CONFIRMATION OF

HIGH PDA AND CORONA PROBE READINGS

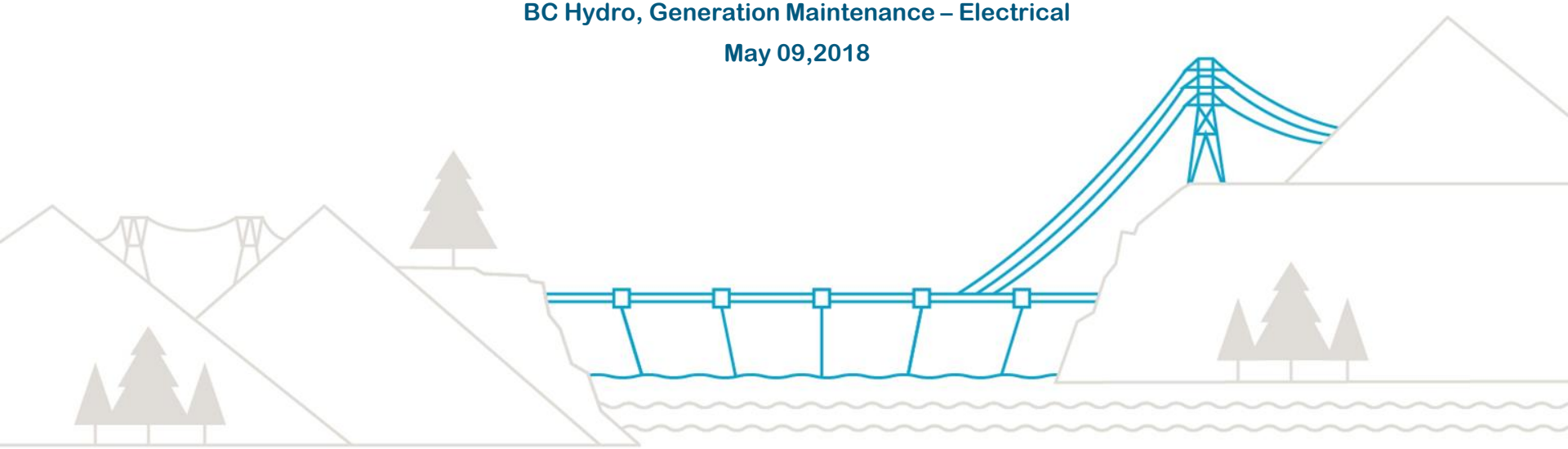
ON A LARGE HYDRO GENERATOR

2018 IRMC

Igor Chichkin, P.Eng

BC Hydro, Generation Maintenance – Electrical

May 09,2018



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Partial Discharge

- **Incomplete** electrical discharge between insulation surfaces, or between insulation and a conductor.

- **Corona** is a partial discharge from an open conductor to surrounding gas. Corona is type of PD that can be seen. If you can't see it – it's not Corona.

- Full Discharge is an electrical discharge between two conductors (insulation failure).

Partial Discharge activity can eventually cause Full discharge !

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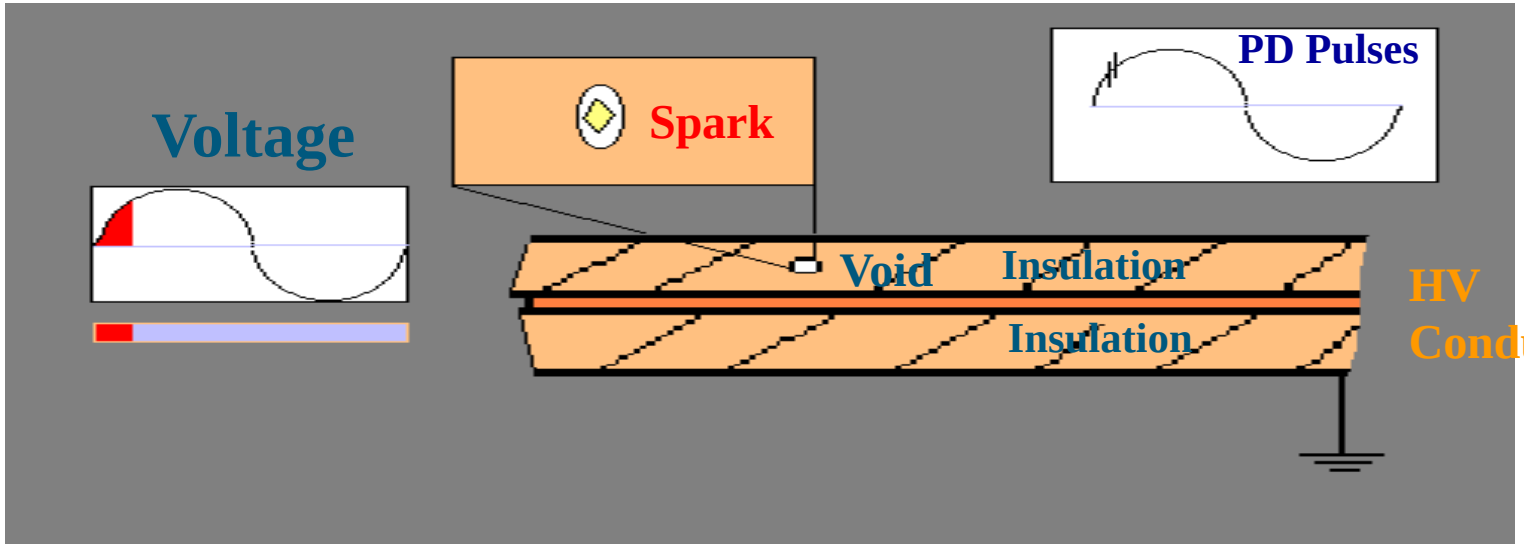
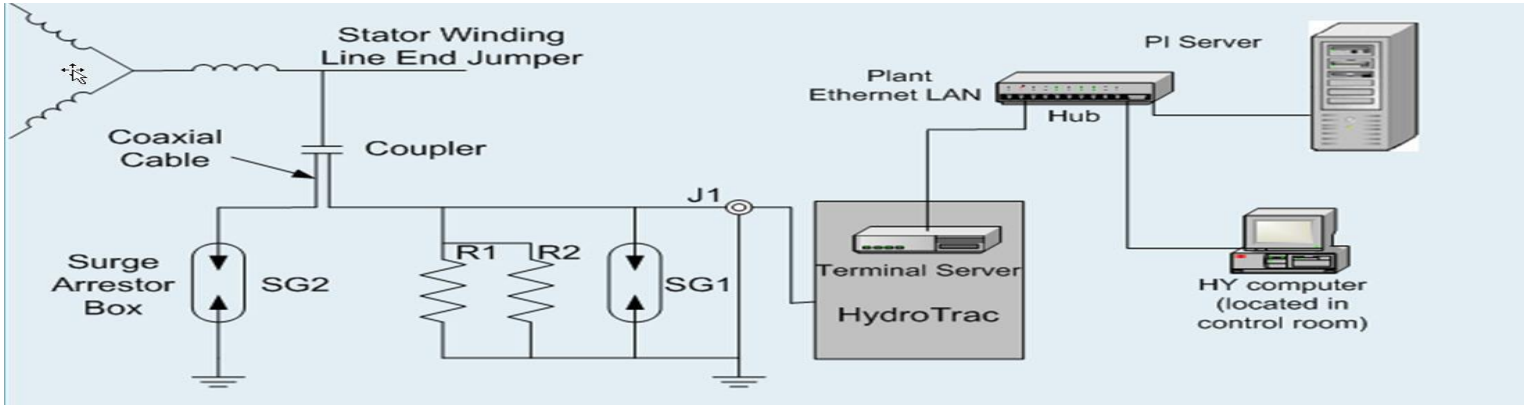
What is Partial Discharge?





- Small electrical sparks in air-filled cavities in or adjacent to HV electrical insulation.
- Occur because breakdown strength of air **(3 kV/mm)** < solid insulation **(~300 kV/mm)**
- PD creates small voltage pulses and PD monitoring measures these pulses

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2016 IRIS PD Database

Qm values for air-cooled machines with differential capacitive couplers (PDA)

Rated V	6-9kV	10-12kV	13-15kV	16-18kV	> 19kV	
25%	12	20	34	23	90	25% of the results have Qm levels below this value
50%	33	50	88	81	176	50% of the results have Qm levels below this value
75%	66	112	190	222	659	75% of the results have Qm levels below this value
90%	172	240	364	557	857	90% of the results have Qm levels below this value
95%	315	385	530	729	993	95% of the results have Qm levels below this value

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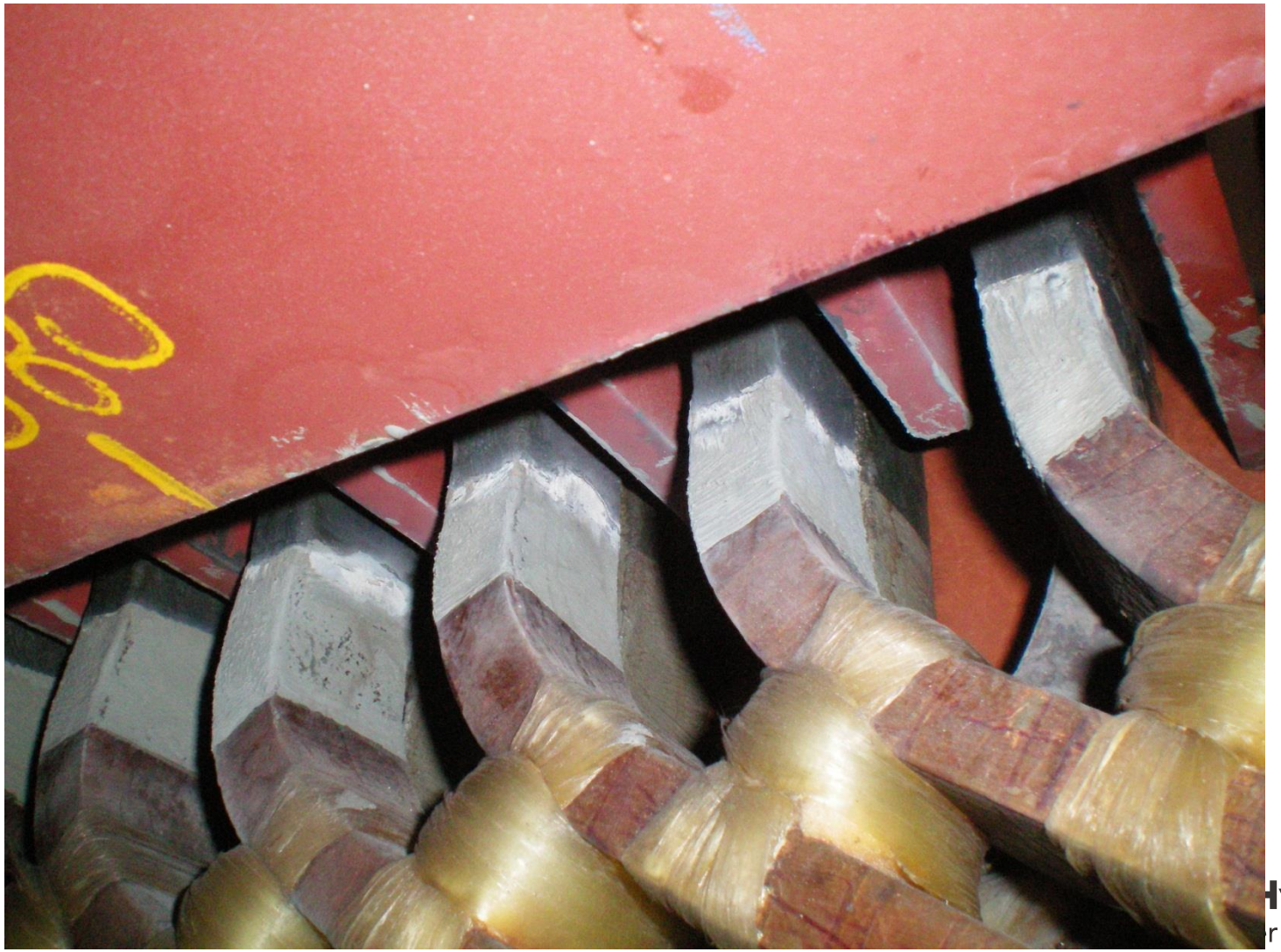
Semi-con/Grading Coating interface deterioration



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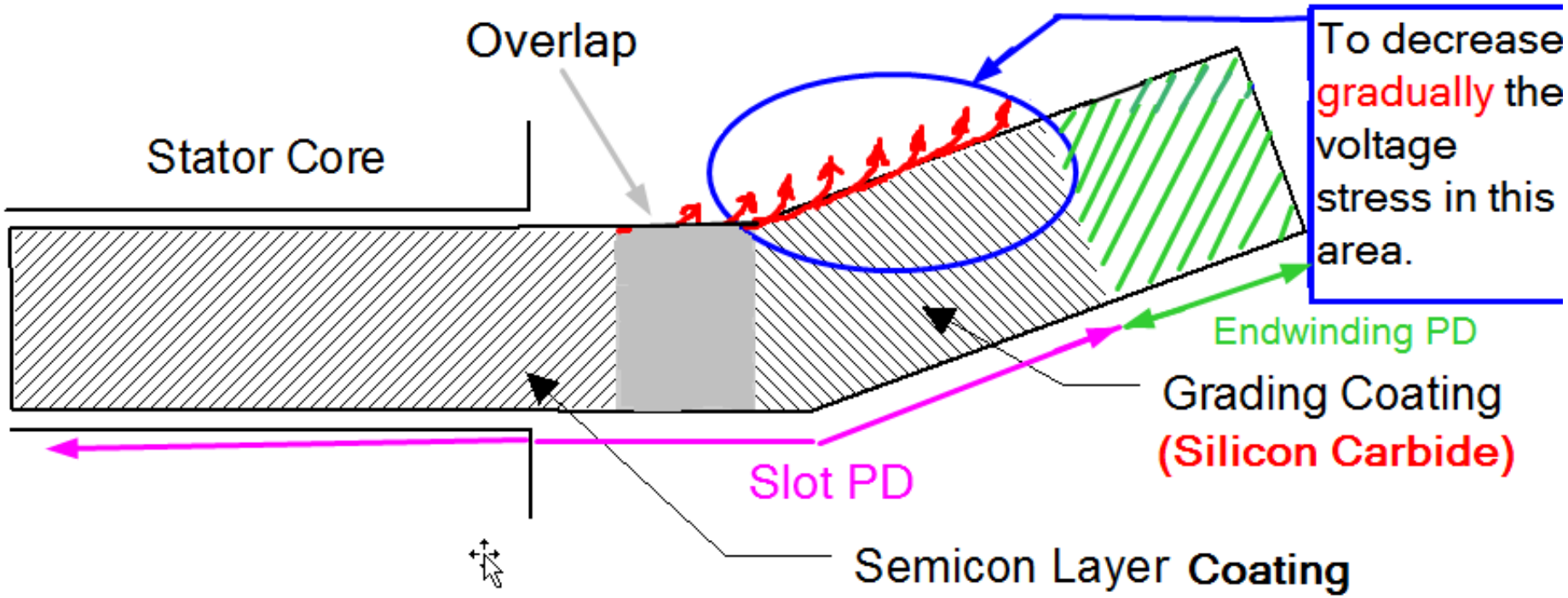
End-winding



- The silicon carbide material has a non-linear resistive property (the resistance decreases with the applied voltage).

- **Purpose** : **gradually decrease** the high voltage in the end-winding to ZERO at the grounded semi-conductive slot coating ,thus avoiding discharges on the surface.

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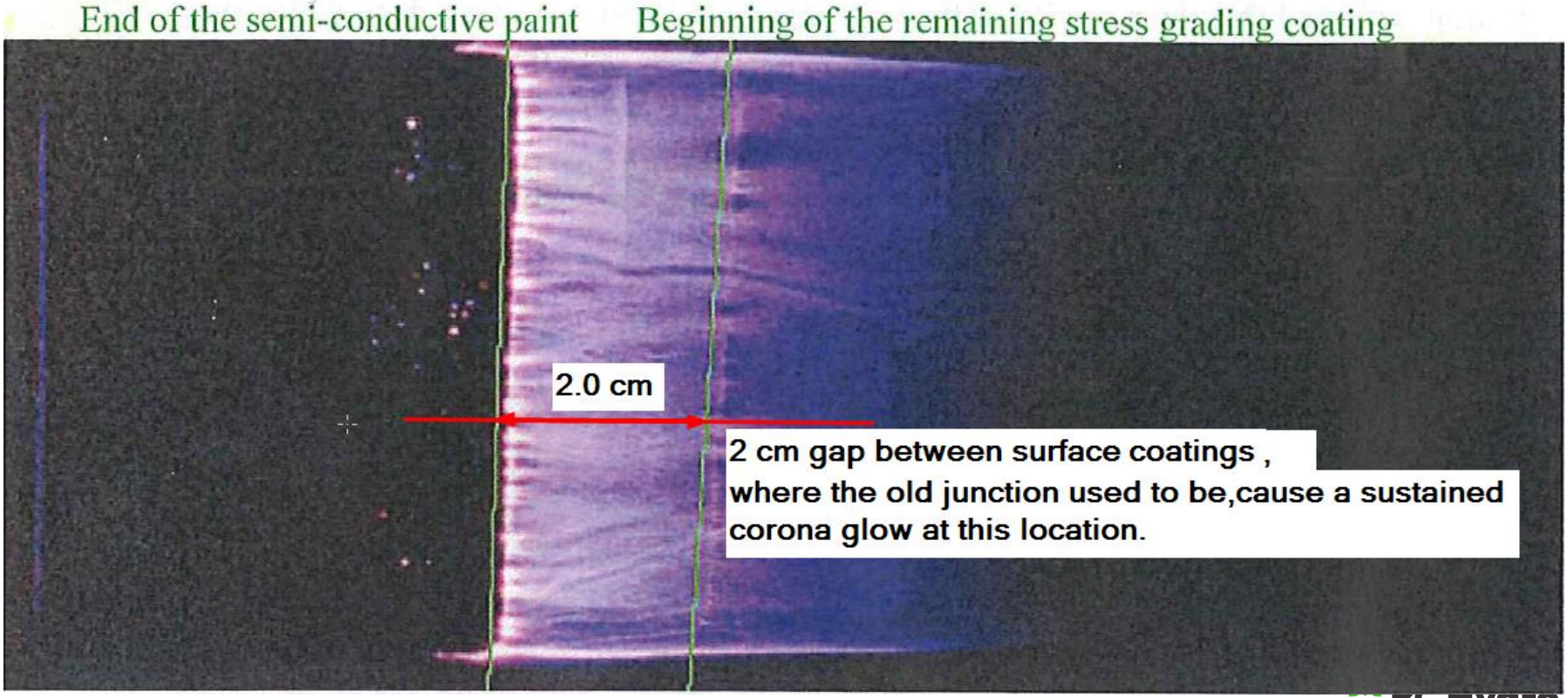
END WINDINGS

Corona discharges
at the abraded junction @ 20 kV

Stator bar in the Lab



Compare to Others - Statistical

High PD		Deterioration
Typical PD		Normal
Low PD		Good winding

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Yellow flag raising

PD Doubling – means it is likely High PD

Significant issue :

+Qm/Qm- >1.5 positive

-Qm/Qm+ >1.5 negative

PD is a symptom of failure mechanisms

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HYDROTRAC II

GMS G3 GENERATOR

RATED AT 321 MVA, 13.8KV, 0.95 PF, 150 RPM

- The stator was replaced and the rotor frame was rehabilitated in 2007 by Alstom Canada.

