Partial Discharge Activity vs. Operating Temperature Investigation

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Introduction

Partial Discharge is the term used for sparking between insulation and a conductor, or inside or on the surface of insulation across a gap. A full discharge would be a spark through the insulation between a conductor and ground. Corona is also a term also used to describe partial discharges. This term is normally used to describe sparking on surfaces where the sparking or the effects of the sparking can be seen.

The generators used in this investigation are the three American Falls generating units. They are a 1978 vintage Westinghouse 30.8 MVA vertical shaft hydro generator operating at 13.8 kV. The insulation system is a polyester mica resin rich tape that is wound onto the coils and then heated and pressed to cure the resin. This is referred to as a B stage insulation system. This system is known to have more voids in the insulation than a vacuum pressure impregnation, VPI, system.

The units have a pair of standard IRIS Epoxy Mica Capacitors installed where the two coil strings attach to the high side collector ring. Since there are only two strings and the one is wound in reverse, the collector ring is only about 2 meters long. This coupler installation is known as a differential configuration. It allows for noise to be cancelled out as a pulse arriving at the test instrument from both capacitors at the same time had to come from outside the unit.

The partial discharge activity, PDA, on the American Falls units is greater than 95% of the 13.8 kV units that have IRIS couplers installed on them. The normal PDA on some of the American Falls couplers is well over twice the 95% level. These very high levels are due to the inherent voids in the insulation system and have been seen since the installation of the couplers in 2002.

These high levels of PDA will, along with other causes, eventually lead to the failure of the insulation system. Another contributor to insulation damage is thermal cycling leading to loosening of the coils in the slot. Loosening of coils in the slots leads to more surface PDA. As the resin in the insulation breaks down, the insulation can expand due to the lower clamping pressure and more voids form in the bulk insulation. Then PDA in the bulk insulation can increase. Loose coils will also lead to increased mechanical wear of the coil surface. The loss of the semi conductive layer on the surface will then lead to increased surface PDA.

The American Falls units in the spring and the fall will operate at low load and low stator temperatures. The flows are controlled by the Bureau of Reclamation so the units are basically operated as a run of river type plant. The units may spend weeks or months at low flow and low temperature conditions. There is currently no automatic way to control the stator temperatures.

Due to the low stator temperature operations of these units, a study was initiated to determine how the low temperatures were affecting the PDA levels. The thesis was that the low temperature condition is when the winding coils would be the loosest due to the contraction of the core compared to the high temperature condition.

Study Method

The study consisted of two phases. The first phase was an initial assessment of the differences between full load hot and low load cold PDA levels. This was undertaken to determine if there was a sufficient difference in PDA levels to conduct further controlled condition testing of the units. The second phase consisted of taking units operating at constant conditions and varying the stator temperature from cold to hot. In these tests cold is in the 30C range and hot is in the 70C range.

The first phase was an in situ investigation of PDA levels at two operating conditions. One condition is full load and maximum temperature and the other is low load and a minimum temperature. The test results were taken months or years apart but would give a good indication of the effect of temperature.

The second phase would be to take a unit operating at constant conditions and over a period of hours vary the stator temperature. This method would remove any variables that could have occurred between the samples in the first phase of testing. These units have water to air coolers and flow can be manually adjusted to the coolers to control stator temperatures.

Testing

All testing was conducted using the standard IRIS PDA-IV test instrument. In the first phase, Units 1 and 2 were compared at the two conditions. The full load tests were taken on 6/18/2012 with both units approximately 32 MW and 72C. The low load tests were taken on 10/04/2012 with the units at approximately 10 MW and 39C. The 2002 data was taken at similar condition on 5/2/2002.

The second phase of the study involved testing in April of 2013. The testing involved all three units. Two power levels were used and the temperature was varied by reducing cooling water flow.

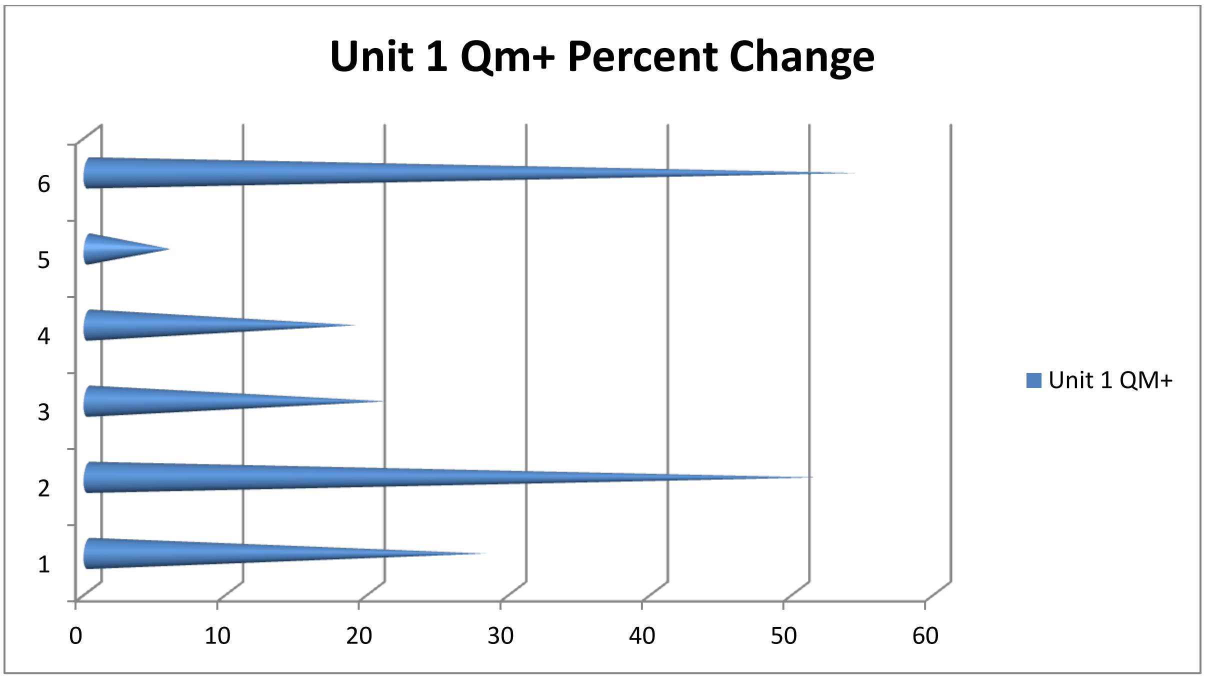
The results and conclusions will be arraigned by the study phase.

