attributed by the TGA-S to Slot 13 at the line end of one of the two circuit in B-phase by means of the SSC that had been installed at the opposite connection end of this slot. No PD was attributed to the end windings by the TGA-S analyzer. The PD data from the directional couplers on B-phase are shown in Fig. 5(b) for the machine and in Fig. 5(c) for power system "noise" including PD associated with the isolated phase bus. Figure 5(d) shows a phase plot of the PD attributed to the machine.

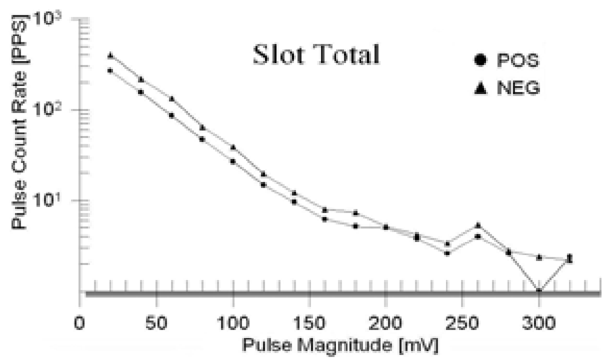

Fig.5(a) SSC – PD Attributed to Slot 13 B-phase line end in air

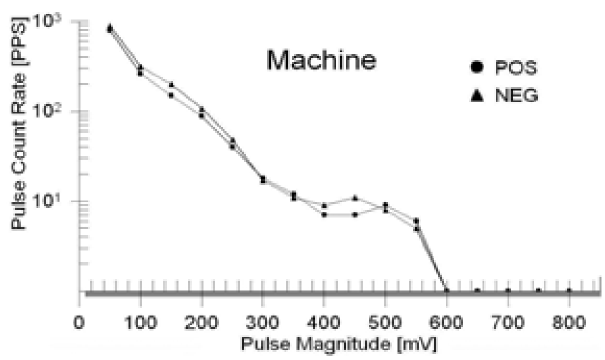

Fig. 5(b) 80 pF couplers – PD attributed to B-phase of machine in air

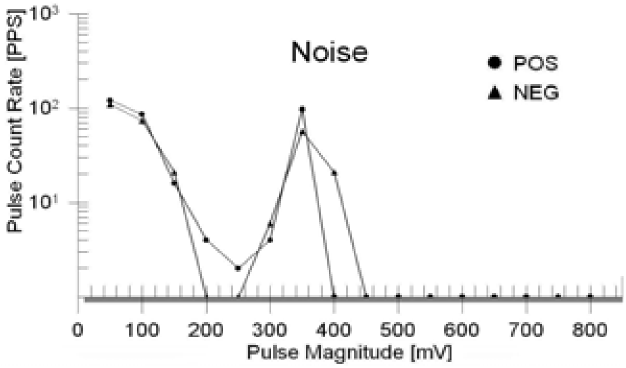

Fig. 5(c) 80 pF couplers – B-phase power system noise & IPB PD

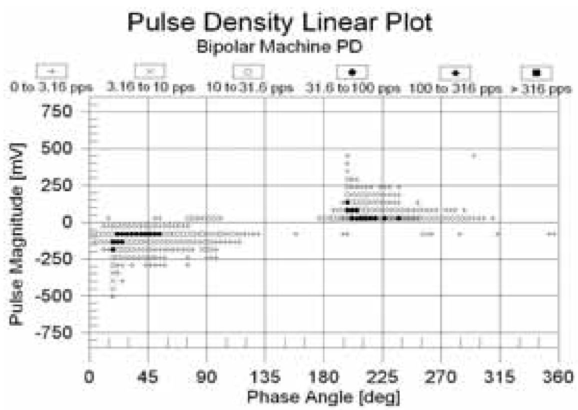

Fig. 5(d) 80 pF couplers – PD attributed to B-phase of machine in air

In February 1998 with the machine running in hydrogen at 207 kPa (gauge), loading at 19 MVA 17.0 kV, and stator winding temperature of 41°C, on-line PD measurements were made. The data will be found in Fig. 6(a) – Fig. 6(d). Note that the PD attributed to Slot 13 is less than what was observed with the winding operating in air, but the magnitudes are higher than for the previously discussed epoxy-mica winding in Fig. 3 and Fig. 4. As for the directional couplers, there was a reduction in pulses with a phase position typical of winding PD with the machine operating in hydrogen, but an increase in pulses that may reflect discharges external to the slot.