- The operation is limited to 275 MVA due to the capacity of the generator terminal equipment.

- The stator winding has thermosetting epoxy-mica class F insulation.

GMS G3

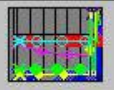
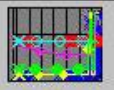
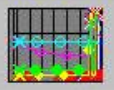
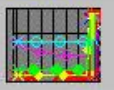
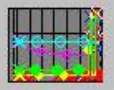
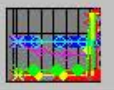
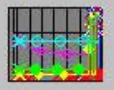
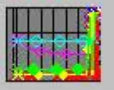
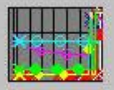
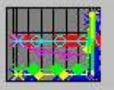
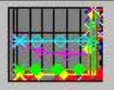
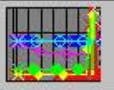
PD ON-LINE MONITORING

GMS U03 - Partial Discharge Signals

Stator Winding MAX Temp	Stator Winding AVG Temp	kV	MW	Mvar	
86 °C	80 °C	13.9	228	-08	

DATA IS OLDER THAN 24 HRS

HydroTracII Measurements:

				C1				C2						
Phase	Pair	Last Measurement Date / Time dd-mmm-yyyy hh:mm:ss	Coupler Pair	+NQN	-NQN	+Qm (mV)	-Qm (mV)	+NQN	-NQN	+Qm (mV)	-Qm (mV)	NQN Signals	QM Signals	Measurement Quality
A	1	3-Apr-2017 16:00:05	A-C1 (T11) -- A-C2 (T16)	0	0	0	0	528	640	488	514			Ok
B	2	3-Apr-2017 16:01:33	B-C1 (T21) -- B-C2 (T26)	676	697	593	559	0	80	0	0			Ok
C	3	3-Apr-2017 16:03:18	C-C1 (T31) -- C-C2 (T36)	545	496	320	340	0	0	0	0			Invalid
A	4	3-Apr-2017 16:05:16	A2-C1 (T12) -- A2-C2 (T15)	430	504	378	373	224	227	189	190			Ok
B	5	3-Apr-2017 16:06:26	B2-C1 (T22) -- B2-C2 (T25)	0	0	0	0	233	246	335	337			Ok
C	6	3-Apr-2017 16:07:37	C2-C1 (T32) -- C2-C2 (T35)	412	424	214	232	0	0	0	0			Ok

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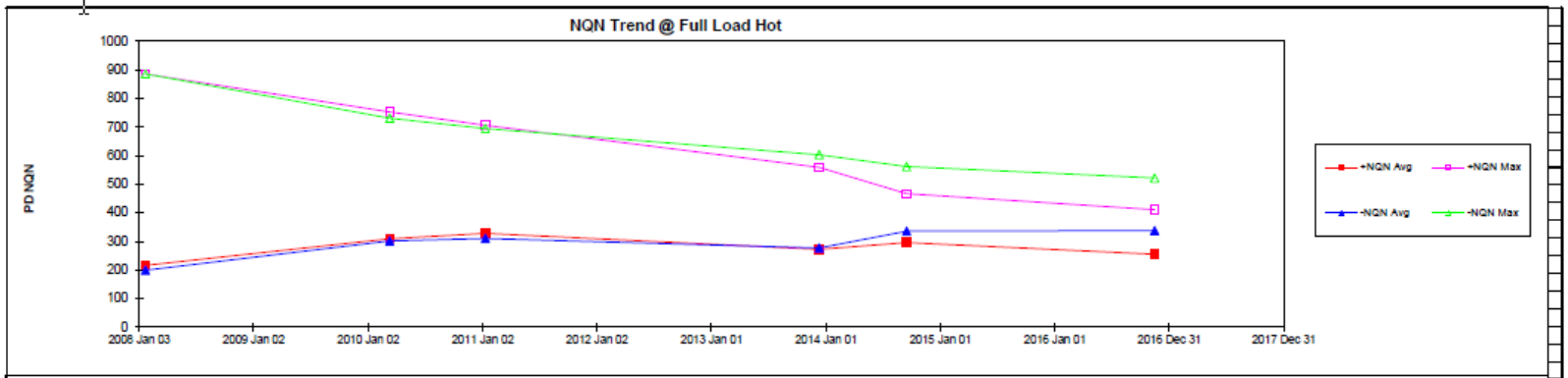
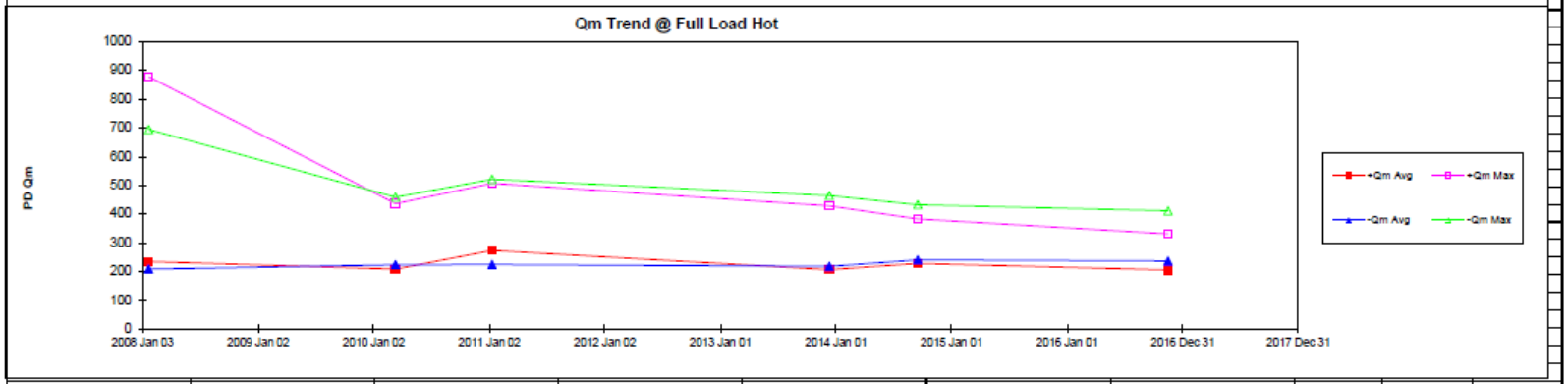
GMS G03 PDA Data





	2008 Jan 23	2010 Mar 12	2011 Jan 11	2013 Dec 11	2014 Sep 16	2016 Nov 15
Test Type	FLH	FLH	FLH	FLH	FLH	FLH
MW	249	260	251	254	254.8	271
MVar	-3	-22	0	5	-26.94	3.26
MVA	249.0	260.9	251.0	254.0	256.2	271.0
kV	13.8	13.6	13.9	13.8	13.5	13.9
kA	10.4	11.1	10.4	10.6	11.0	11.3
Winding °C	73	94	90	58	77	92.2
%RH	22.5	22	22.4	23	n/a	n/a
Ambient °C	15	18	16	18	n/a	n/a

	2008 Jan 23	2010 Mar 12	2011 Jan 11	2013 Dec 11	2014 Sep 16	2016 Nov 15
+NQN Avg	216	309	328	273	297	255
+NQN Max	886	753.4	707	559	467	411
-NQN Avg	199	302	310	277	336	338
-NQN Max	886	731.2	695	603.5	562	522

	2008 Jan 23	2010 Mar 12	2011 Jan 11	2013 Dec 11	2014 Sep 16	2016 Nov 15
+Qm Avg	234	208	273	206	227	206
+Qm Max	878	436	507	428	383	331
-Qm Avg	208	223	224	217	240	236
-Qm Max	694	459	521	464	432	411

SEQUENTIAL LISTING OF BARS

T= TOP BAR
B= BOTTOM BAR

CIRCUIT #																	NEUTRAL
1	78B	67T	77B	66T	76B	65T ■	75B	64T	51T	62B	52T	63B	53T	64B	54T	65B ■	53B	A
	42T	52B	41T	51B	40T	50B	39T	49B	38T	26T	37B	27T	38B	28T	39B	29T	40B	
	27B	16T	26B	15T	25B	14T ■	24B	13T	612T	11B	1T	12B	2T	13B	3T	14B ■	2B	
	603T	1B	602T	612B	601T	611B	600T	610B	599T	587T	598B	588T	599B	589T	600B	590T	601B	
2	180B	169T	179B	168T	178B	167T ■	177B	166T	153T	184B	154T	165B	155T	166B	156T	167B ■	155B	
	144T	154B	143T	153B	142T	152B	141T	151B	140T	128T	139B	129T	140B	130T	141B	131T	142B	
	129B	118T	128B	117T	127B	116T ■	126B	115T	102T	113B	103T	114B	104T	115B	105T	116B ■	104B	
	93T	103B	92T	102B	91T	101B	90T	100B	89T	77T	88B	78T	89B	79T	90B	80T	91B	
3	282B	271T	281B	270T	280B	269T ■	279B	268T	255T	266B	256T	267B	257T	268B	258T	269B ■	257B	
	246T	256B	245T	255B	244T	254B	243T	253B	242T	230T	241B	231T	242B	232T	243B	233T	244B	
	231B	220T	230B	219T	229B	218T ■	228B	217T	204T	215B	205T	216B	206T	217B	207T	218B ■	206B	
	195T	205B	194T	204B	193T	203B	192T	202B	191T	179T	190B	180T	191B	181T	192B	182T	193B	
4	384B	373T	383B	372T	382B	371T ■	381B	370T	357T	368B	358T	369B	359T	370B	360T	371B ■	359B	
	348T	358B	347T	357B	346T	356B	345T	355B	344T	332T	343B	333T	344B	334T	345B	335T	346B	
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	450T	460B	449T	459B	448T	458B	447T	457B	446T	434T	445B	435T	446B	436T	447B	437T	448B	
	435B	424T	434B	423T	433B	422T ■	432B	421T	408T	419B	409T	420B	410T	421B	411T	422B ■	410B	
	399T	409B	398T	408B	397T	407B	396T	406B	395T	383T	394B	384T	395B	385T	396B	386T	397B	
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	537B	526T	536B	525T	535B	524T ■	534B	523T	510T	521B	511T	522B	512T	523B	513T	524B ■	512B	
	501T	511B	500T	510B	499T	509B	498T	508B	497T	485T	496B	486T	497B	487T	498B	488T	499B	
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	74B	61B	50T	60B	49T	59B	48T ■	58B	47T	34T	45B	35T	46B	36T	47B	37T	48B ■	
	36B	25T	35B	24T	34B	23T	33B	22T	32B	21T	9T	20B	10T	21B	11T	22B	12T	
	23B	10B	611T	9B	610T	8B	609T ■	7B	608T	595T	606B	596T	607B	597T	608B	598T	609B ■	
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	138B	127T	137B	126T	136B	125T	135B	124T	134B	123T	111T	122B	112T	123B	113T	124B	114T	
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	278B	265B	254T	264B	253T	263B	252T ■	262B	251T	238T	249B	239T	250B	240T	251B	241T	252B ■	
	240B	229T	239B	228T	238B	227T	237B	226T	236B	225T	213T	224B	214T	225B	215T	226B	216T	
	227B	214B	203T	213B	202T	212B	201T ■	211B	200T	187T	198B	188T	199B	189T	200B	190T	201B ■	
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	380B	367B	356T	366B	355T	365B	354T ■	364B	353T	340T	351B	341T	352B	342T	353B	343T	354B ■	
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	57B	44B	33T	43B	32T	42B	31T ■	41B	30T	17T	28B	18T	29B	19T	30B	20T	31B ■	
	19B	8T	18B	7T	17B	6T	16B	5T	15B	4T	604T	3B	605T	4B	606T	5B	607T	
	6B	605B	594T	604B	593T	603B	592T ■	602B	591T	578T	589B	579T	590B	580T	591B	581T	592B ■	
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	159B	146B	135T	145B	134T	144B	133T ■	143B	132T	119T	130B	120T	131B	121T	132B	122T	133B ■	
	121B	110T	120B	109T	119B	108T	118B	107T	117B	106T	94T	105B	95T	106B	96T	107B	97T	
	108B	95B	84T	94B	83T	93B	82T ■	92B	81T	68T	79B	69T	80B	70T	81B	71T	82B ■	
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	261B	248B	237T	247B	236T	246B	235T ■	245B	234T	221T	232B	222T	233B	223T	234B	224T	235B ■	
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	363B	350B	339T	349B	338T	348B	337T ■	347B	336T	323T	334B	324T	335B	325T	336B	326T	337B ■	
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	427B	416T	426B	415T	425B	414T	424B	413T	423B	412T	400T	411B	401T	412B	402T	413B	403T	
	414B	401B	390T	400B	389T	399B	388T ■	398B	387T	374T	385B	375T	386B	376T	387B	377T	388B ■	
6	580B	569T	579B	568T	578B	567T	577B	566T	576B	565T	553T	564B	554T	565B	555T	566B	556T	
	567B	554B	543T	553B	542T	552B	541T ■	551B	540T	527T	538B	528T	539B	529T	540B	530T	541B ■	
	529B	518T	528B	517T	527B	516T	526B	515T	525B	514T	502T	513B	503T	514B	504T	515B	505T	
	516B	503B	492T	502B	491T	501B	490T ■	500B	489T	476T	487B	477T	488B	478T	489B	479T	490B ■	

13.8 kV machines
Distribution of Qm on the terminals :
25% - 35 mV
50% - 93 mV
75% - 193 mV
90% - 376 mV
95% - 561 mV

■ ADJAC

High PD circuits and their line-end stator bars (6 bars ,i.e.10% of the circuit)require visual inspection.

Circuits indicated YELLOW have PD exceed 90% percentile (i.e. Qm > 376 mV) that cou suggest the winding is significantly deteriora (as per IRIS Database).

BC hydro

Contract No. Q5-5375

ACCEPTED

This review was for observing general conformity to the contract only. BC Hydro accepts no legal responsibility for the content, accuracy or completeness of this document even if it has been accepted with or without revision based on BC Hydro's observations.

By: Rudy Goldberg
Hydro's Representative

Date: 3:48 pm, Dec 01, 2011

AS BUILT

ALSTOM

"AS-BUILT" INDICATES THAT THIS DRAWING WAS UPDATED TO REFLECT CHANGES DURING INSTALLATION.