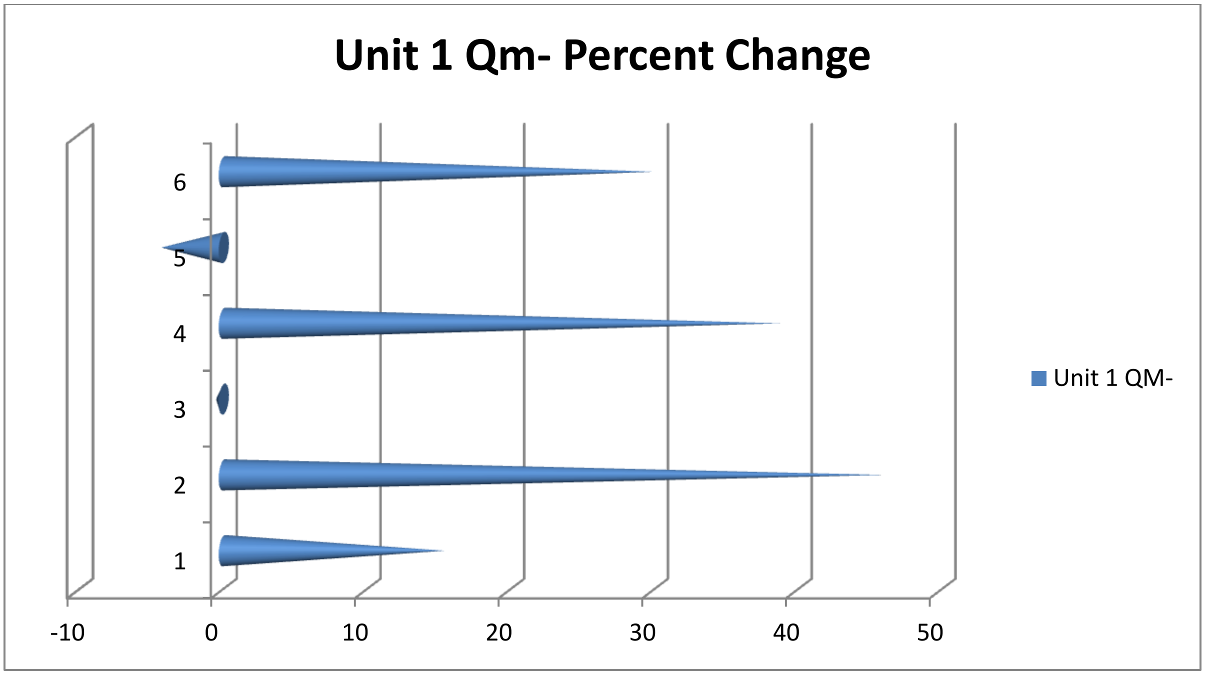
Phase 1 Results

The PDA results normally used to compare levels are called Qm+ and Qm-. Qm, or Peak Magnitude, is the magnitude of the pulses for one fundamental pulse category that has a repetition rate 10 pulses per second and corresponds to the peak PD activity. Qm is an indicator of how severe the PD is at the most deteriorated part of the winding (1). The positive and negative refer to where the PD occurs relative to the 60 Hz voltage wave. Surface PDA is shown by a positive Qm predominance. Loose windings are also shown by a positive Qm predominance since the gaps on the surface in the slots will lead to more surface PD. Qm being approximately equal is an indicator of the PD being in voids in the insulation. A negative predominance shows the PD is near the surface of the copper.

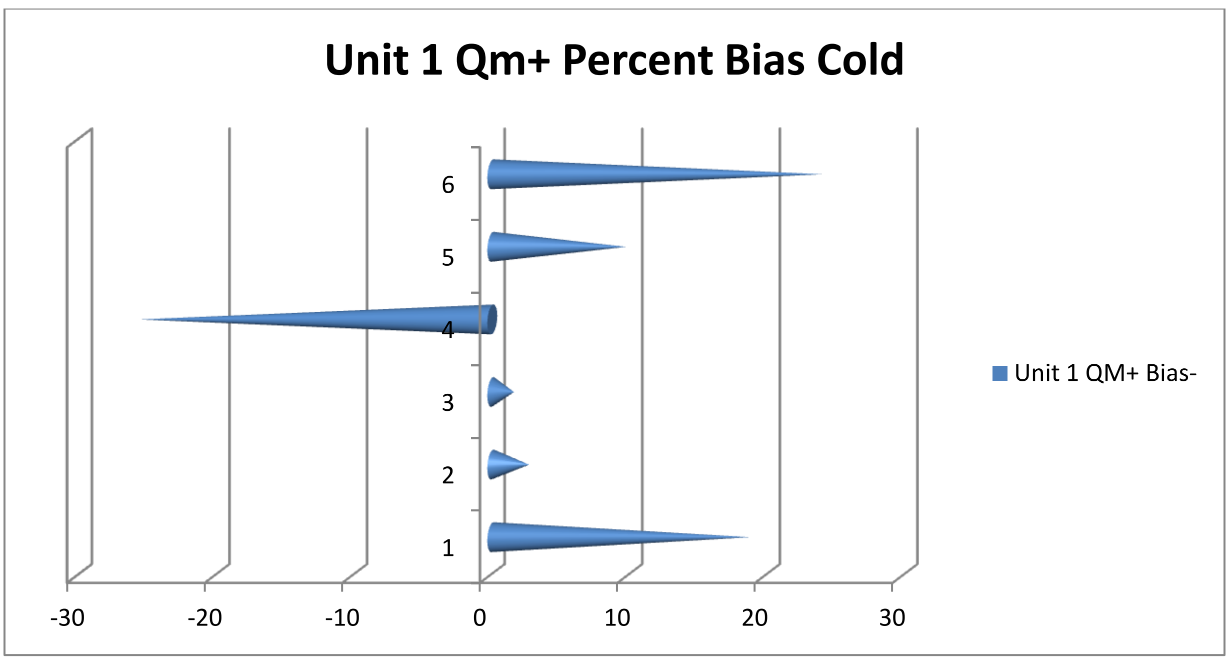
2012 Results

At full load hot the units show no significant predominance in the Qm results. The first 2 charts look at the change in Qm levels between the two operating conditions for Unit 1 with the change being from high low to low load.