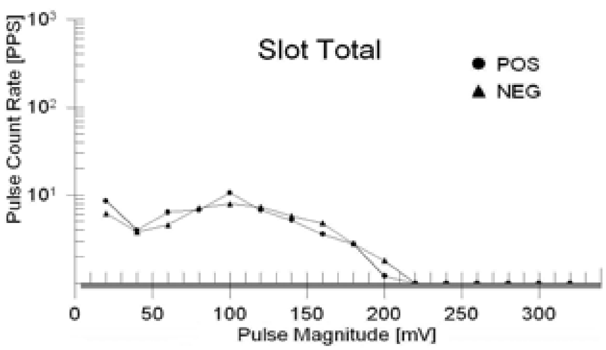

Fig.6 (a) SSC – PD Attributed to Slot 13 B-ph line end in hydrogen

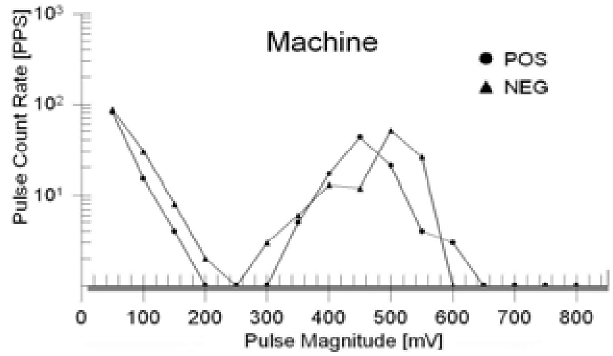

Fig.6 (b) 80 pF couplers – PD attributed to B-ph of machine in hydrogen

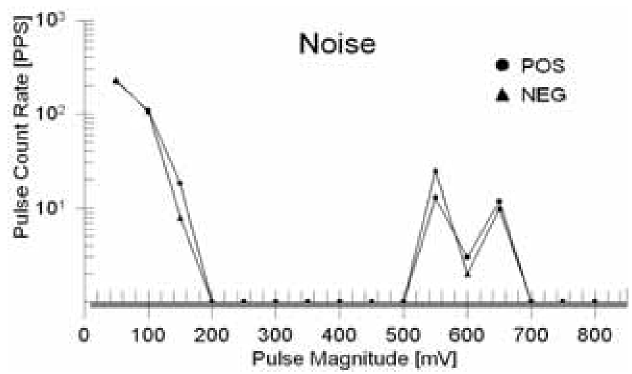

Fig. 6(c) 80 pF couplers – B-phase power system noise & IPB PD

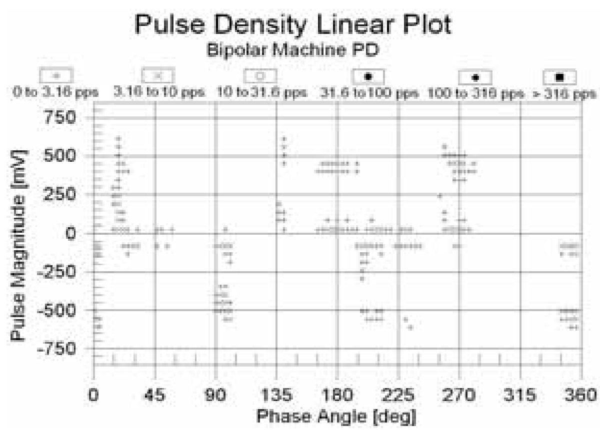

Fig. 6(d) 80 pF couplers – PD attributed to B-ph of machine in hydrogen

C. 300 MVA 13.8 kV unit with epoxy mica insulation

Resin rich epoxy mica insulated tank cured stator bars were installed in 1990 with a radial ripple spring wedge system. In 2004 the machine was overhauled to correct a fretting corrosion problem involving the rotor that had resulted in a red rust contaminant throughout the unit. At this time it was found that some of the iron oxide coating on the stator winding end windings, caps and jumpers was flaking. This loose coating was removed and a new coating was applied. It was not necessary to re-wedge this winding.

Also in 2004 stator slot couplers were installed at the opposite connection end of slots associated with the line end of each of the 12 circuits. On the same occasion 80 pF epoxy mica couplers were re-located from the air side to the hydrogen side of the line end terminal bushings. The 80 pF couplers associated with the isolated phase bus were left in the original position approximately 2 m from the machine terminal.

In February 2005 electromagnetic (TVA) probe measurements were made with the winding energized at 8 kVrms 60 Hz after the renewal of the iron oxide coating. The readings obtained indicated a maximum of 12 mA peak pulse for stator bars at the line end of the circuit in which the SSC is installed in Slot 62.