ITEM	QTY.	SPARE	DESCRIPTION

MATERIAL REQUIRED FOR: 1 UNIT

GM SHRUM GENERATING STATION

POWERHOUSE – UNITS G1, G2, G3,
GENERATOR
STATOR
STATOR WINDING DIAGRAM

Contract No.	Dist. Code	DWG No.
Q5-5375	7	CAD 100

DIMENSIONS ARE IN MILLIMETI

THIRD ANGLE PROJECTION

INGÉNIEUR - ENGINEER
François Drouin
35930

A

REPLAC

P01: Contamination on bottom end winding

P02: Contamination on bottom end winding

P03: A washer found between front and back bar in slot 245

P04: The washer and burn marks possible due to pd between the bars

P05: Sections of circuit ring bus discolored

P06: Sections of circuit ring bus discolored – Neutral Side

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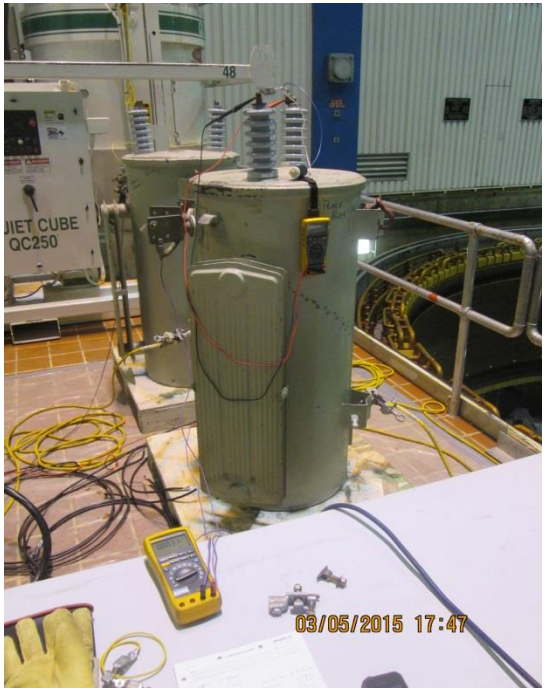
GMS G3 Corona Probe Test setup



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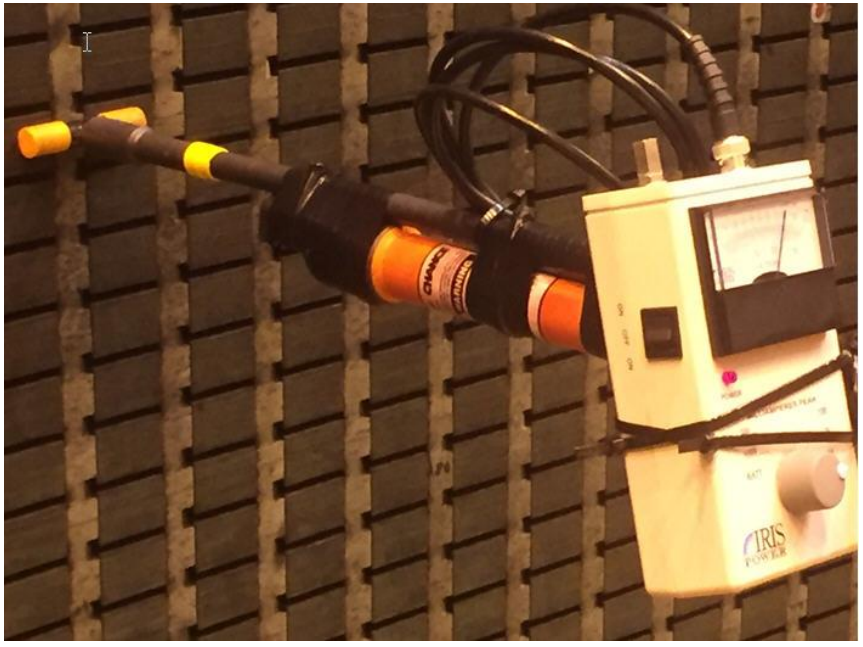
GMS G3 Corona Probe Test



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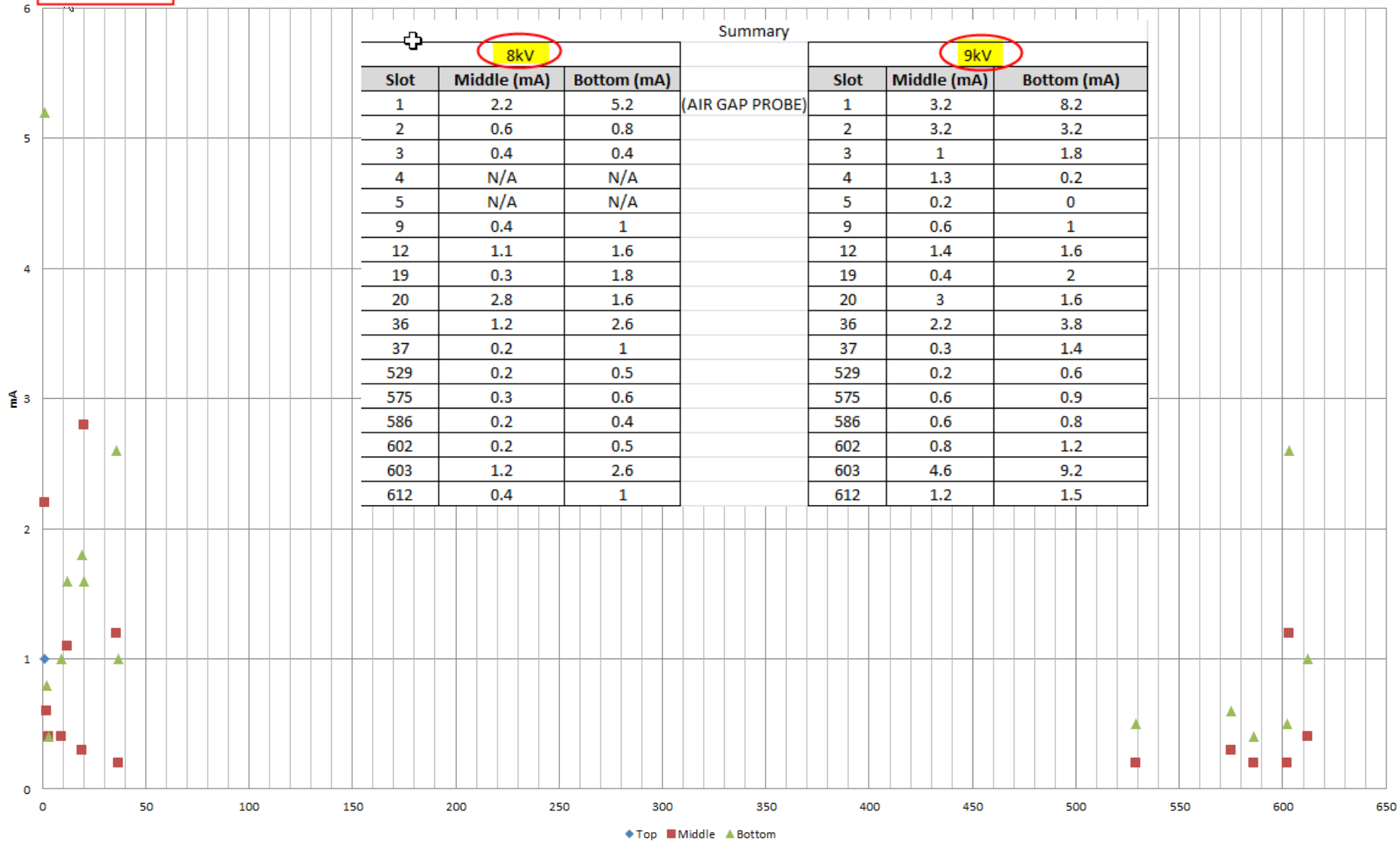
GMS G3

Corona Probe Test Result 2015

Summary

8kV				9kV		
Slot	Middle (mA)	Bottom (mA)		Slot	Middle (mA)	Bottom (mA)
1	2.2	5.2	(AIR GAP PROBE)	1	3.2	8.2
2	0.6	0.8		2	3.2	3.2
3	0.4	0.4		3	1	1.8
4	N/A	N/A		4	1.3	0.2
5	N/A	N/A		5	0.2	0
9	0.4	1		9	0.6	1
12	1.1	1.6		12	1.4	1.6
19	0.3	1.8		19	0.4	2
20	2.8	1.6		20	3	1.6
36	1.2	2.6		36	2.2	3.8
37	0.2	1		37	0.3	1.4
529	0.2	0.5		529	0.2	0.6
575	0.3	0.6		575	0.6	0.9
586	0.2	0.4		586	0.6	0.8
602	0.2	0.5		602	0.8	1.2
603	1.2	2.6		603	4.6	9.2
612	0.4	1		612	1.2	1.5



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Conclusions after Corona Probe Test

Corona Scope and Black Out tests

GMS G3

Corona Scope stator end-winding test was performed at different voltage steps: 4.0 to 9.0 kV and Black Out test was performed at 9.0 kV to ground. Both tests showed no PD activity except very little PD discharge at the end-portion of the winding in a few spots only. The Apparatus testers will provide a chart for these tests at a later date.

Conclusions

Based on the currently obtained off-line test results, it is not possible to conclude with good accuracy which bar to remove for dissection on this particular machine. It could be one of the top 10% line-end bars in Phase A circuits: T1-3,T1-4,T1-6 ; or in Phase B circuits: T2-5,T2-6 ; or in Phase C circuit: T3-1. All of these circuits experience high PD activity during on-line operation but show very low or no PD activity during off-line testing. More investigation, including thorough top-end winding visual inspection (by erecting scaffolding or inspecting with the rotor in place) and generator on-line testing is required to make a conclusive recommendation for which bar to remove.

GMS G3

APPENDIX 1

GMS G3 on-line and off-line PD activity plots for most high PD activity circuits.

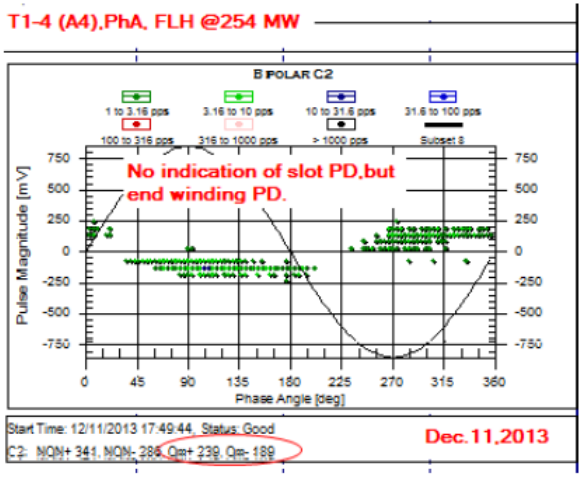

Fig. 1 PD on-line test of circuit T1-4 at 254 MW, FLH

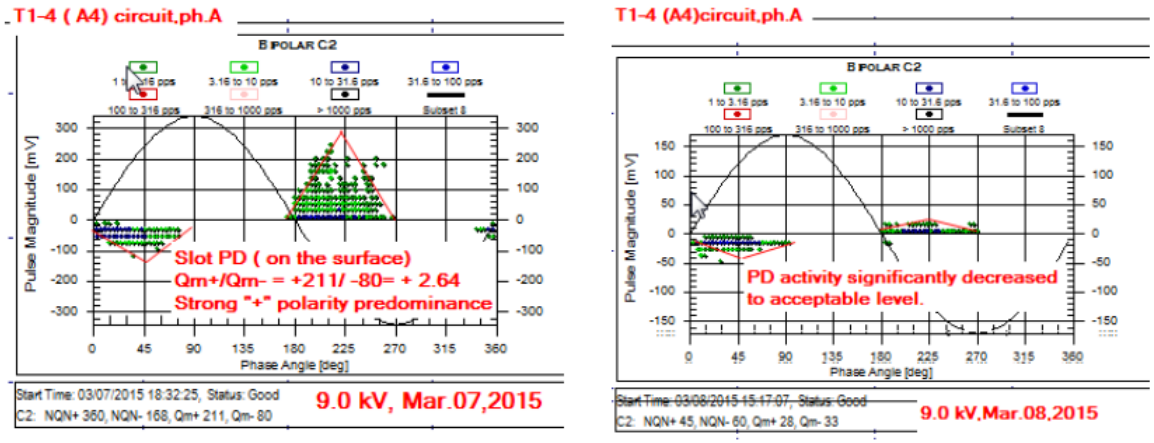

Fig.2 PD Off-line test of the same T1-4 (A4) circuit : On March 07 and March 08
(Notice the diference in PD magnitude of the tests taken on March 07 and March 08)

(Qm+) decreased from 211 mV to 28 mV
(Qm-) decreased from 80 mV to 33 mV

Note : Test conditions and winding setup were the same during both days of testing.

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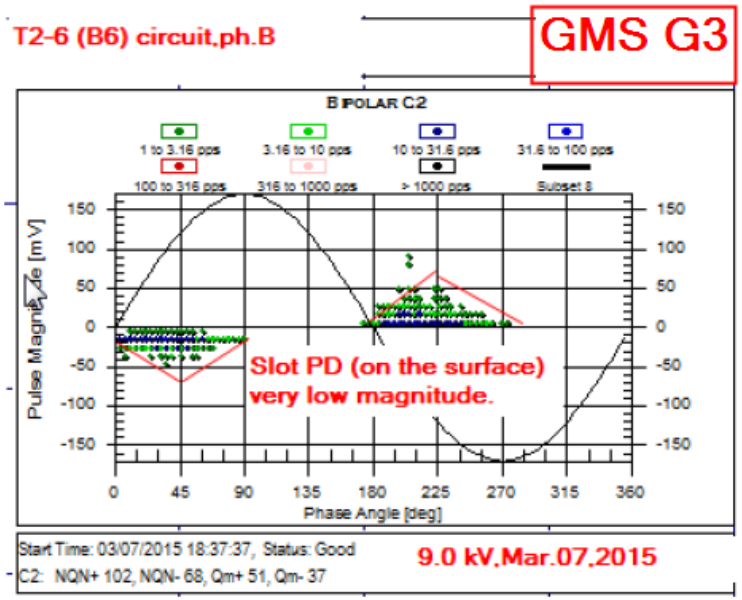

Fig. 3 PD off-line test of circuit **T2-6 (B6)** at 9.0 kV on March 07, 2015

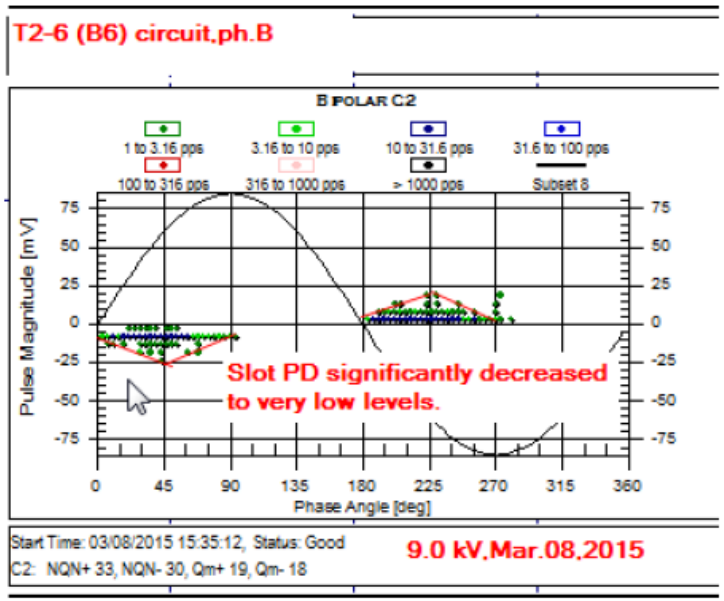

Fig. 4 PD off-line test of circuit **T2-6 (B6)** at 9.0 kV on March 08, 2015
(notice the diference in PD magnitude compared to the March 08, 2015 test)

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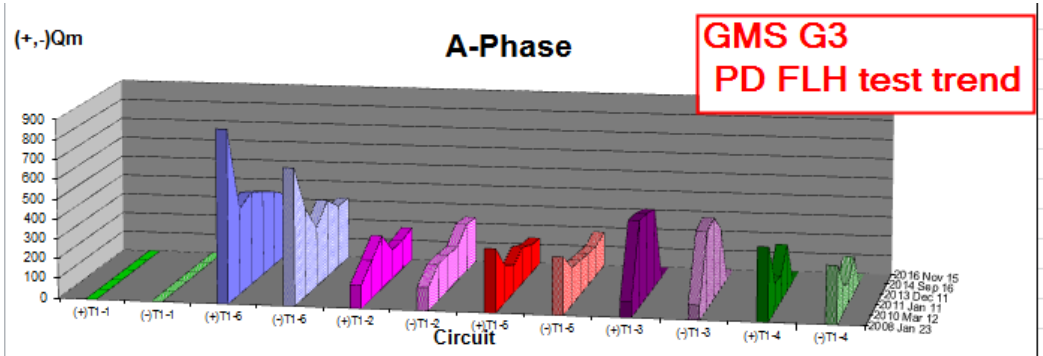
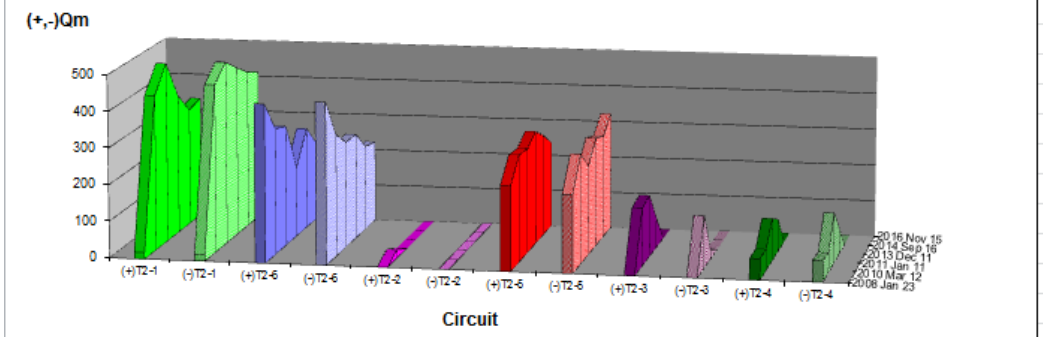
GMS G3
PD FLH test trend