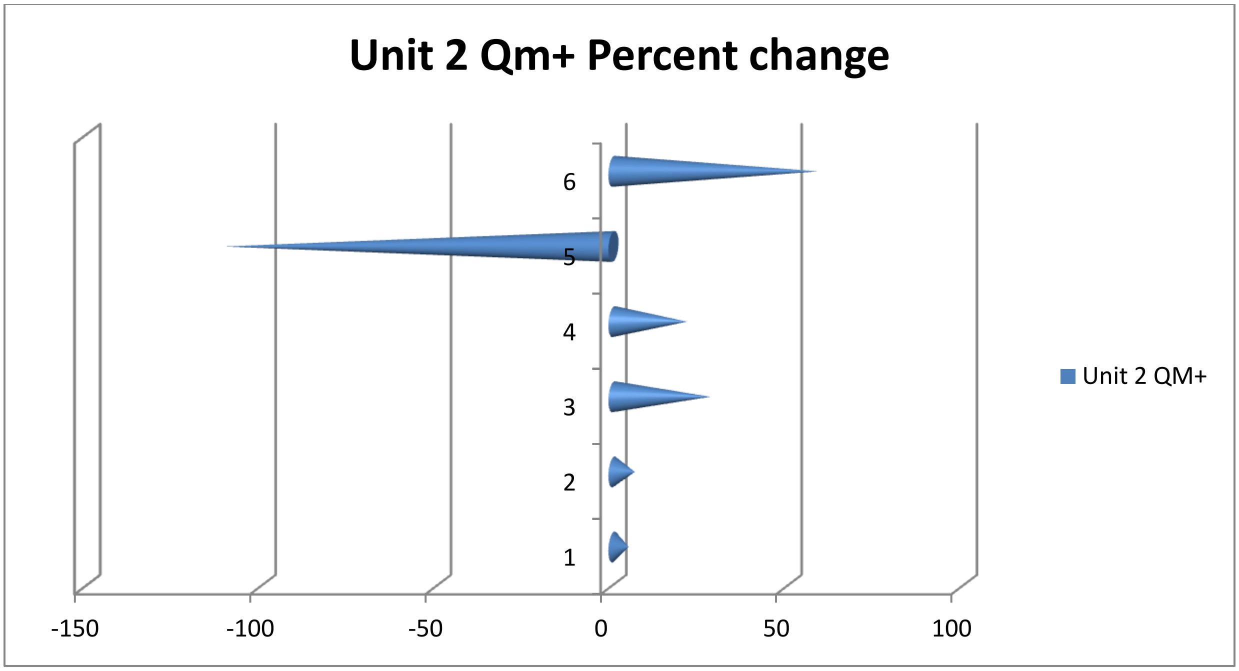


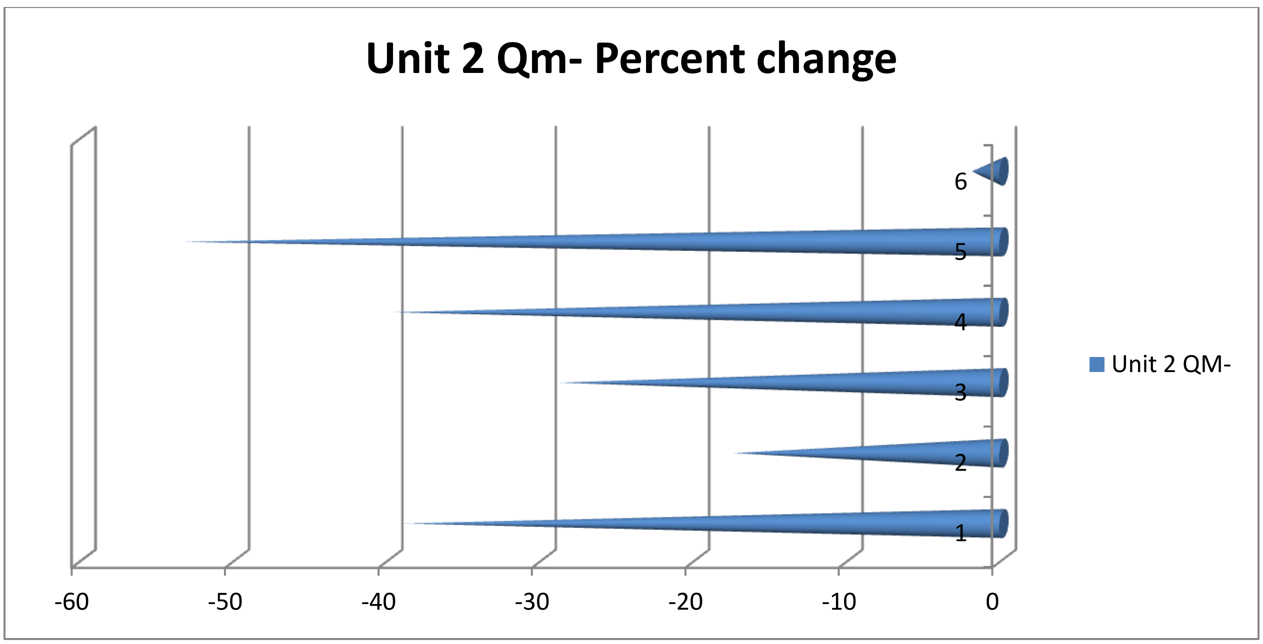


As shown in the charts, Unit 1 Qm levels rose significantly when the power level and temperature was reduced in the unit. To see if any predominance occurred in the unit when cold, the following chart depicts the change in Qm with a shift toward the Qm+ as a positive number to the right. The chart shows a slight shift to Qm+ but not substantial. The results for this unit show that overall PDA levels increase in this unit when cold and at low power and that the PDA remains in the bulk of the insulation.