In May 2005 with the machine running in air at 8 MVA 13.2 kV and a stator winding temperature of 52°C on-line PD measurements were made. Fig. 7(a) shows the PD attributed by means of a SSC to Slot 62. Virtually no PD was attributed to the end windings. The PD data from the directional couplers on B-phase are shown in Fig. 7(b) and Fig. 7(c). Fig. 7(d) shows a phase plot of the PD attributed to the machine. The predominance of positive polarity pulses suggests the external coating of the winding.

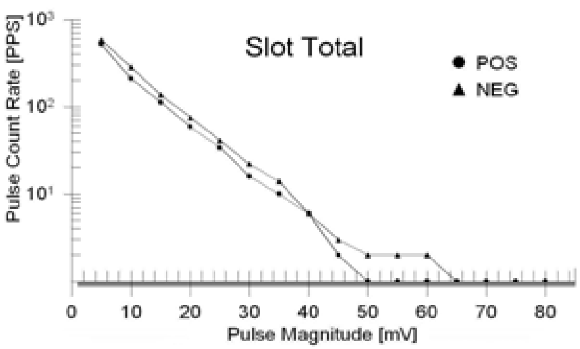

Fig.7 (a) SSC – PD Attributed to Slot 62 B-phase line end in air

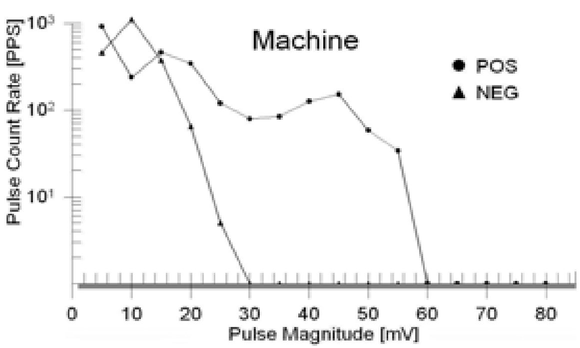

Fig.7 (b) 80 pF couplers – PD attributed to B-phase of machine in air

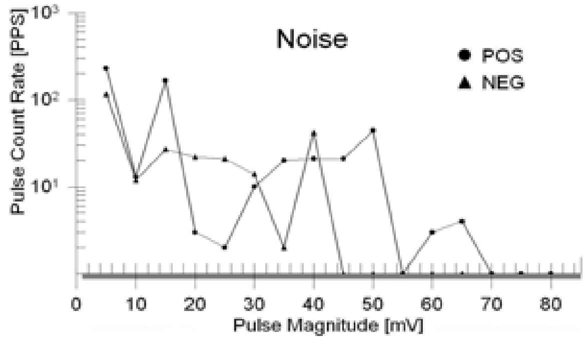

Fig. 7 (c) 80 pF couplers – B-phase power system noise & IPB PD

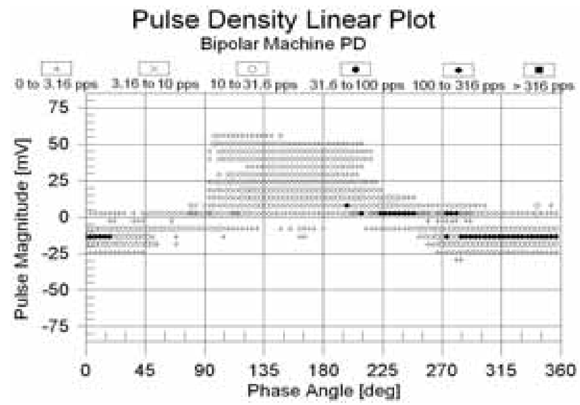

Fig. 7(d) 80 pF couplers – PD attributed to B-phase of machine in air

In September 2005 with the machine running in hydrogen at 162 kPa (gauge), loading 10 MVA 13.8 kV at a stator winding temperature of 75°C, on-line PD measurements were made. As shown in Fig. 8(a) the PD attributed to Slot 62 by the TGA-S was significantly higher than had been measured with the machine operating in air and now showed signs of negative pulse predominance. The data from the directional couplers are shown in Fig. 8(b) - Fig. 8(e). The phase position of the PD attributed to the winding suggests end arms or circuit ring bus, but the magnitude is low. Pulses attributed to the IPB have the characteristic phase position for discharges related to line-to-ground voltage, but polarity is reversed.