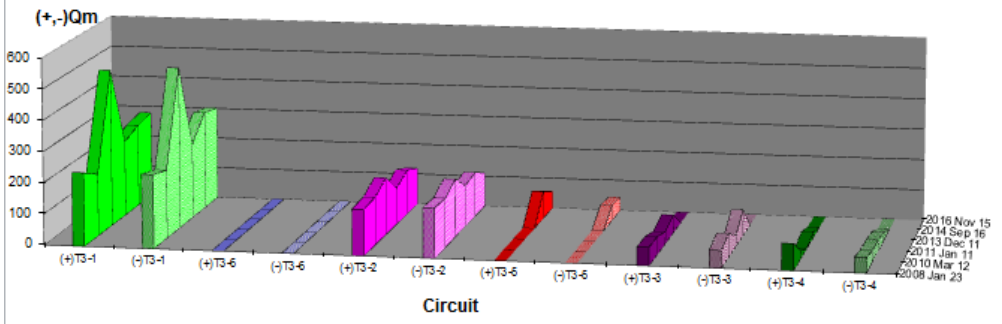
A-Phase



B-Phase



C-Phase



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REV G4

Partial Discharge Investigation

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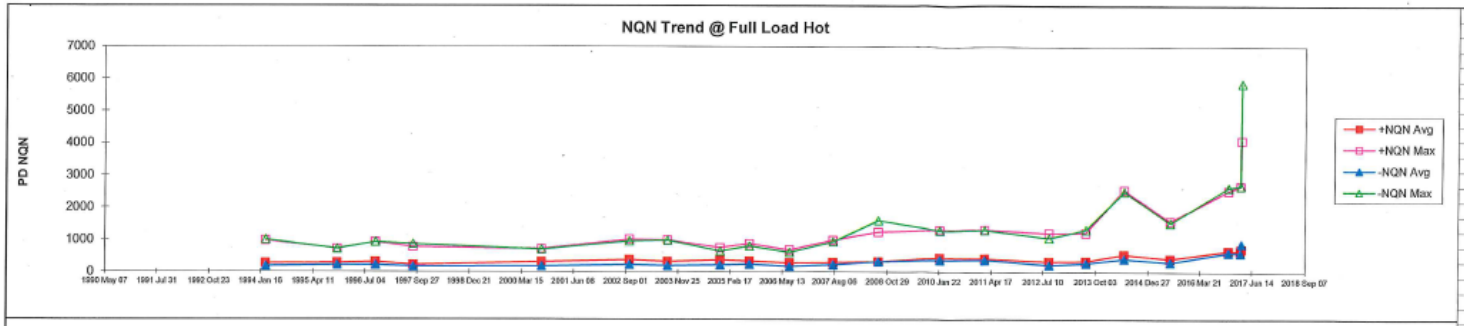
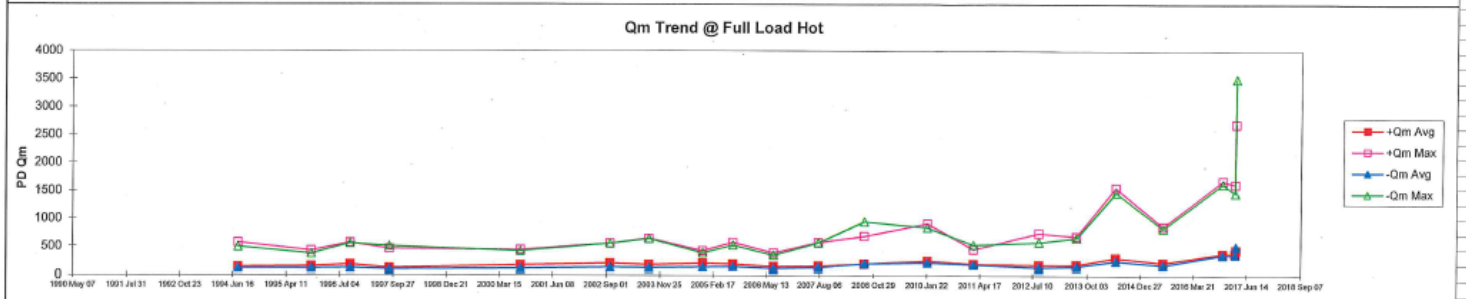
REV G4 PD Trend

REV G04 PDA Data





	1994 Mar 02	1995 Nov 07	1996 Oct 02	1997 Aug 25	2000 Sep 06	2002 Oct 01	2003 Aug 26	2004 Nov 22	2005 Aug 04	2006 Jul 12	2007 Jul 24	2008 Aug 13	2010 Jan 27	2011 Feb 18	2012 Aug 29	2013 Jul 09	2014 Jun 05	2015 Jul 09	2016 Nov 24	2017 Mar 09	2017 Mar 16
Test Type	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	FLH	356 MW
MW	300	425	400	450	492	465	459	478	465	499	497	495	461	0	496	488	475	499	485	485	356
MVar	-60	5	-5	-20	14	3	-4	50	-3	-9	12.5	30	-103	77	-45	112	30	45	-39	7	-25.8
MVA	305.9	425.0	400.0	450.4	492.2	465.0	459.0	480.6	465.0	499.1	497.2	495.9	472.4	77.0	498.0	500.7	475.9	501.0	486.6	485.1	356.9
kV	16.5	16.5	16.5	16.4	16.4	16.2	16.0	16.5	15.9	16.2	16.2	16.4	15.9	16.4	15.8	16.7	16.1	16.2	16.0	16.2	16.3
kA	10.7	14.9	14.0	15.9	17.3	16.6	16.6	16.8	16.9	17.8	17.7	17.5	17.2	2.7	18.2	17.3	17.1	17.9	17.6	17.3	12.7
Winding °C	52	67	62	66	73	75	75	77	75	77	72	77	24	77	73	78	72	78	77	72	55.6
%RH	42	10	38	50	48	32	54	23	44	58	48	50	15.9	19	49	46	50	44	n/a	n/a	n/a
Ambient °C	21				19.6	21	20.8	22	21	20	21	21	24	21	24	22	22	24	n/a	n/a	n/a

	1994 Mar 02	1995 Nov 07	1996 Oct 02	1997 Aug 25	2000 Sep 06	2002 Oct 01	2003 Aug 26	2004 Nov 22	2005 Aug 04	2006 Jul 12	2007 Jul 24	2008 Aug 13	2010 Jan 27	2011 Feb 18	2012 Aug 29	2013 Jul 09	2014 Jun 05	2015 Jul 09	2016 Nov 24	2017 Mar 09	2017 Mar 16
+NQN Avg	267	283	312	220	311	374	321	372	344	282	301	331	442	416	331	341	547	413	663	654	712
+NQN Max	977	720	924	772	715	1012	989	754	881	682	991	1247	1309.4	1318	1213.1	1223.1	2551.1	1583	2525	2672	4088
-NQN Avg	182	215	216	171	179	227	194	219	244	179	230	329	375	376	224	281	416	307	607	595	876
-NQN Max	1001	715	928	866	696	958	980	643	802	610	941	1608	1284.7	1306.4	1062.8	1323	2495.2	1529	2630	2682	5859

	1994 Mar 02	1995 Nov 07	1996 Oct 02	1997 Aug 25	2000 Sep 06	2002 Oct 01	2003 Aug 26	2004 Nov 22	2005 Aug 04	2006 Jul 12	2007 Jul 24	2008 Aug 13	2010 Jan 27	2011 Feb 18	2012 Aug 29	2013 Jul 09	2014 Jun 05	2015 Jul 09	2016 Nov 24	2017 Mar 09	2017 Mar 16
+Qm Avg	139	150	182	122	171	202	180	203	188	143	154	192	248	192	177	180	301	213	378	380	441
+Qm Max	571	427	568	463	442	556	644	423	574	387	572	686	915	451	742	683	1557	862	1678	1618	2695
-Qm Avg	114	113	121	101	111	131	126	137	144	110	130	195	216	181	133	151	244	173	358	366	507
-Qm Max	493	373	557	509	421	555	640	386	522	345	564	947	839	534	580	657	1468	825	1625	1460	3500

2016 IRIS PD Database

Qm values for air-cooled machines with differential capacitive couplers (PDA)

Rated V	6-9kV	10-12kV	13-15kV	16-18kV	> 19kV	
25%	12	20	34	23	90	25% of the results have Qm levels below this value
50%	33	50	88	81	176	50% of the results have Qm levels below this value
75%	66	112	190	222	659	75% of the results have Qm levels below this value
90%	172	240	364	557	857	90% of the results have Qm levels below this value
95%	315	385	530	729	993	95% of the results have Qm levels below this value

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REV G4 PD plots

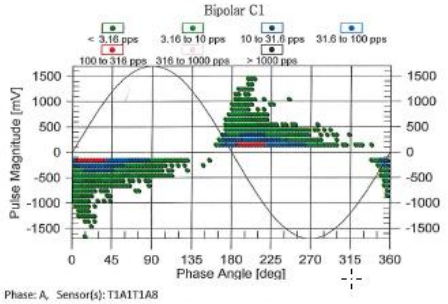
Off-line

Pulse Phase Analysis (PRPD, no phase shift) Apr.11-13,2017

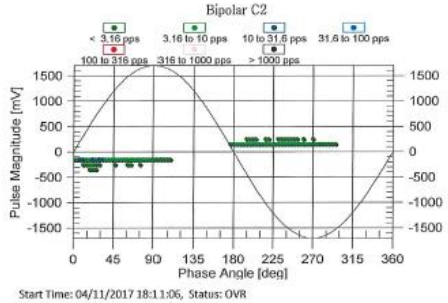
Asset Name: G4 (Off-line) 10.0 kV

Folder: BCH\REV\, Asset Class: Hydro Generator, Serial Number:
Class: PDA, Sensor Type: Epoxy Mica Capacitor (80pF)

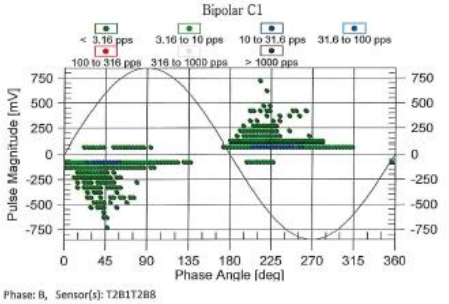
Operating Load: N/A, Reactive Load: N/A, Operating Asset Temp: 19 deg C, Operating Voltage: 10.00 kV
Ambient Temp: 19 deg C, Ambient Humidity: 18.00 % Freq. (Test Duration): 60 Hz, (5 sec.)



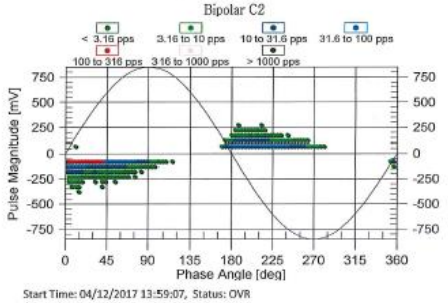
Phase: A, Sensor(s): T1A1T1A8
C1: NQN+2240/-2239, Qm+1074/-1088 K-scale: 1.00



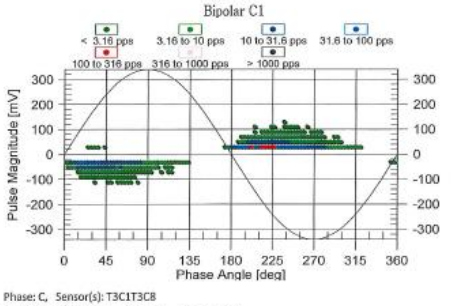
Start Time: 04/11/2017 18:11:06, Status: OVR
C2: NQN+358/-428, Qm+238/-265



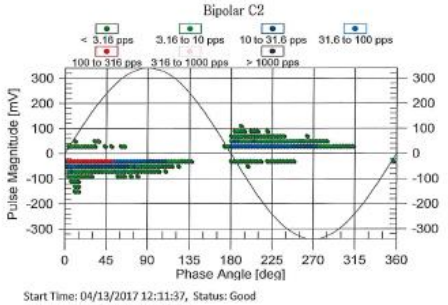
Phase: B, Sensor(s): T2B1T2B8
C1: NQN+677/-749, Qm+292/-413 K-scale: 1.00



Start Time: 04/12/2017 13:59:07, Status: OVR
C2: NQN+443/-601, Qm+218/-282



Phase: C, Sensor(s): T3C1T3C8
C1: NQN+213/-200, Qm+99/-101 K-scale: 1.00



Start Time: 04/13/2017 12:11:37, Status: Good
C2: NQN+164/-237, Qm+82/-104

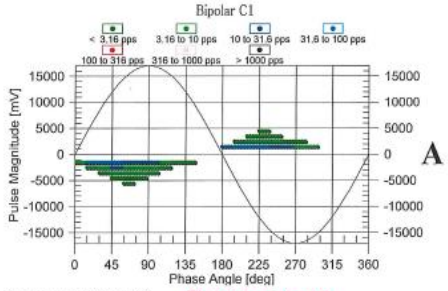
On-line

Pulse Phase Analysis (PRPD, rotation:ABC) Mar.16,2017

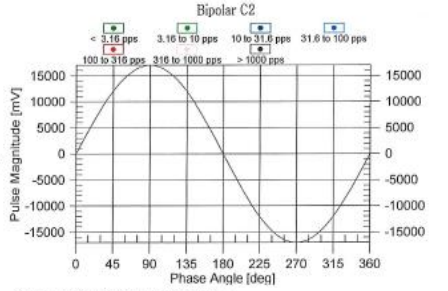
Asset Name: REV G04 356 MW

Folder: REV G.S.\, Asset Class: Hydro Generator, Serial Number:
Class: HydroTrac II, Sensor Type: Epoxy Mica Capacitor (80pF)

Operating Load: 356.0MW, Reactive Load: -37.0 MVAr, Operating Asset Temp: 46.5 deg C, Operating Voltage: 15.89 kV
Ambient Temp: N/A, Ambient Humidity: 0.00 % Freq. (Test Duration): 59 Hz, (5 sec.)

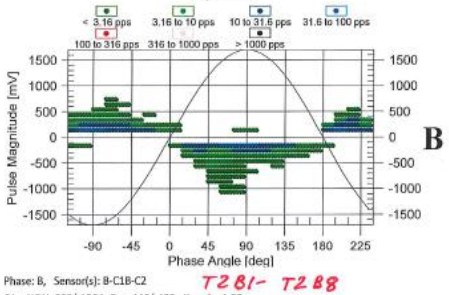


Phase: A, Sensor(s): A-C1A-C2 T1-A1, T1-A8
C1: NQN+4088/-5859, Qm+2695/-3500 K-scale: 1.00

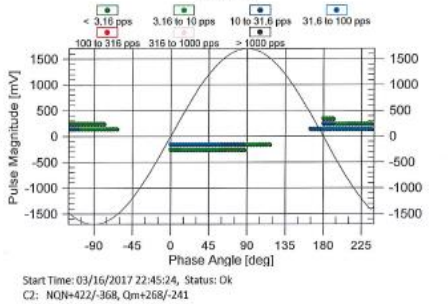


Start Time: 03/16/2017 10:15:19, Status: Ok
C2: NQN+0/-0, Qm+0/-0

A

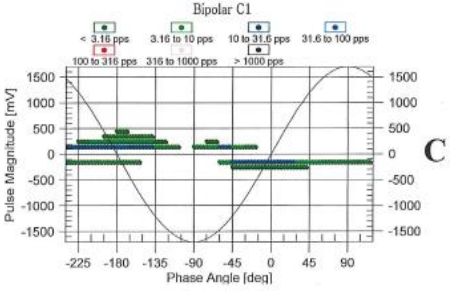


Phase: B, Sensor(s): B-C1B-C2 T2B1- T2B8
C1: NQN+808/-1064, Qm+446/-483 K-scale: 1.00

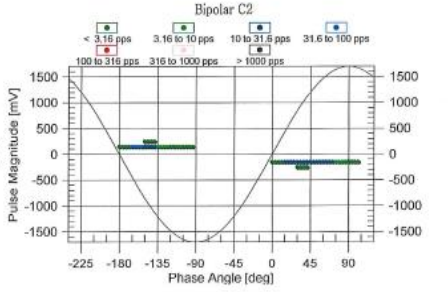


Start Time: 03/16/2017 22:45:24, Status: Ok
C2: NQN+422/-368, Qm+268/-241

B



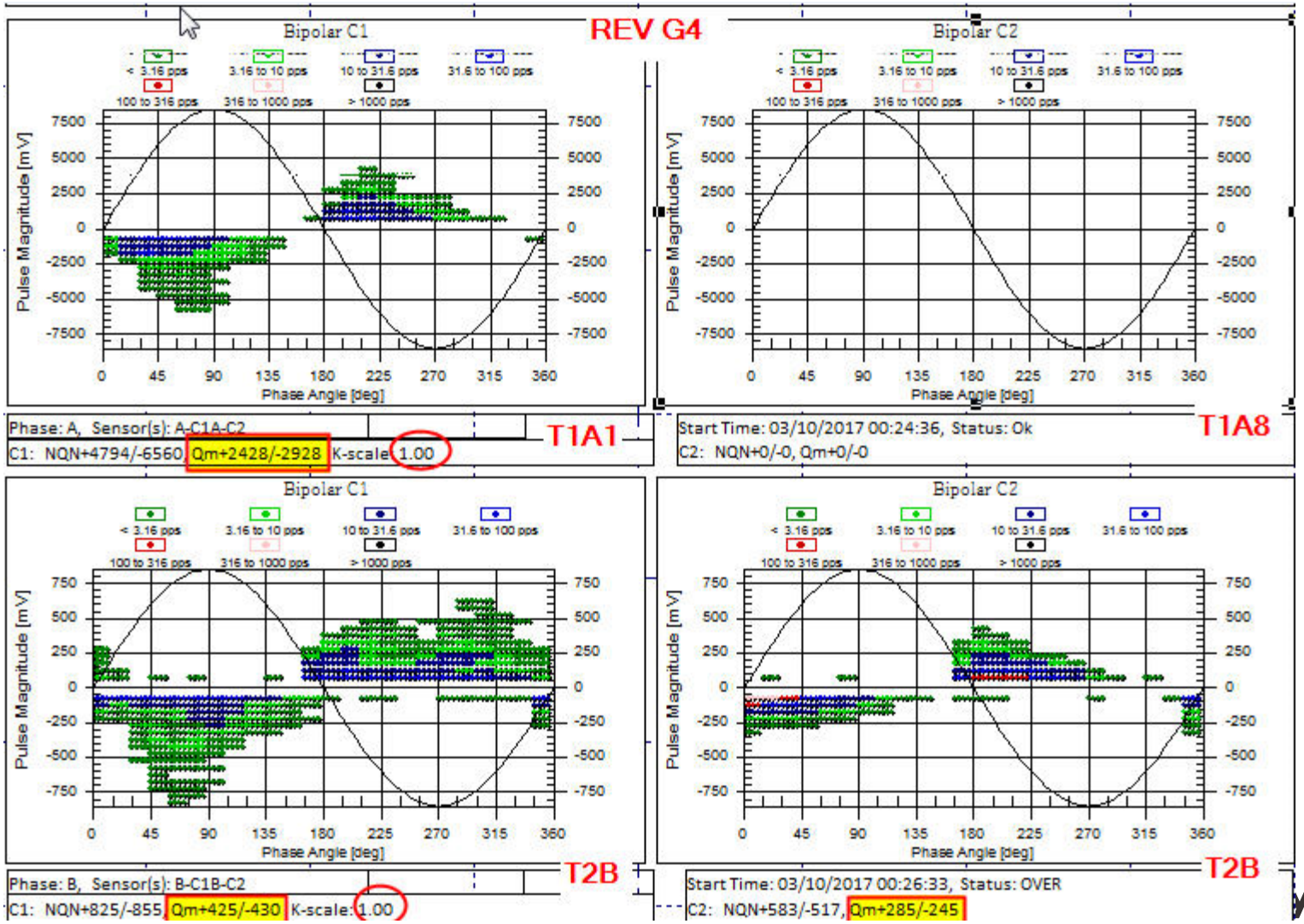
Phase: C, Sensor(s): C-C1C-C2 T3-C1, T3-C8
C1: NQN+444/-289, Qm+281/-197 K-scale: 1.00