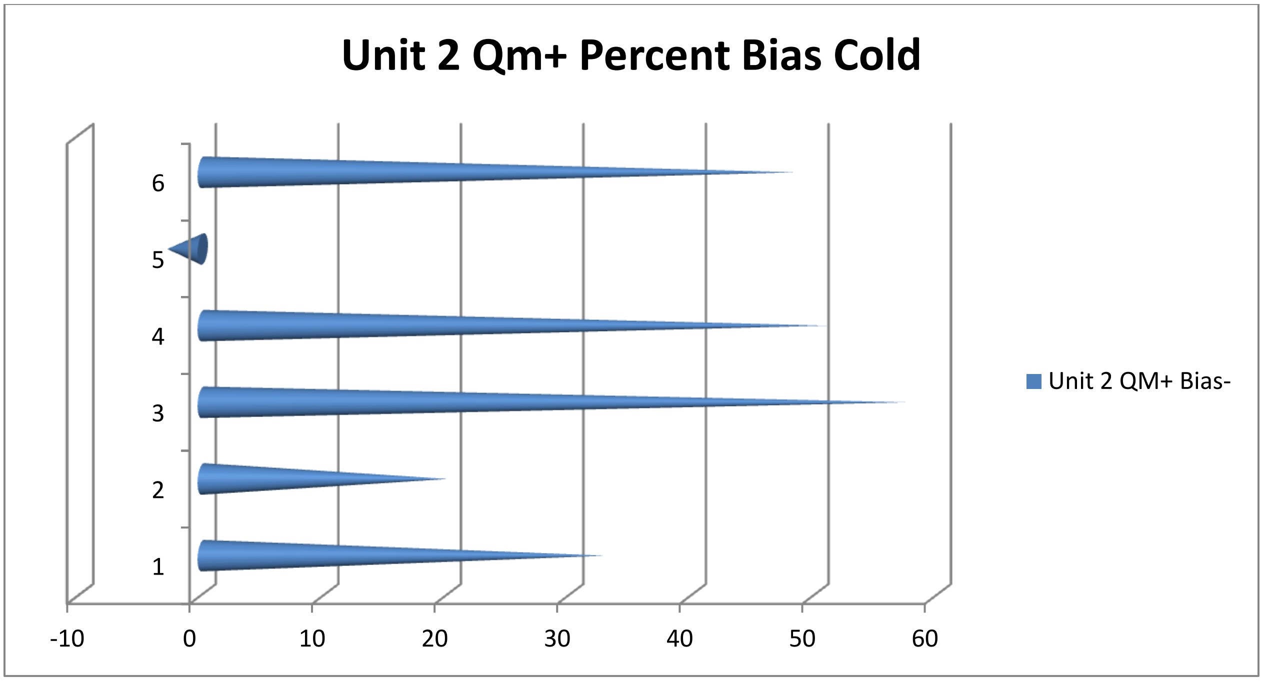
The next two charts look at the change in Qm levels between the two operating conditions for Unit 2.





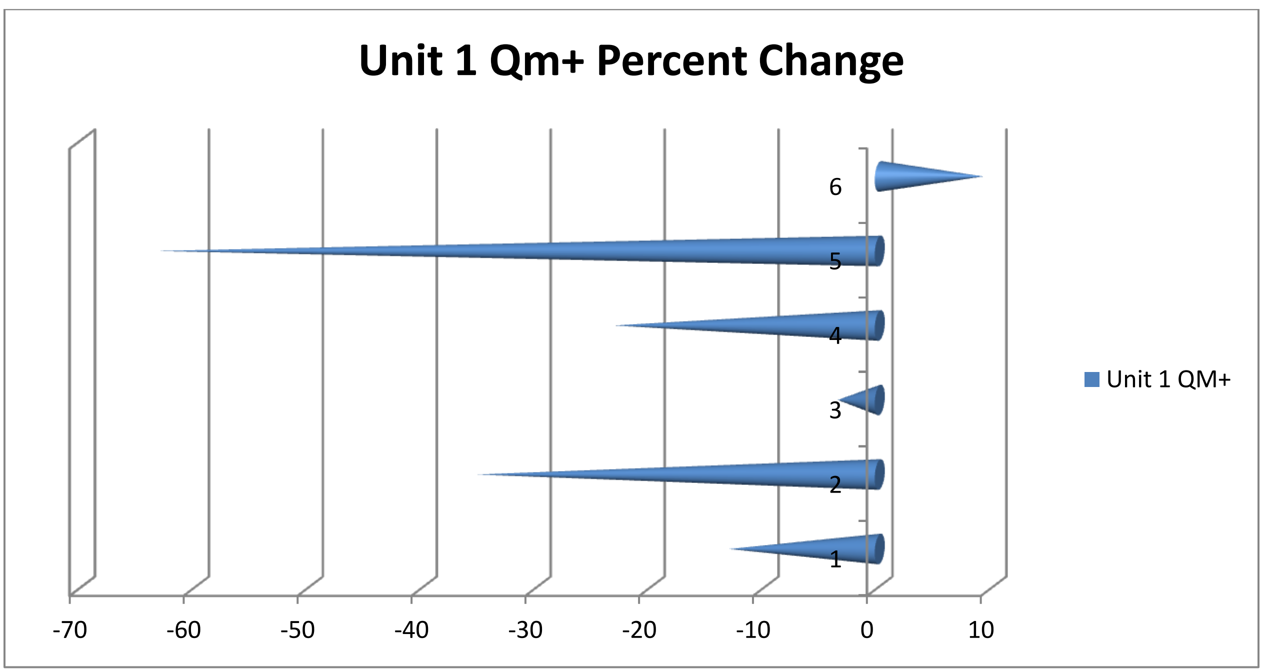
The results show that the Qm+ levels of 5 of 6 couplers increased with the remaining coupler falling over 100%. This coupler is consistent over time as in 2002 it showed the largest negative change.

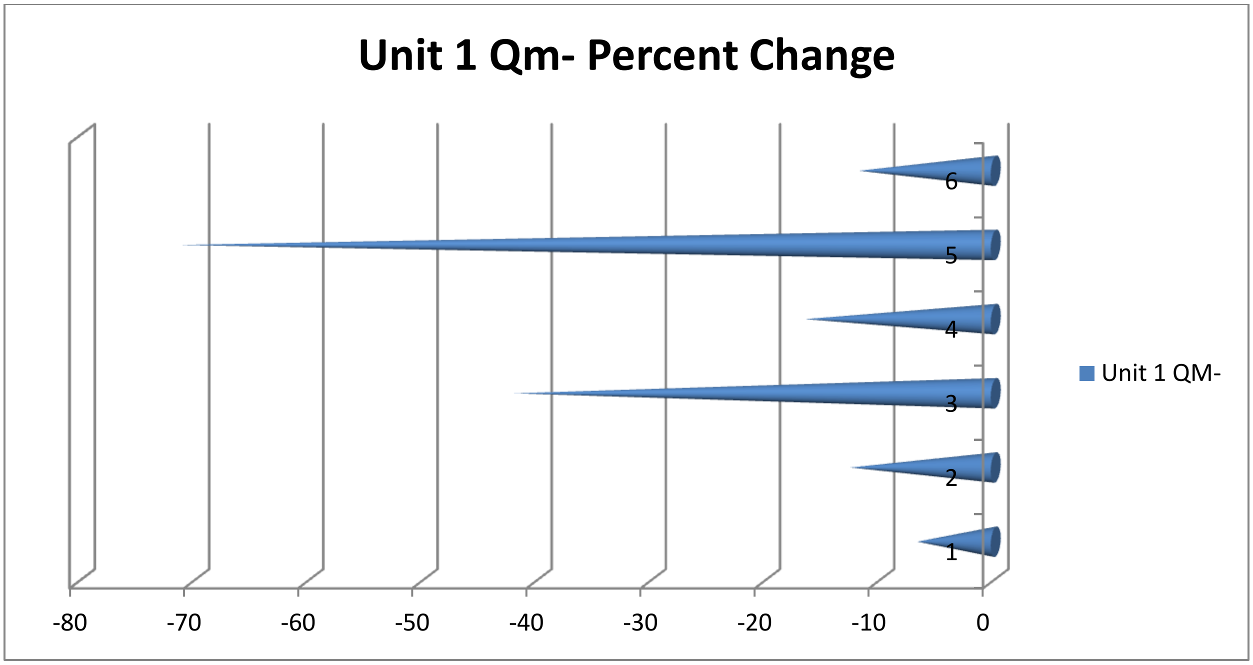
The Qm- levels changed significantly in the negative direction. The chart below shows that there was a significant bias towards Qm+ when the unit was cold and thus the amount of surface PDA increased in this unit compared to the hot condition.