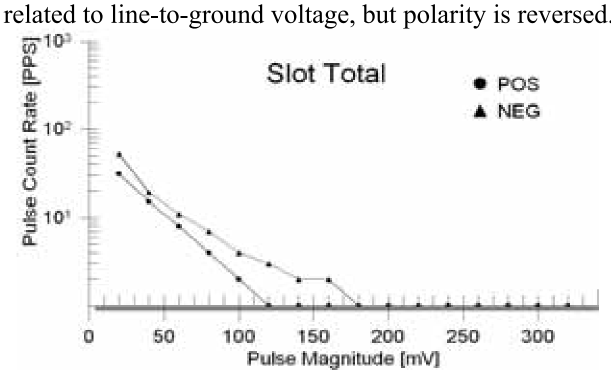

Fig.8 (a) SSC – PD Attributed to Slot 62 B-phase line end in hydrogen

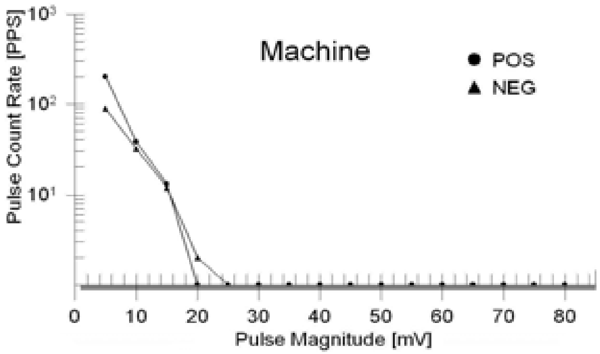

Fig.8 (b) 80 pF couplers – PD attributed to B-ph of machine in hydrogen

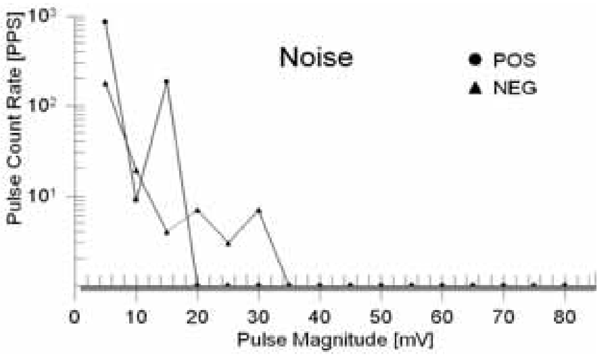

Fig. 8 (c) 80 pF couplers – B-phase power system noise & IPB PD

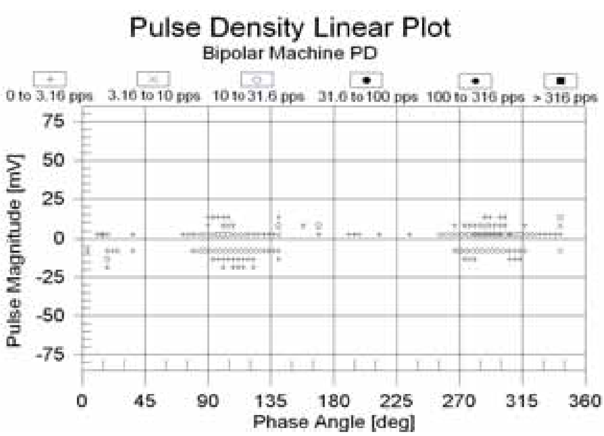

Fig. 8(d) 80 pF couplers – PD attributed to B-ph of machine in hydrogen

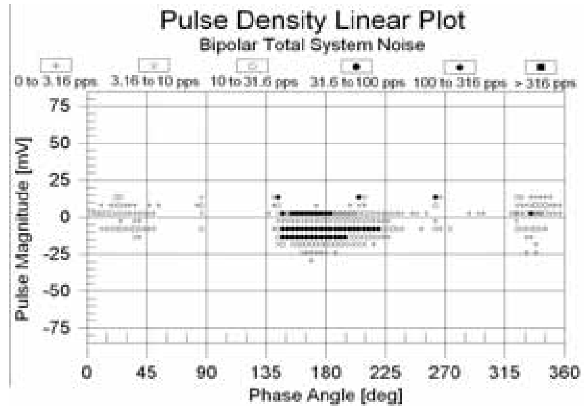

Fig. 8(e) 80 pF couplers – Pulses attributed to B-ph of IPB in hydrogen

IV. Conclusions

Reliability of on-line PD data in a high noise environment has been improved by locating directional couplers as close as possible to the winding under test. The installation of stator slot couplers has provided an independent source of noise-free data.

Acknowledgment

J.C. Bromley of Manitoba Hydro is thanked for changing the graphics in this paper into a form that is suitable for publication.

References

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