Start Time: 03/16/2017 09:25:42, Status: Ok
C2: NQN+181/-195, Qm+185/-189

C

REV G4 - PD test plots



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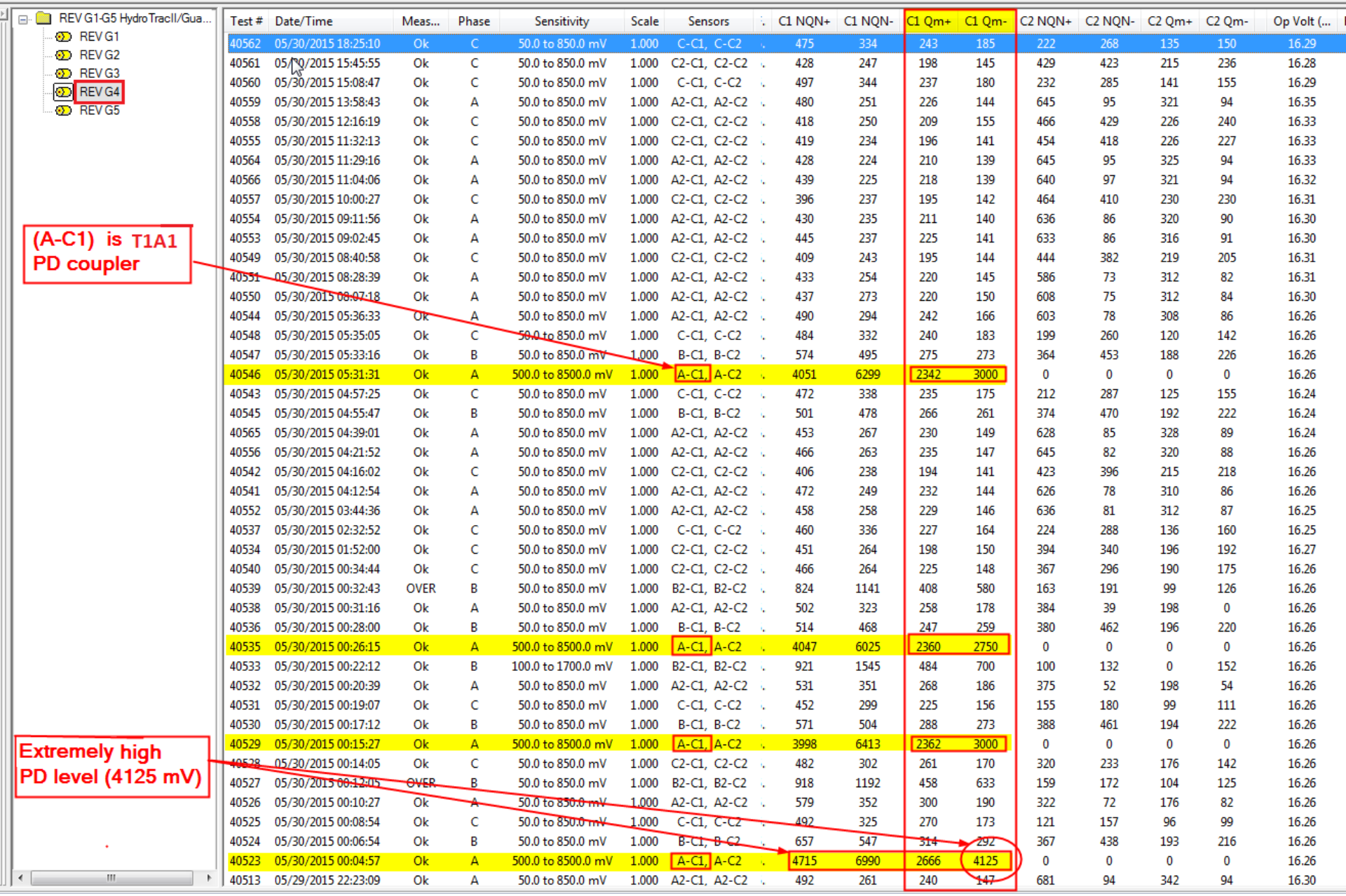
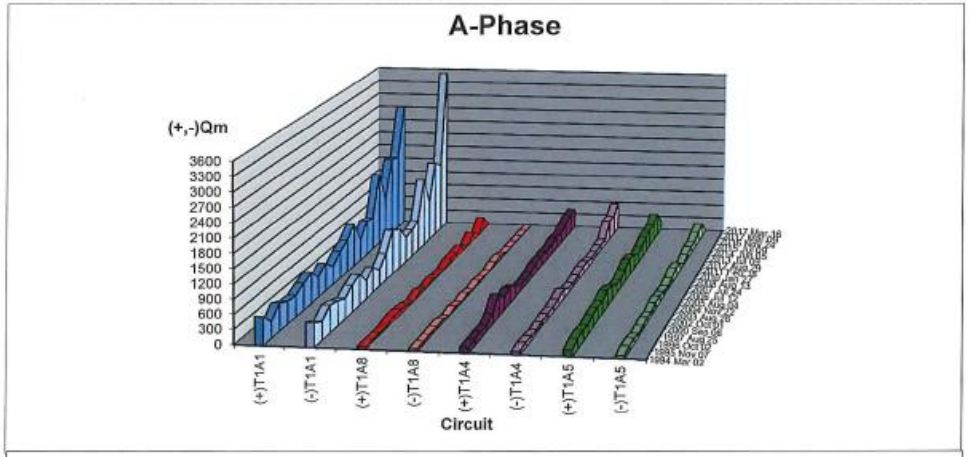
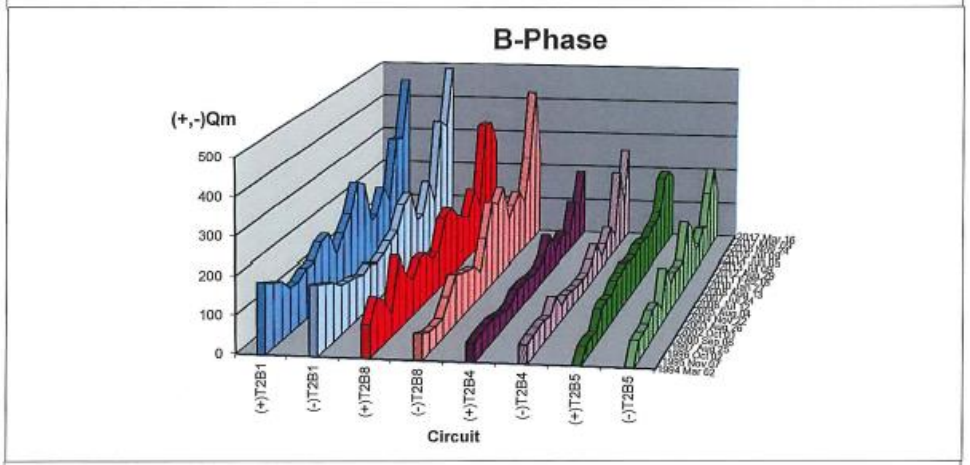
REV G4 PDMS (PD on-line Monitoring System)

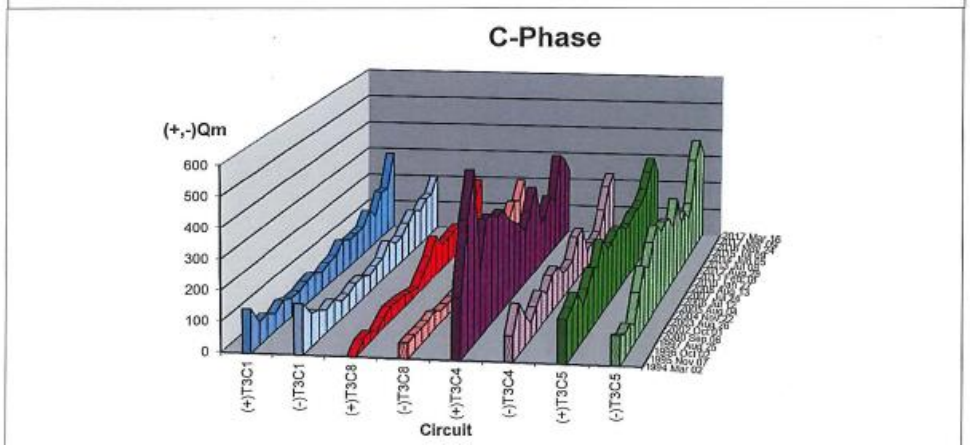


Test #	Date/Time	Meas...	Phase	Sensitivity	Scale	Sensors	C1 NQN+	C1 NQN-	C1 Qm+	C1 Qm-	C2 NQN+	C2 NQN-	C2 Qm+	C2 Qm-	Op Volt (...
40562	05/30/2015 18:25:10	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	475	334	243	185	222	268	135	150	16.29
40561	05/30/2015 15:45:55	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	428	247	198	145	429	423	215	236	16.28
40560	05/30/2015 15:08:47	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	497	344	237	180	232	285	141	155	16.29
40559	05/30/2015 13:58:43	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	480	251	226	144	645	95	321	94	16.35
40558	05/30/2015 12:16:19	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	418	250	209	155	466	429	226	240	16.33
40555	05/30/2015 11:32:13	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	419	234	196	141	454	418	226	227	16.33
40564	05/30/2015 11:29:16	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	428	224	210	139	645	95	325	94	16.33
40566	05/30/2015 11:04:06	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	439	225	218	139	640	97	321	94	16.32
40557	05/30/2015 10:00:27	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	396	237	195	142	464	410	230	230	16.31
40554	05/30/2015 09:11:56	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	430	235	211	140	636	86	320	90	16.30
40553	05/30/2015 09:02:45	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	445	237	225	141	633	86	316	91	16.30
40549	05/30/2015 08:40:58	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	409	243	195	144	444	382	219	205	16.31
40551	05/30/2015 08:28:39	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	433	254	220	145	586	73	312	82	16.31
40550	05/30/2015 08:07:18	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	437	273	220	150	608	75	312	84	16.30
40544	05/30/2015 05:36:33	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	490	294	242	166	603	78	308	86	16.26
40548	05/30/2015 05:35:05	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	484	332	240	183	199	260	120	142	16.26
40547	05/30/2015 05:33:16	Ok	B	50.0 to 850.0 mV	1.000	B-C1, B-C2	574	495	275	273	364	453	188	226	16.26
40546	05/30/2015 05:31:31	Ok	A	500.0 to 8500.0 mV	1.000	A-C1, A-C2	4051	6299	2342	3000	0	0	0	0	16.26
40543	05/30/2015 04:57:25	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	472	338	235	175	212	287	125	155	16.24
40545	05/30/2015 04:55:47	Ok	B	50.0 to 850.0 mV	1.000	B-C1, B-C2	501	478	266	261	374	470	192	222	16.24
40565	05/30/2015 04:39:01	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	453	267	230	149	628	85	328	89	16.24
40556	05/30/2015 04:21:52	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	466	263	235	147	645	82	320	88	16.26
40542	05/30/2015 04:16:02	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	406	238	194	141	423	396	215	218	16.26
40541	05/30/2015 04:12:54	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	472	249	232	144	626	78	310	86	16.26
40552	05/30/2015 03:44:36	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	458	258	229	146	636	81	312	87	16.25
40537	05/30/2015 02:32:52	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	460	336	227	164	224	288	136	160	16.25
40534	05/30/2015 01:52:00	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	451	264	198	150	394	340	196	192	16.27
40540	05/30/2015 00:34:44	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	466	264	225	148	367	296	190	175	16.26
40539	05/30/2015 00:32:43	OVER	B	50.0 to 850.0 mV	1.000	B2-C1, B2-C2	824	1141	408	580	163	191	99	126	16.26
40538	05/30/2015 00:31:16	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	502	323	258	178	384	39	198	0	16.26
40536	05/30/2015 00:28:00	Ok	B	50.0 to 850.0 mV	1.000	B-C1, B-C2	514	468	247	259	380	462	196	220	16.26
40535	05/30/2015 00:26:15	Ok	A	500.0 to 8500.0 mV	1.000	A-C1, A-C2	4047	6025	2360	2750	0	0	0	0	16.26
40533	05/30/2015 00:22:12	Ok	B	100.0 to 1700.0 mV	1.000	B2-C1, B2-C2	921	1545	484	700	100	132	0	152	16.26
40532	05/30/2015 00:20:39	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	531	351	268	186	375	52	198	54	16.26
40531	05/30/2015 00:19:07	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	452	299	225	156	155	180	99	111	16.26
40530	05/30/2015 00:17:12	Ok	B	50.0 to 850.0 mV	1.000	B-C1, B-C2	571	504	288	273	388	461	194	222	16.26
40529	05/30/2015 00:15:27	Ok	A	500.0 to 8500.0 mV	1.000	A-C1, A-C2	3998	6413	2362	3000	0	0	0	0	16.26
40528	05/30/2015 00:14:05	Ok	C	50.0 to 850.0 mV	1.000	C2-C1, C2-C2	482	302	261	170	320	233	176	142	16.26
40527	05/30/2015 00:12:05	OVER	B	50.0 to 850.0 mV	1.000	B2-C1, B2-C2	918	1192	458	633	159	172	104	125	16.26
40526	05/30/2015 00:10:27	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	579	352	300	190	322	72	176	82	16.26
40525	05/30/2015 00:08:54	Ok	C	50.0 to 850.0 mV	1.000	C-C1, C-C2	492	325	270	173	121	157	96	99	16.26
40524	05/30/2015 00:06:54	Ok	B	50.0 to 850.0 mV	1.000	B-C1, B-C2	657	547	314	292	367	438	193	216	16.26
40523	05/30/2015 00:04:57	Ok	A	500.0 to 8500.0 mV	1.000	A-C1, A-C2	4715	6990	2666	4125	0	0	0	0	16.26
40513	05/29/2015 22:23:09	Ok	A	50.0 to 850.0 mV	1.000	A2-C1, A2-C2	492	261	240	147	681	94	342	94	16.30

REV G04 PDA Qm Trend (FLH)







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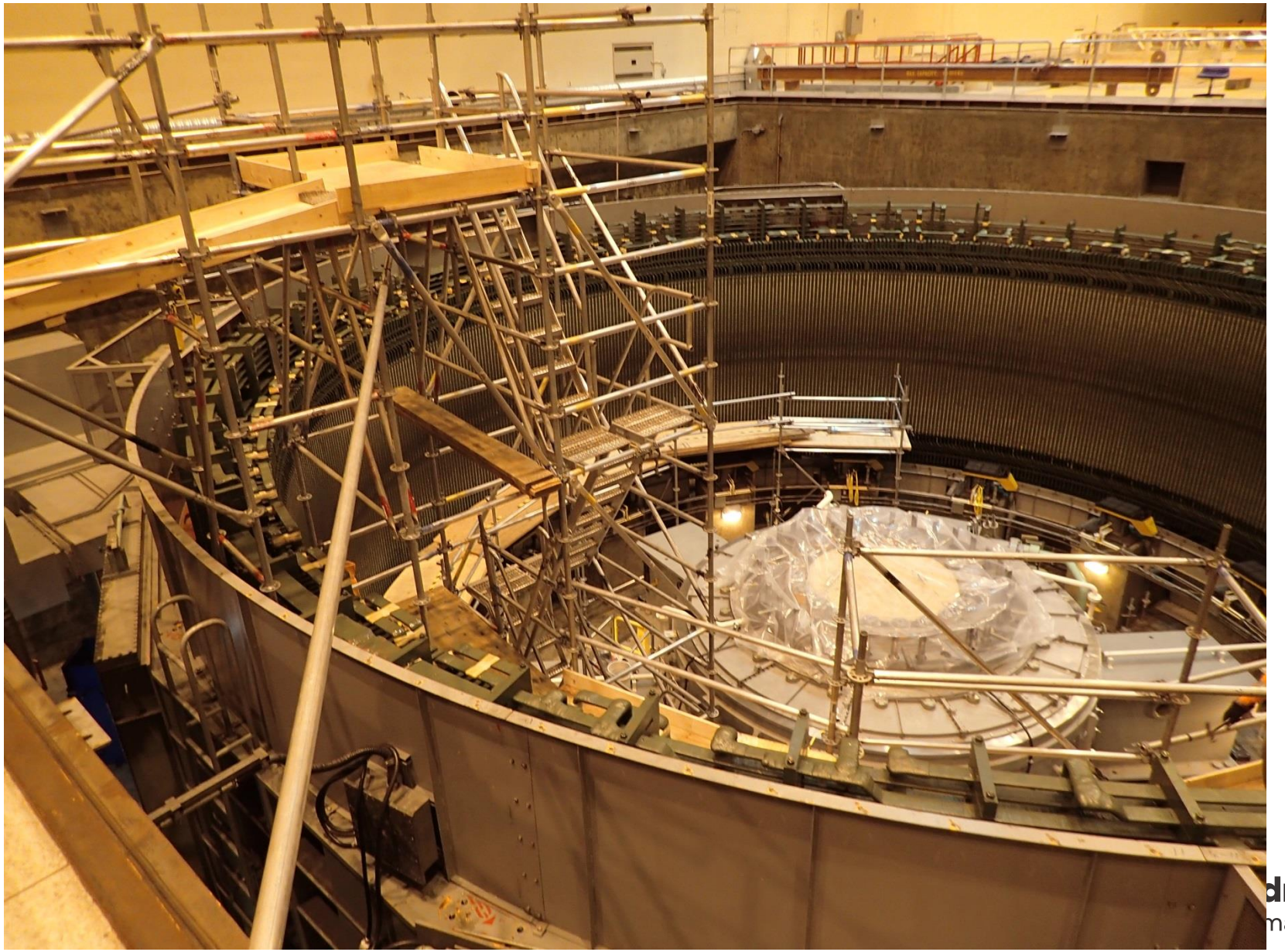
REV G4 with rotor removed