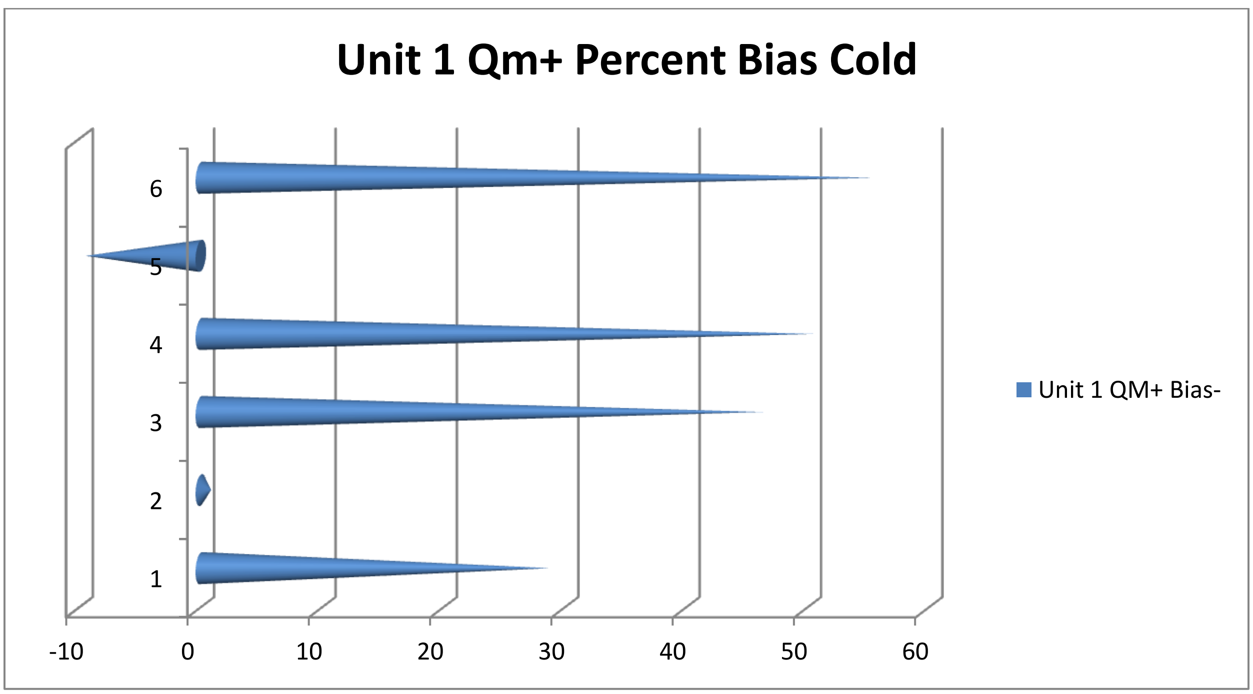
Results 2002

For a comparison, here are the results of the same PDA tests conducted at similar power and temperatures from 2002.

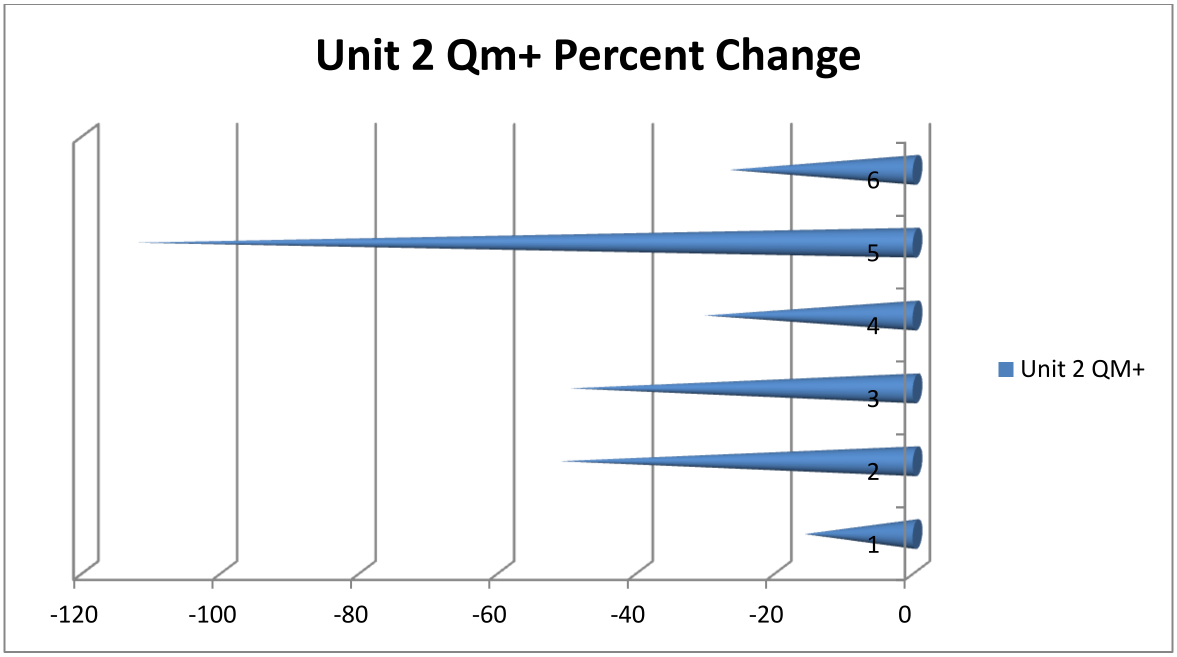


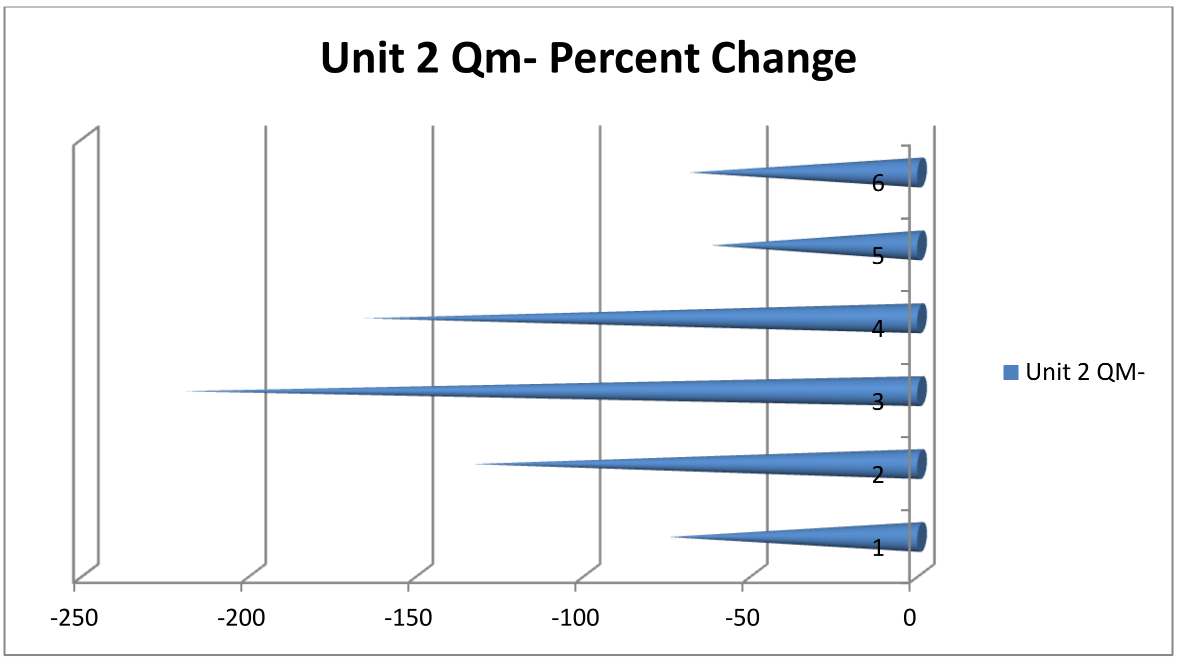


The above charts show that the PDA in Unit 1 has changed from going down to going up on a change from full load hot to low load cold. The bias chart below shows that the bias has shifted from a surface to a bulk insulation PDA. This could be attributed to better control of surface PD by the maintenance crews.

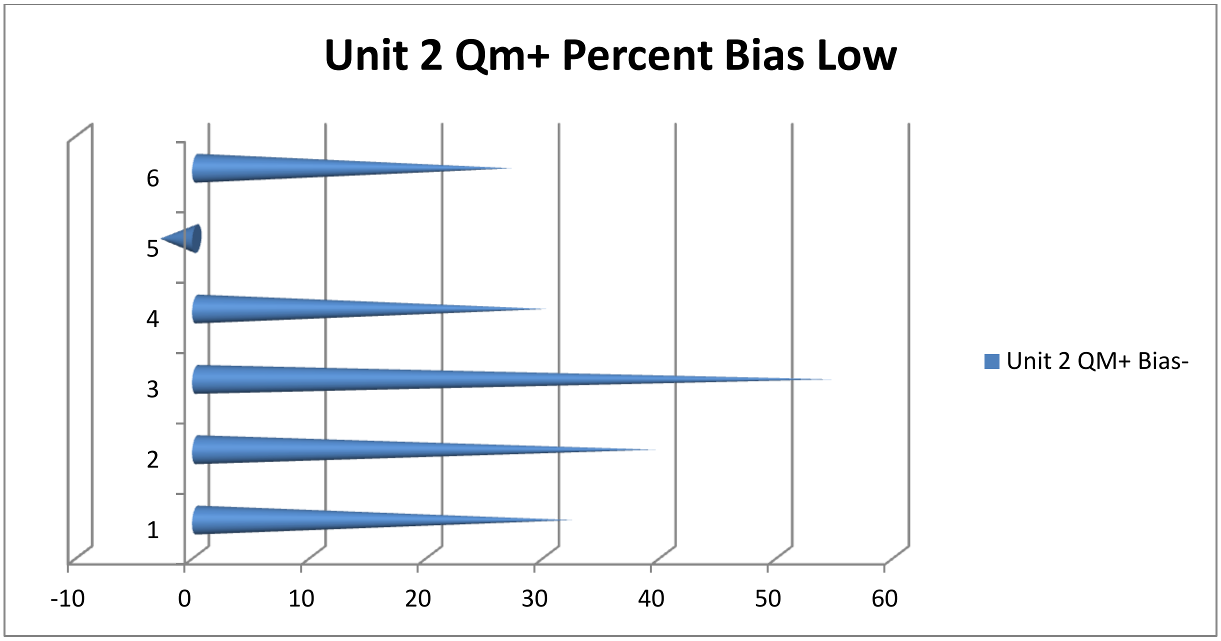


Below are the charts for Unit 2





Unit 2 has also shifted toward more PDA at the lower temperatures. The Qm+ all decreased in 2002. In 2012, only one decreased. In 2002, Qm- decreased a minimum of 63%. In 2012 the maximum decrease was 54%. The chart below compared to 2012 shows that the bias has increased in Unit 2 towards surface PD at the lower temperatures.



Phase 1 Conclusion

The two units studied show two different effects of the operating temperature decrease. Unit one shows an overall increase in PDA with a small bias towards surface PDA. This indicates that as the tension relaxes in the insulation system the insulation expands. This creates more or larger voids for the PDA to occur in the bulk of the insulation with a small increase in voids along the surface of the coil.