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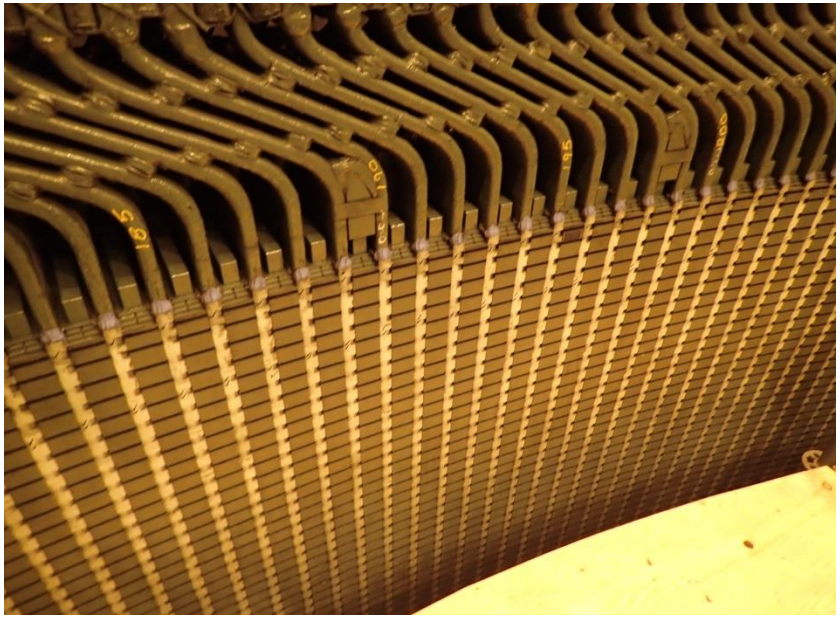
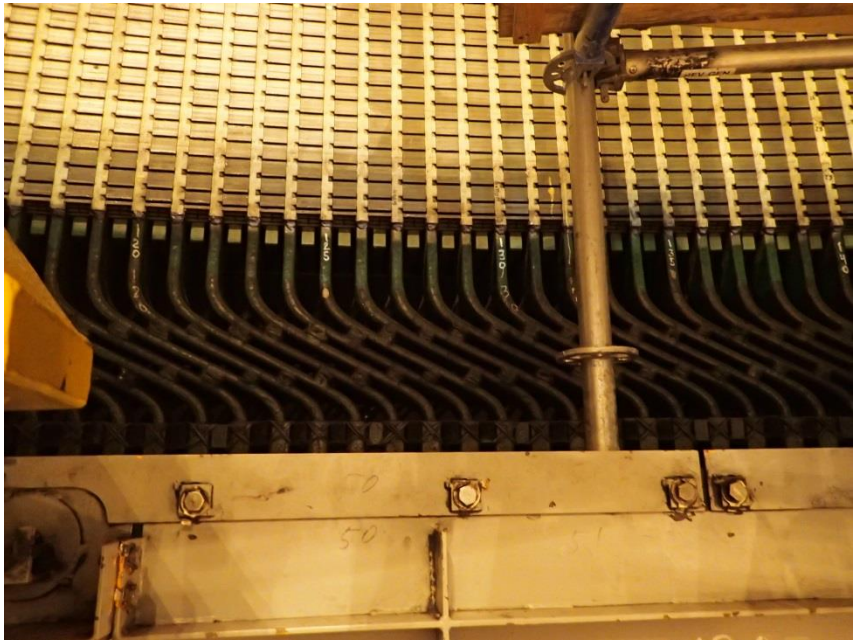
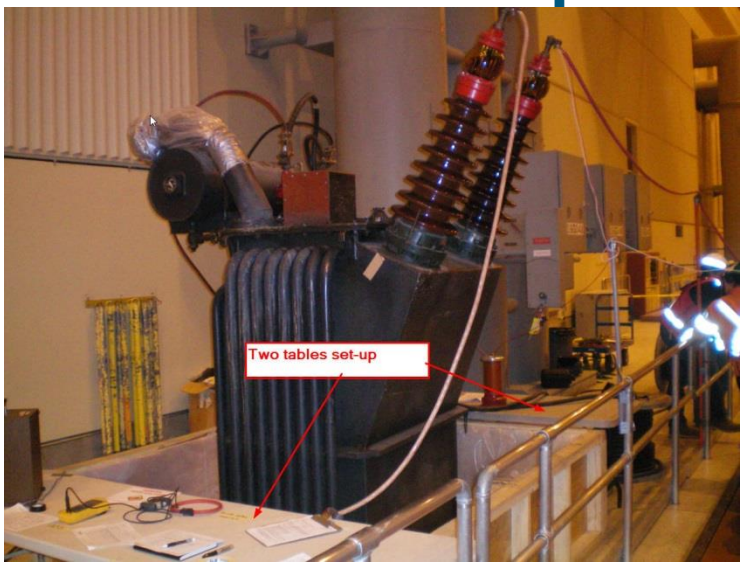
REV G4 with rotor removed

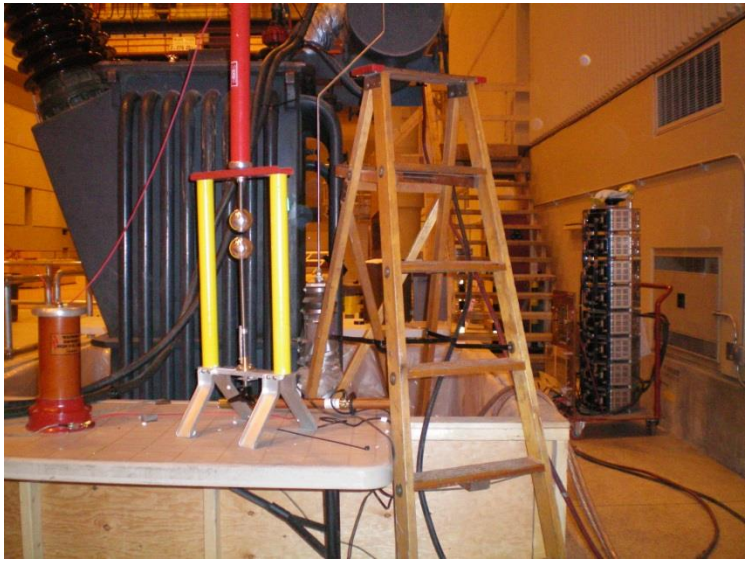




REV G4

PD off-line test setup





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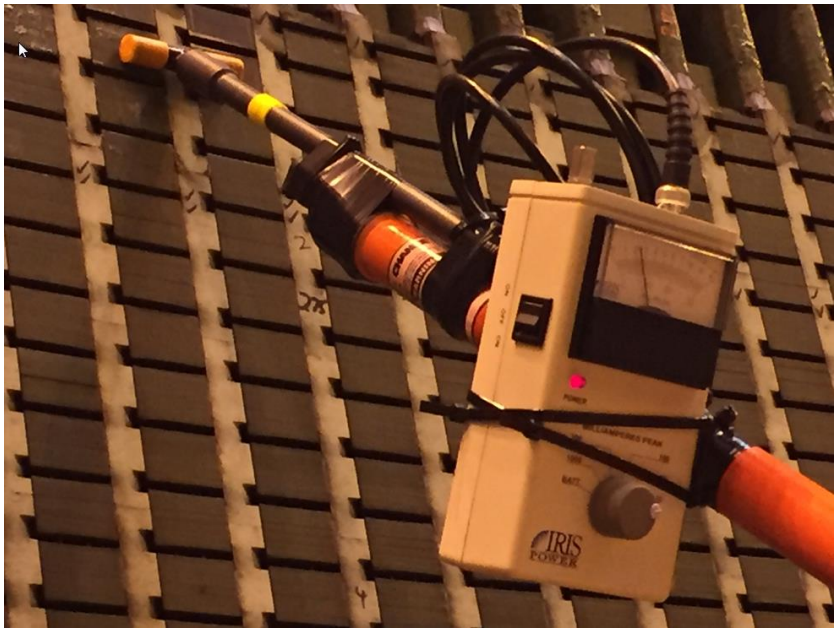
REV G4 Corona Probe tester



Cct in T1 Phase A	kV	BAR Front or Back		Corona Probe (mA)	Corona Scope (visual)	PD in Cct Off-Line +Qm/-Qm	PD in Cct On-line FLH +Qm/-Qm
		F	B				
A1	9	615		120		+1156/**-1315**	+2722/**-3333**
A6	8.3	343		105		No PD coupler installed	
A2	8	12		99		No PD coupler installed	
A4	9	225		88		+396/**-555**	+428/**-637**
A3	8.3	109		65		No PD coupler installed	
A7	7.2	286		62		No PD coupler installed	
A1	1.2	327		58		+1156/**-1316**	+2722/**-3334**
A5	9		235	48		+126/**-145**	+464/**-267**
A6	8	324		48		No PD coupler installed	
A2	8.3	31		40		No PD coupler installed	
A7	9	459		38		No PD coupler installed	
A5	8.7	284		36		+126/**-145**	+464/**-267**
A1	8.8		606	34		+1156/**-1315**	+2722/**-3333**
A3	4.2		21	32		No PD coupler installed	
A1	9.2		1	31	Bottom right side	+1156/**-1315**	+2722/**-3333**
A4	6.9	111		31		+396/**-555**	+428/**-637**
A8	4.6		352	31		+238/**-265**	+428/**-NA**

Cct in T2 Phase B	kV	BAR Front or Back		(mA)	(visual)	Off-Line +Qm/-Qm	On-line FLH +Qm/-Qm
		F	B				
B2	7.6	19		140-200	Audible	No PD coupler installed	
B5	8.3	291		120 /190		+84/-100	+176/-132
B3	7.6	97		100		No PD coupler installed	
B2	8	38		90		No PD coupler installed	
B1	9	17		89		+292/-413	+132/-119
B1	8.7	622		80	Repaired in the past	+292/-413	+132/-119
B1	8.3	603		70		+292/-413	+132/-119
B3	4.9	48		62		No PD coupler installed	
B8	9.2		573	60	Repaired in the past	+218/**-282**	+268/**-242**
B8	8.7	544		52		+218/**-282**	+268/**-241**
B2	8.7	76		50		No PD coupler installed	
B4	2.3	20		45		+120/-159	+182/-242
B6	6.9	293		44		No PD coupler installed	
B1	9.2		27	42		+292/-413	+132/-119
B2	8.5		67	42		No PD coupler installed	
B2	6.9	605		40		No PD coupler installed	

Cct in T3 Phase C	kV	BAR Front or Back		Corona Probe (mA)	Corona Scope (visual)	PD in Cct Off-Line +Qm/-Qm	PD in Cct On-line FLH +Qm/-Qm
		F	B				
C1	7.6	552		130 / 80		+99/-101	+281/-197
C4	9	238		60		+344/-404	+234/-225
C6	7.2	299		52		No PD coupler installed	
C6	8	337		52		No PD coupler installed	
C2	9	82		45		No PD coupler installed	
C7	5.6	309		34		No PD coupler installed	
C8	6.9	436		32		+82/-104	+185/-189
C7	9	472		30		No PD coupler installed	
C3	6.9	46		28		No PD coupler installed	
C6	5.6	231		26		No PD coupler installed	
C4	6.9	124		24		+344/-404	+234/-225
C4	7.2	143		24		+344/-404	+234/-225
C4	7.6	162		24		+344/-404	+234/-225

REV G4

6 bars removed (+ 1 spare bar)shipped for testing at the Powertech Labs

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REV G4 bars PD - Testing

At PowerTech Labs

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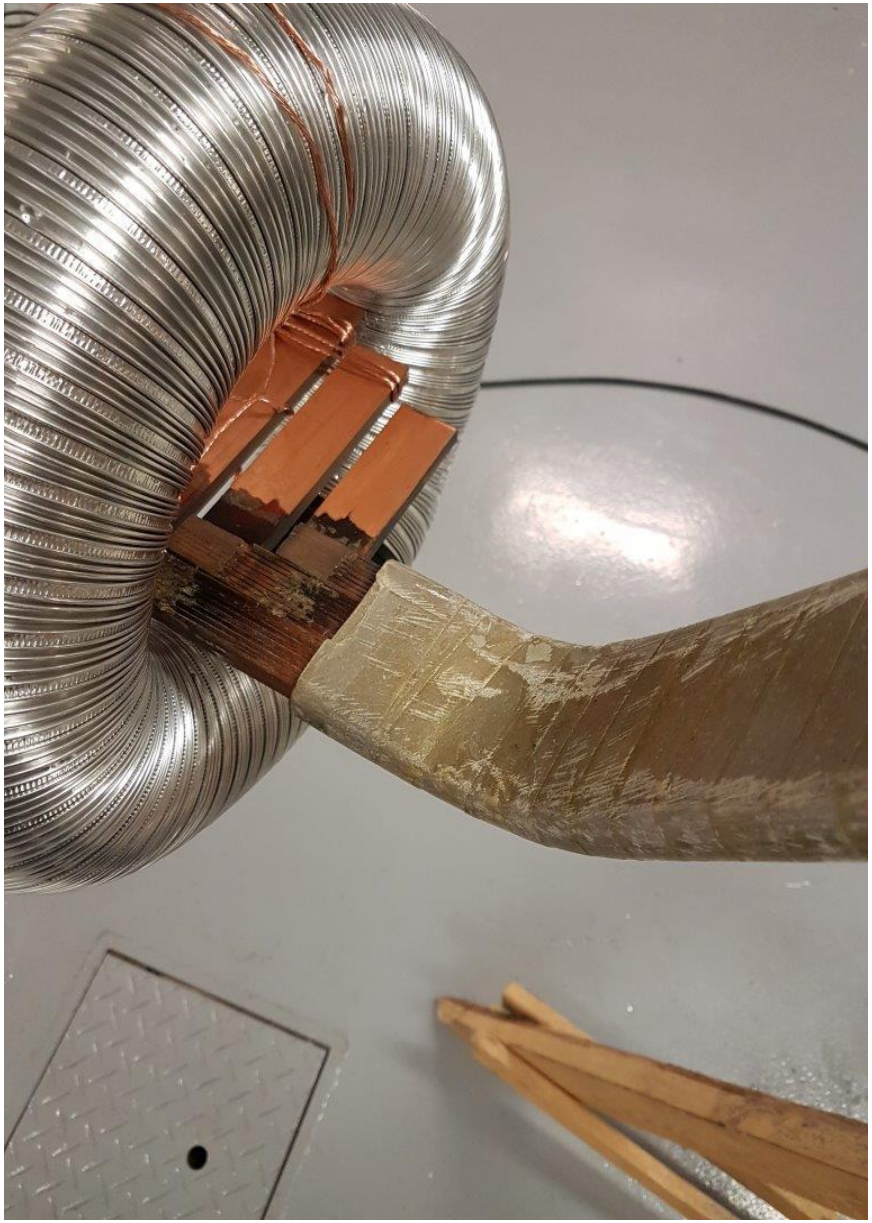
REV G4 bar set up for PD-test

at PowerTech Labs



REV G4 PD - couplers tested at PowerTech Labs

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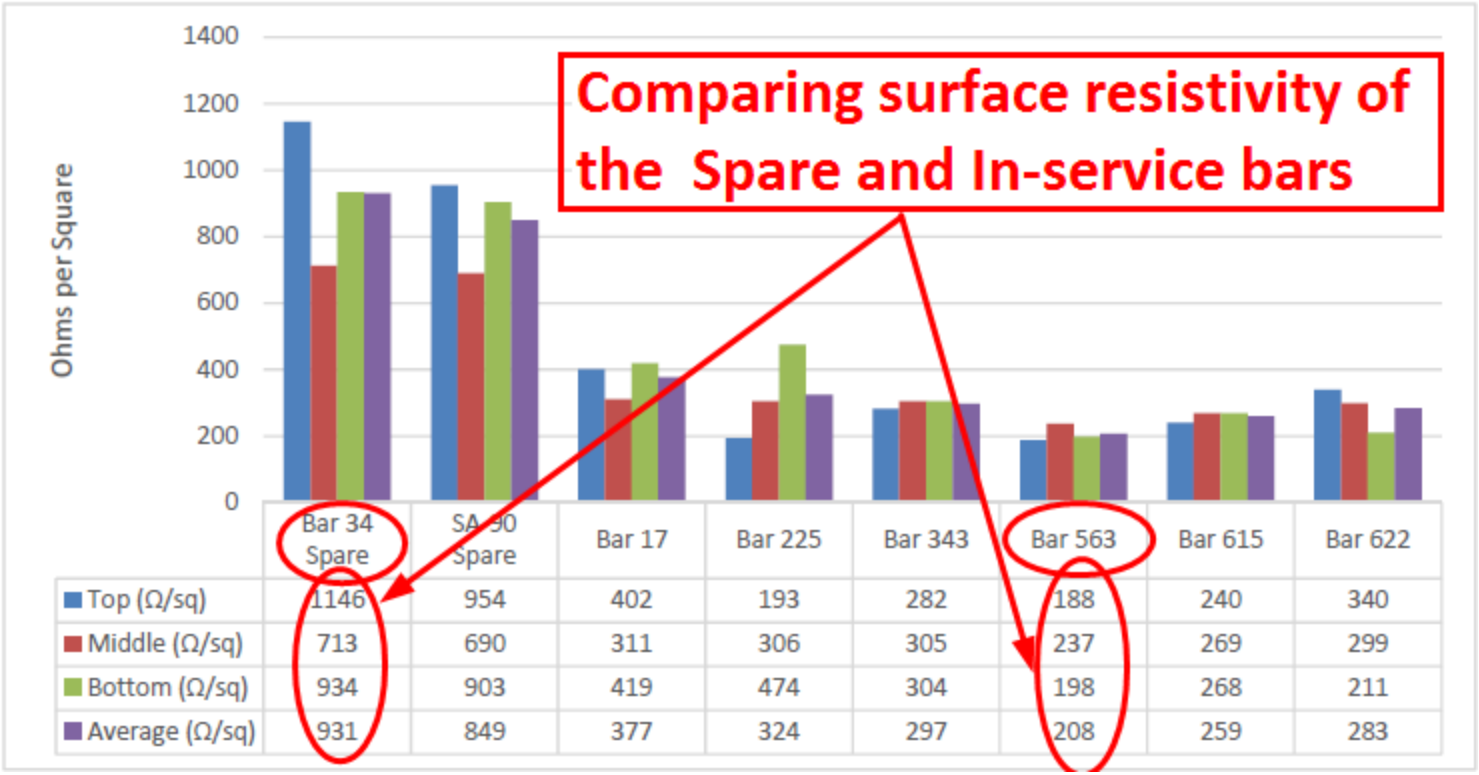
Surface resistivity of the semi-con paint in the slot section



	Bar 34 Spare	SA 90 Spare	Bar 17	Bar 225	Bar 343	Bar 563	Bar 615	Bar 622
Top (Ω/sq)	1146	954	402	193	282	188	240	340
Middle (Ω/sq)	713	690	311	306	305	237	269	299
Bottom (Ω/sq)	934	903	419	474	304	198	268	211
Average (Ω/sq)	931	849	377	324	297	208	259	283

Spare bars have 2-3 times higher surface resistivity compare to the service-aged bars.

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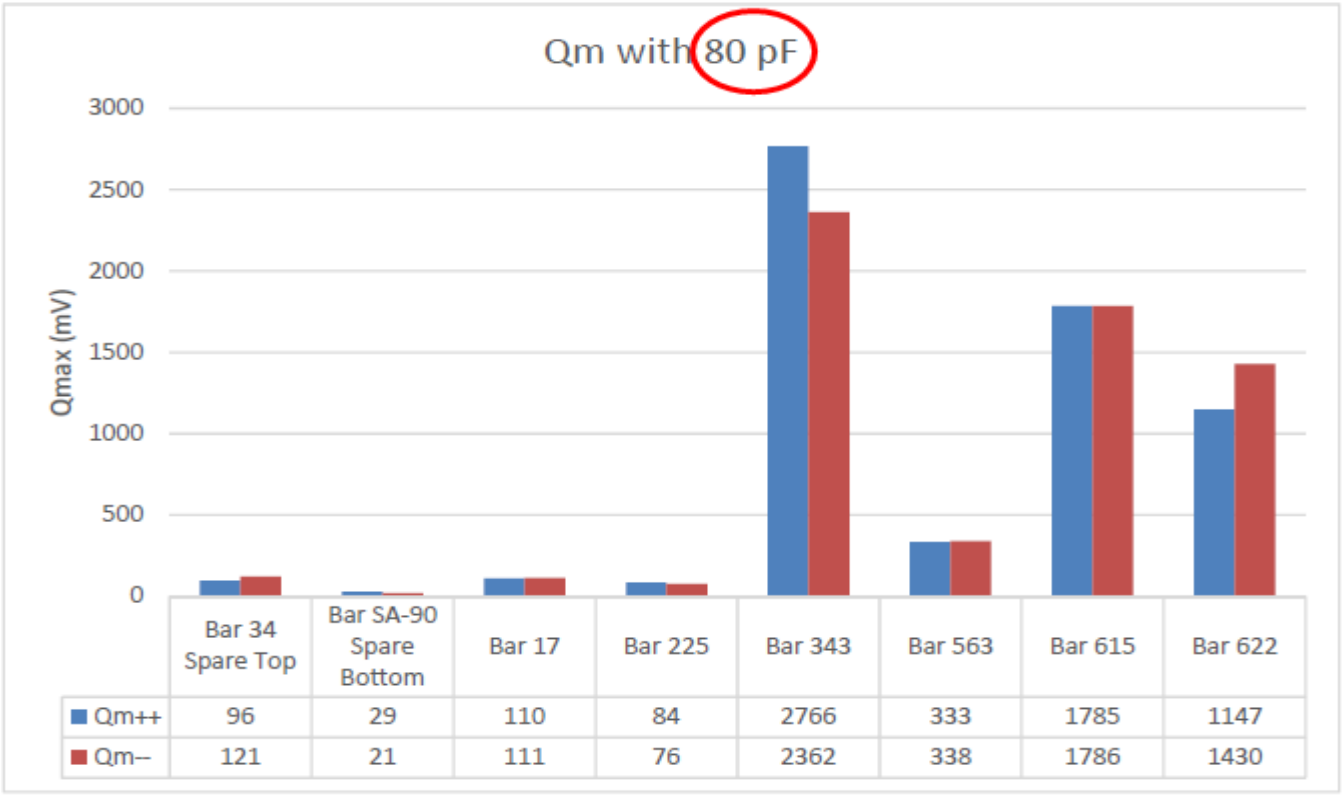
PD testing at the PowerTech Labs



	Bar 34 Spare Top	Bar SA-90 Spare Bottom	Bar 17	Bar 225	Bar 343	Bar 563	Bar 615	Bar 622
Qm++	96	29	110	84	2766	333	1785	1147
Qm--	121	21	111	76	2362	338	1786	1430

Qmax measured with 80 pF coupler

Test Voltage was selected 10 kV that is slightly higher than 9.24 kV to compensate for temperature difference between operating and test conditions.

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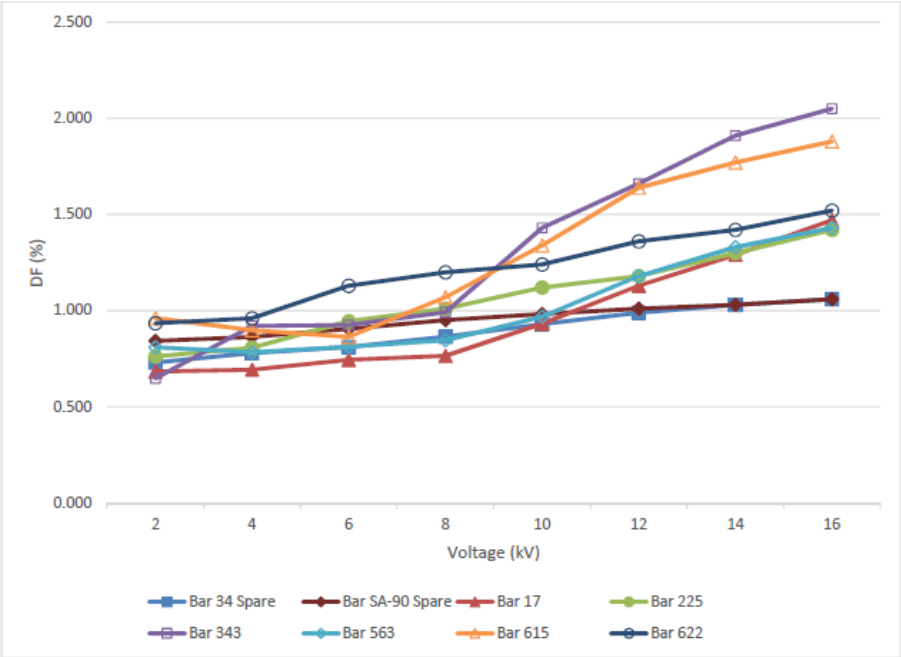
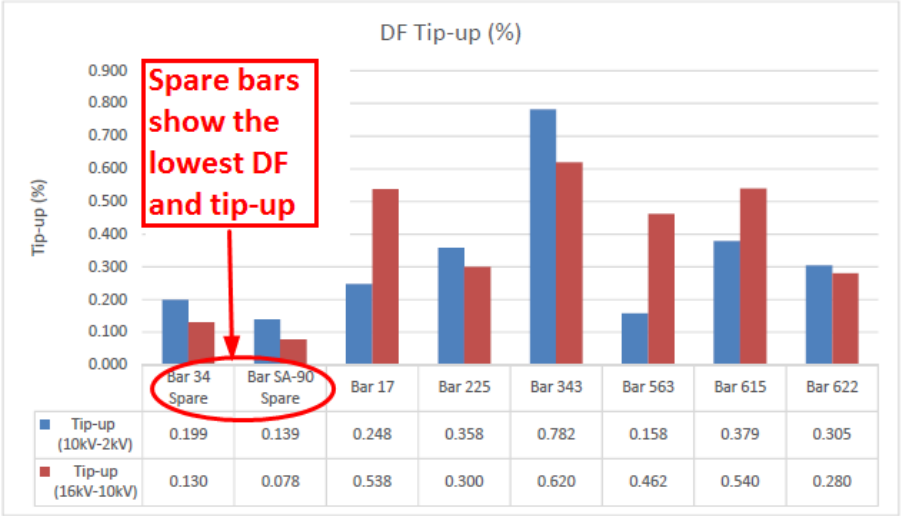
Dissipation Factor (DF) and tip-up



Absolute dissipation factor (%) as a function of applied voltage



	Bar 34 Spare	Bar SA-90 Spare	Bar 17	Bar 225	Bar 343	Bar 563	Bar 615	Bar 622
Tip-up (10kV-2kV)	0.199	0.139	0.248	0.358	0.782	0.158	0.379	0.305
Tip-up (16kV-10kV)	0.130	0.078	0.538	0.300	0.620	0.462	0.540	0.280

Dissipation factor tip-up between 10 and 2, and 16 and 10 kV

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Voltage Endurance (VE)and AC Breakdown tests

- All bars VE tested met requirements of IEEE 1553 Schedule A – 34.7 kVac for 400 hours
- Bars were kept at constant temperature of 90°C based on the highest operating temperature provided by site.
- The minimum breakdown voltage was 51 kVac (that is 3.2 times the line voltage (i.e. 16 kV) of the machine.

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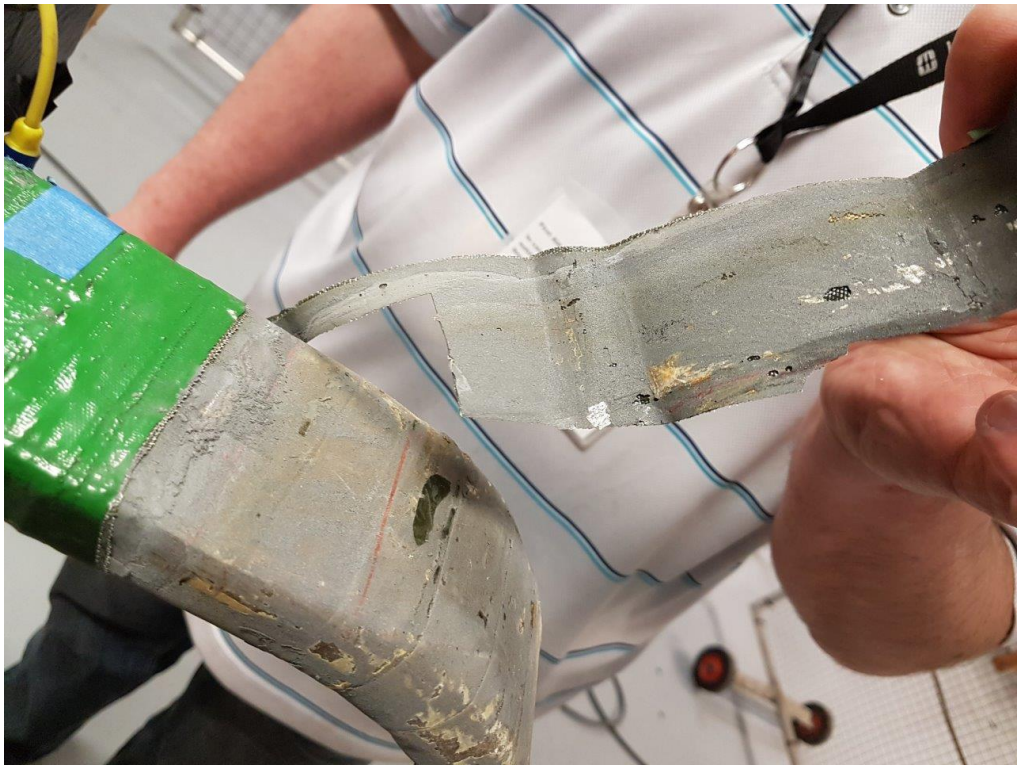
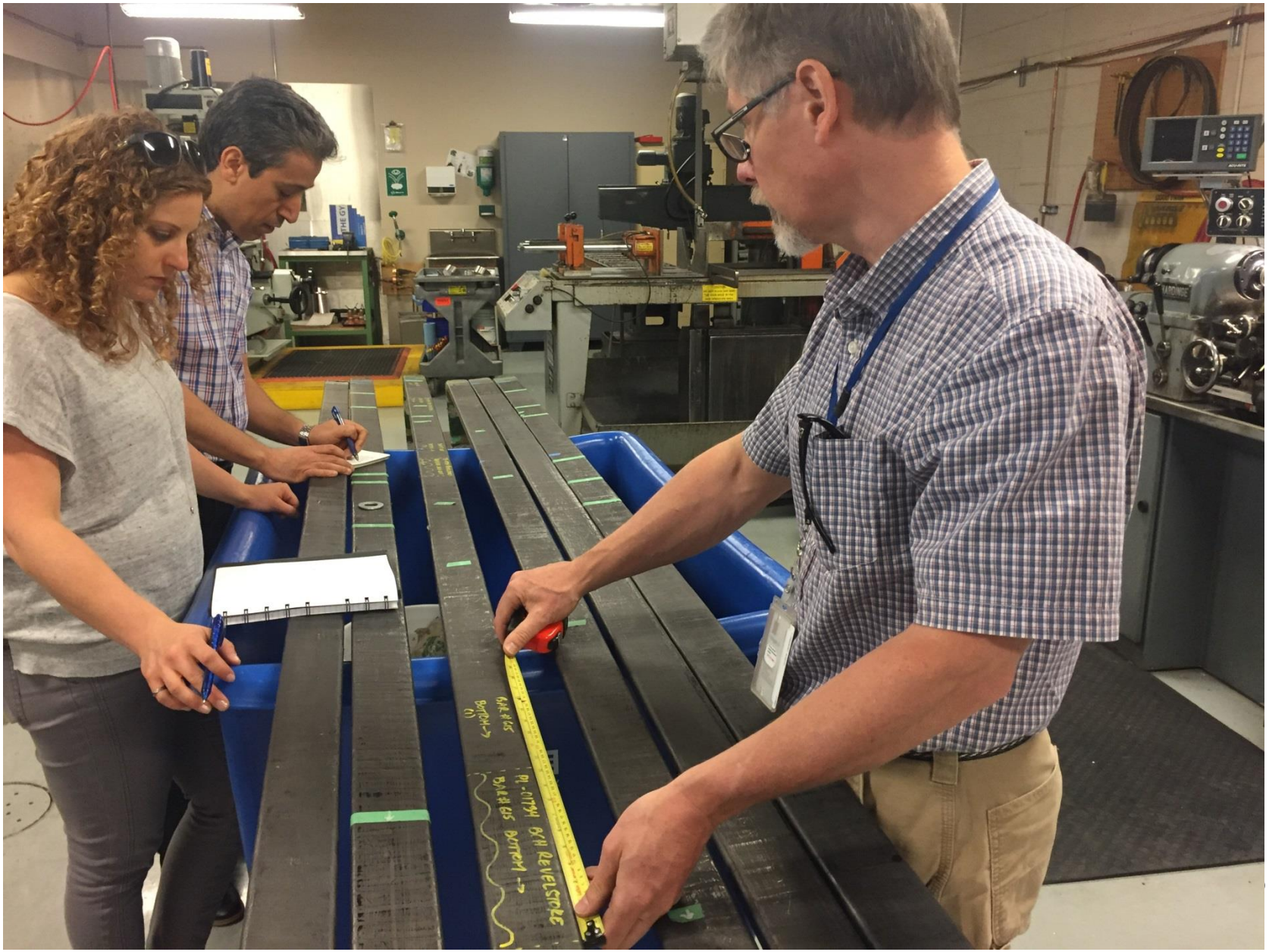
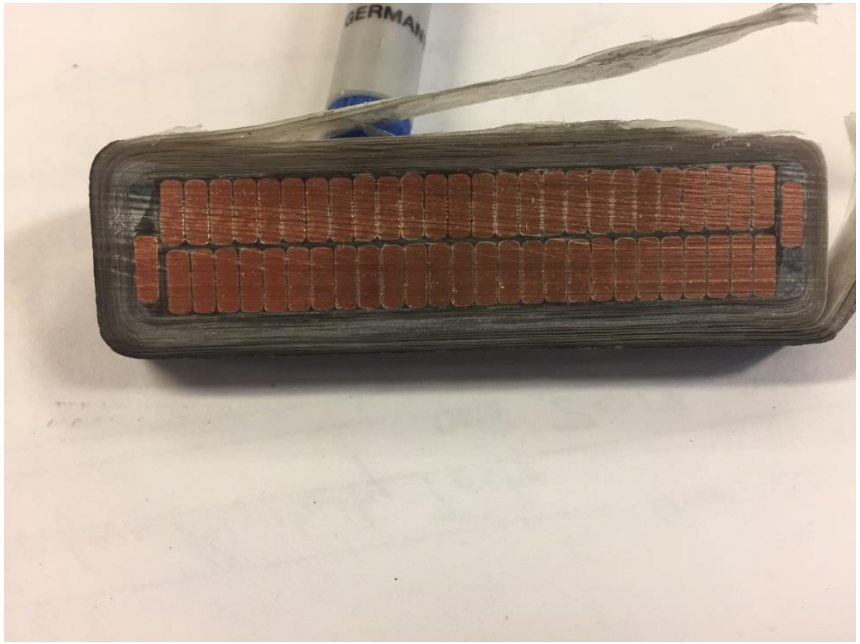
REV G4 bar semi-con /grading interface deterioration