Unit 2 showed a small increase in Qm+ with a decrease in Qm-. This showed that the PDA shifted from the bulk insulation to the surface. This would indicate that the insulation did not expand as much in this unit so the voids occurred between the coils and the stator core or fillers. The ozone created at the surface PDA sites leads to destruction of the conductive coating and filler strips which leads to increased surface PDA.

Previous testing conducted in 2002 compared to the recent testing shows that Unit 1 has changed from a decreasing PDA at lower temperatures and power levels to an increasing PDA. The PDA has shifted from the surface to the bulk insulation.

Unit 2 Qm+ used to decrease but now slightly increases. Unit 2 Qm- still decreases but at a much lower level than in 2002. Unit 2 always had a surface bias at low temperatures and power levels but it has become more pronounced.

The above results show that over time the coils in a stator core are less able to compensate for the stresses that the changes in operating temperature cause. This is seen by increases in the PDA levels at low temperature levels due to more voids in or on the insulation. To minimize PDA levels in older windings, the stator temperatures should be kept at a constant level over all power ranges to minimize these voids.

Phase 2 results

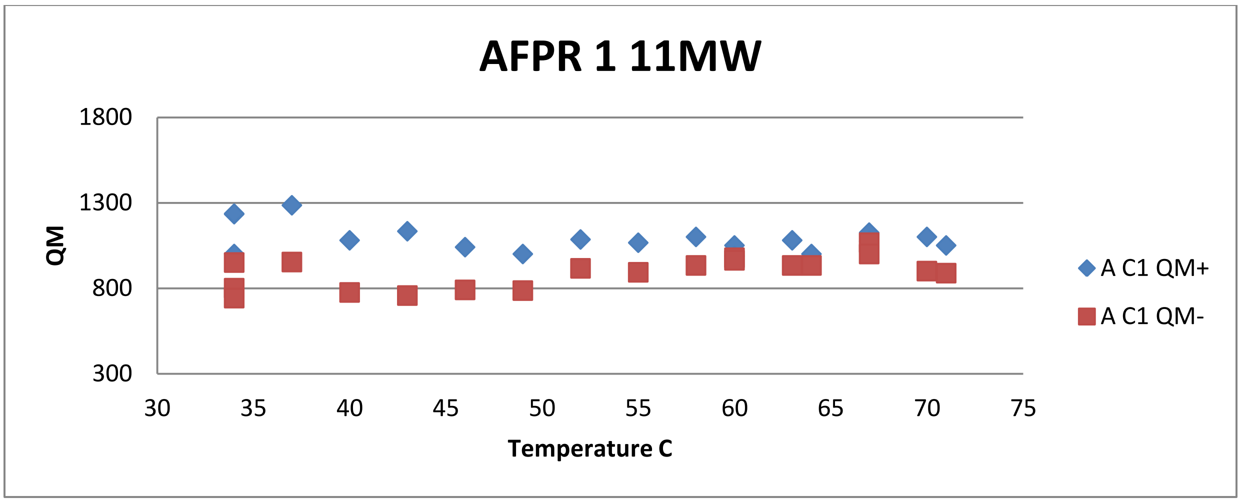
The phase two testing used all three units. The units were run at full load and partial load while the stator temperature was raised from a low temperature to normal summer operating temperature which is in the low 70's C.

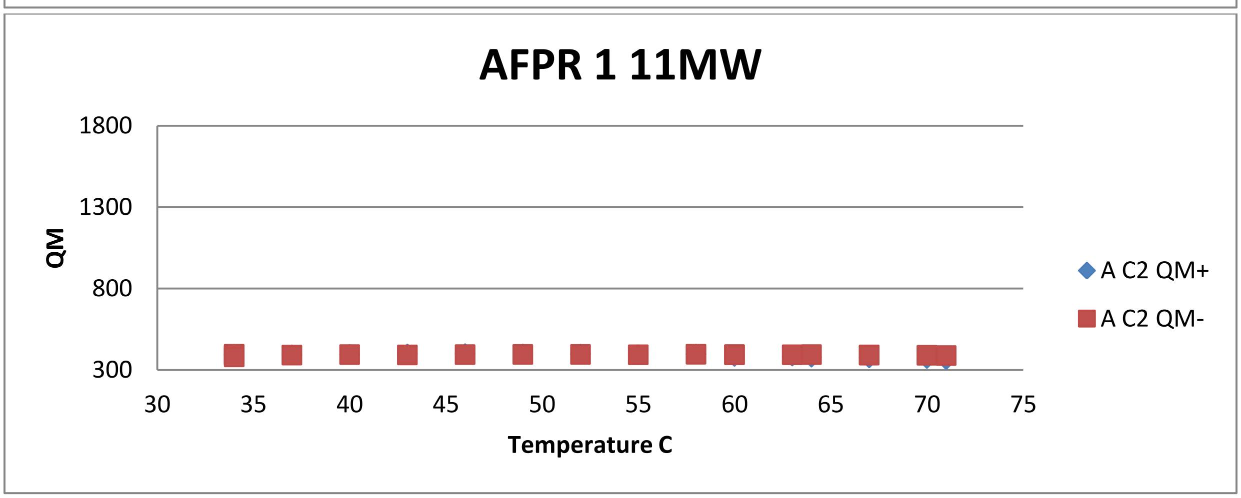
For the testing conducted in the second phase, it was found that a comparison between Qm+ and Qm- versus temperature as the horizontal axis produced a chart that provided a visual method to assess both how the PDA in general was changing along with the how the positive or negative bias was changing. The Pulse Phase Analysis (PPA) plots are included as needed.