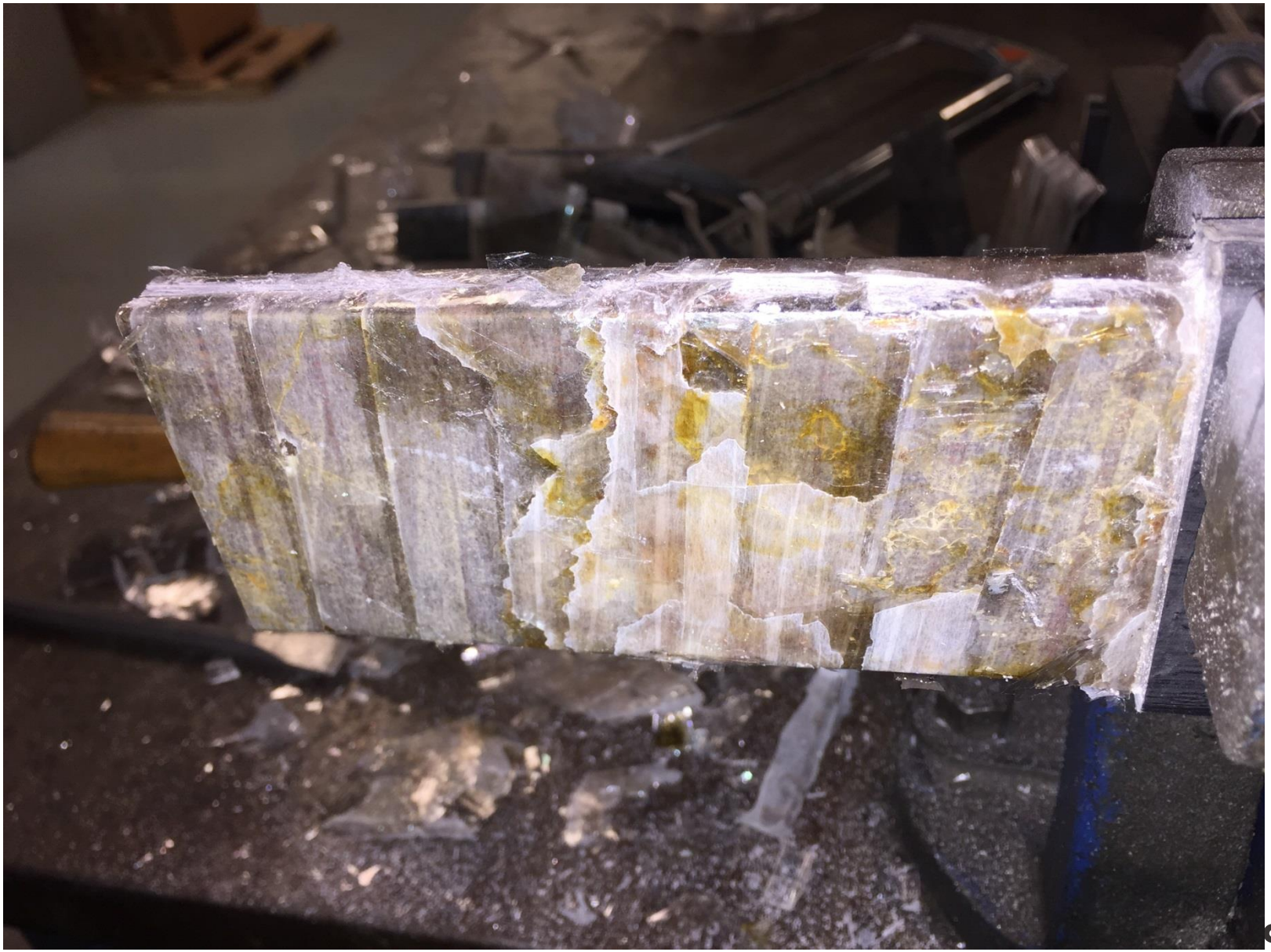
REV G4 bars dissection at PowerTech Labs



REV G4 bars dissection at PowerTech Labs



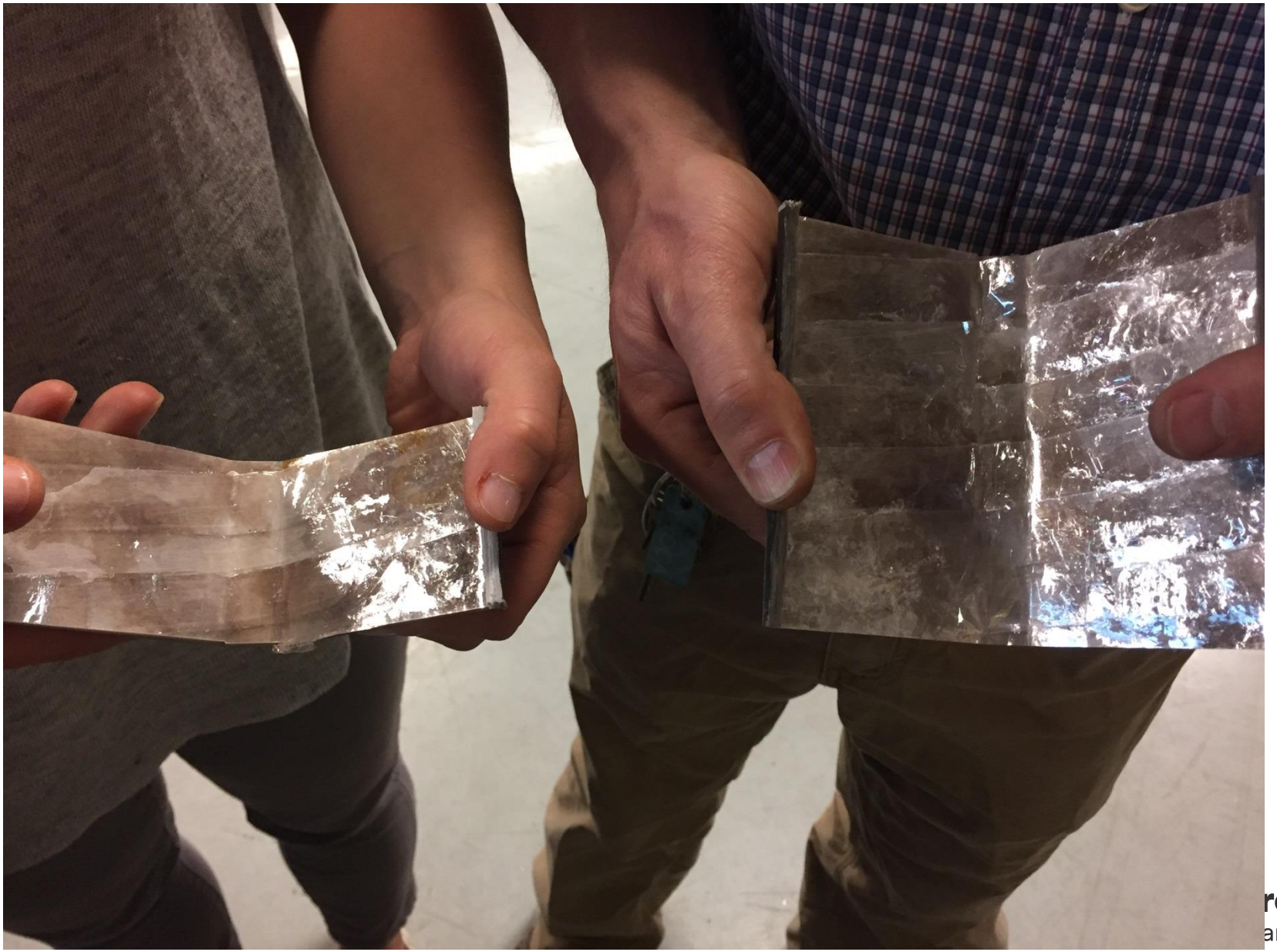
REV G4 bars dissection at Powertech Labs



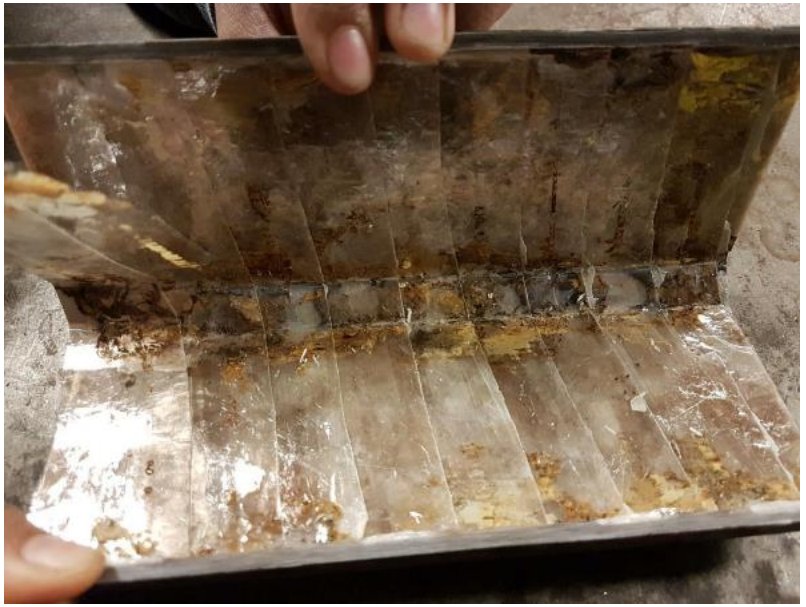
REV G4 bars dissection at Powertech Labs

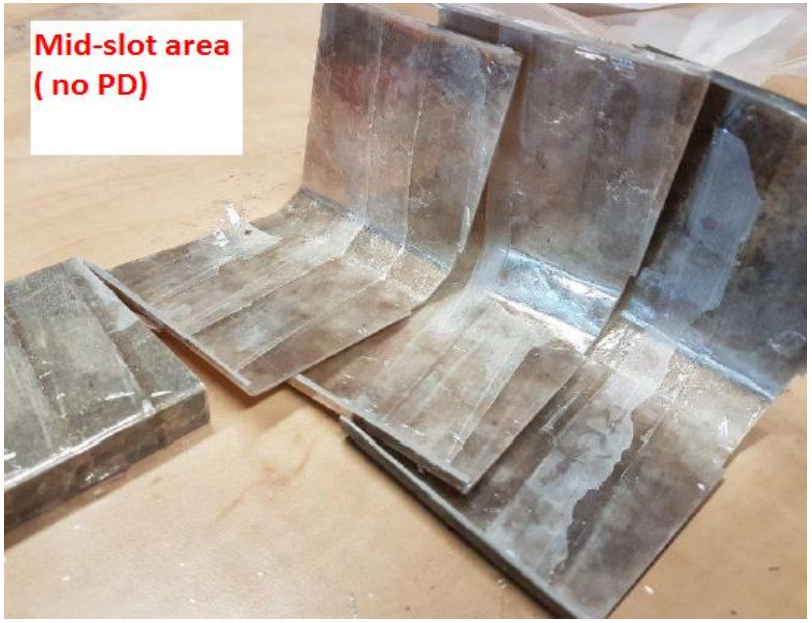
Comparison between REV G4 spare bar and removed in-service aged bar.

REV G4 bars dissection at Powertech Labs



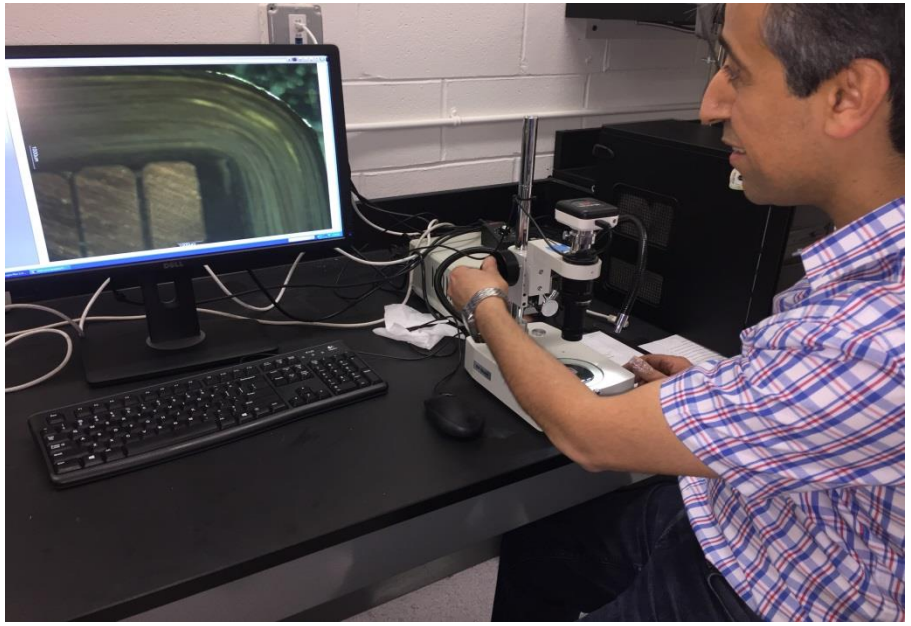
Bars dissection at Powertech Labs

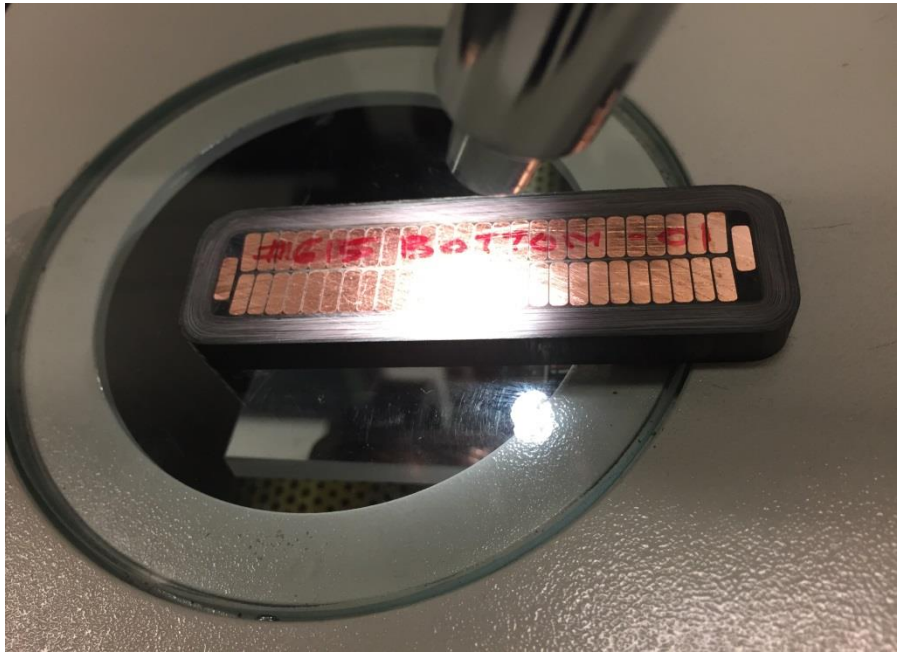


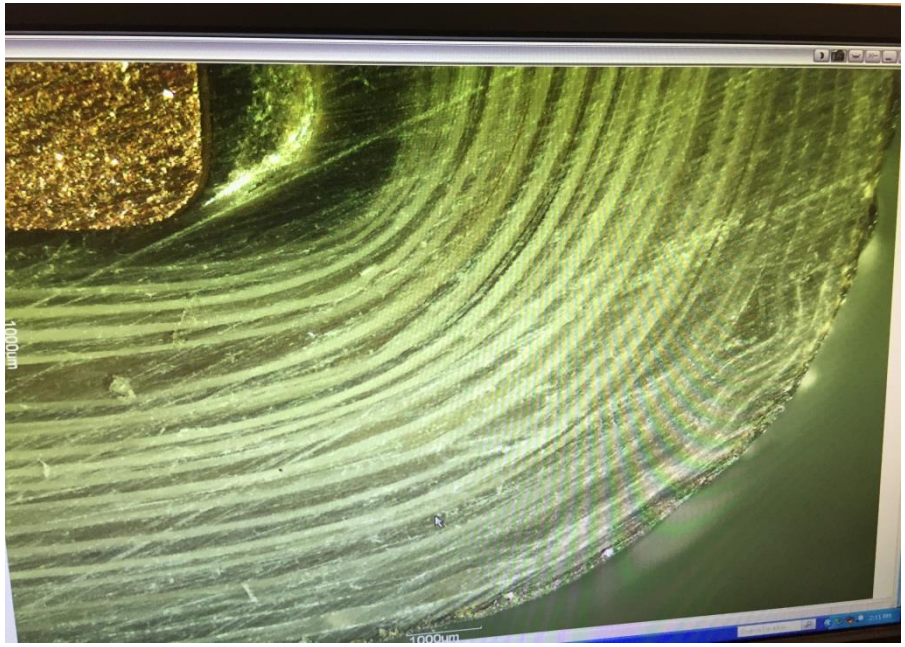


REV G4 bars dissection at Powertech Labs

REV G4 bars dissection at Powertech Labs

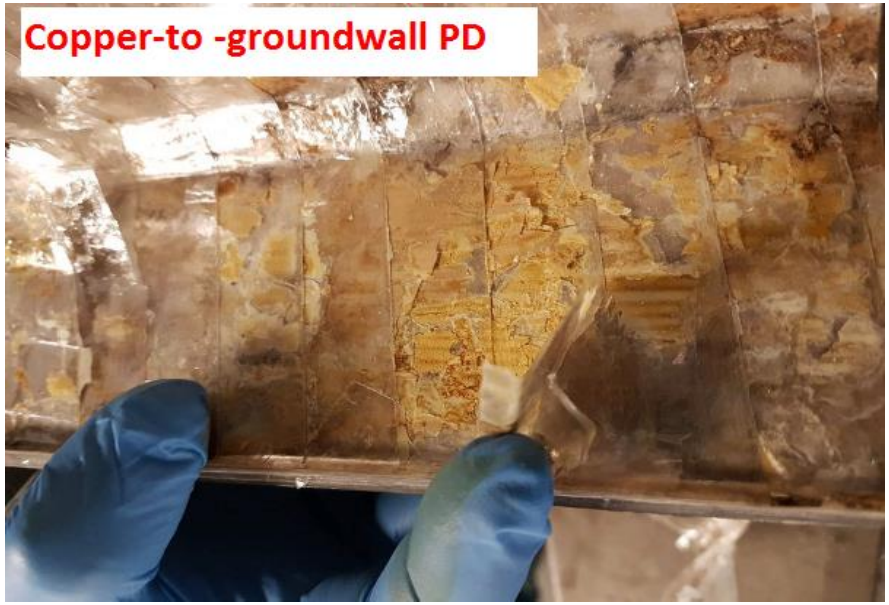






REV G4 bars dissection at Powertech Labs

Bars Breakldown Test



Questions ?

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