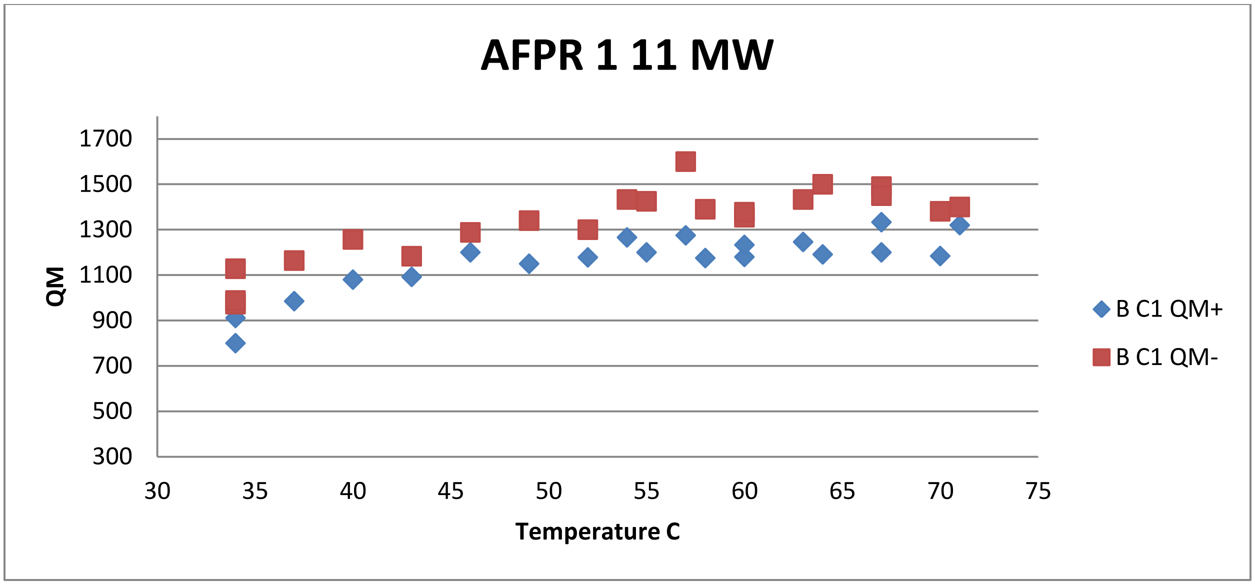
Unit1

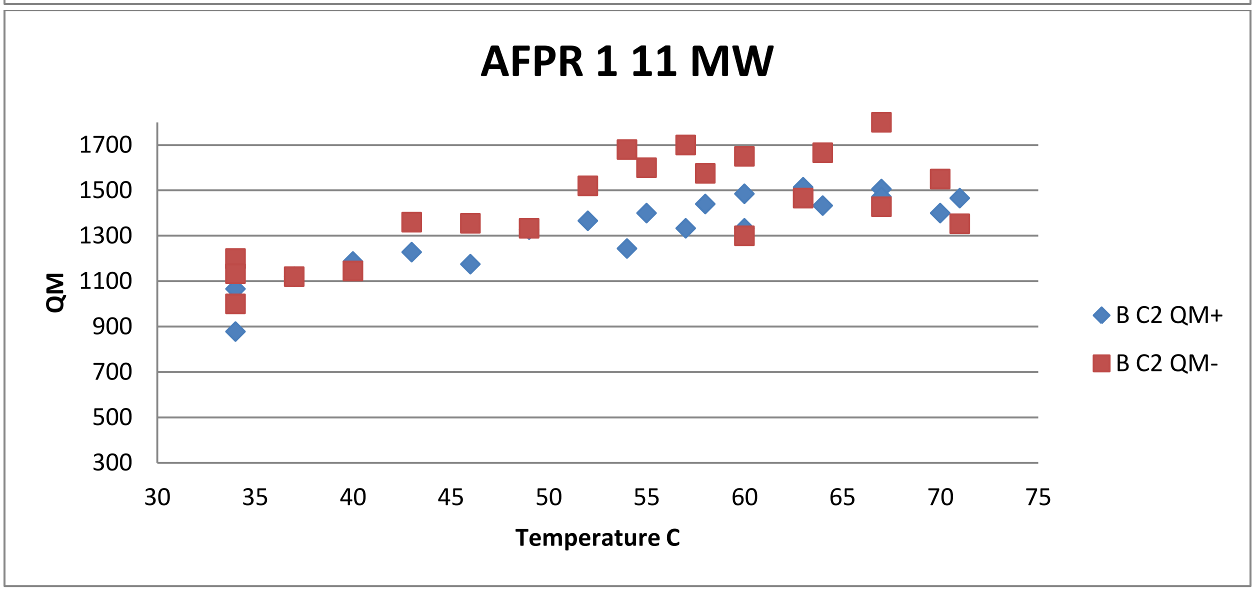
Unit was tested at 33MW and 11 MW. The temperature ranges are as shown in the graphs. The remainder of the units operating parameters were held constant.

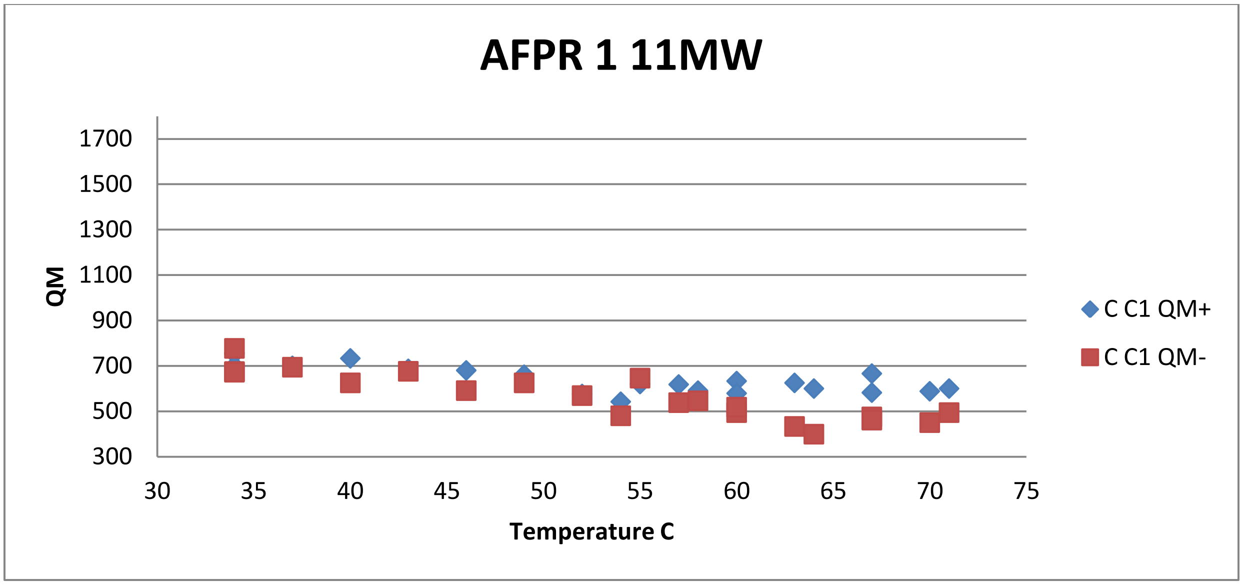
Low Load Test

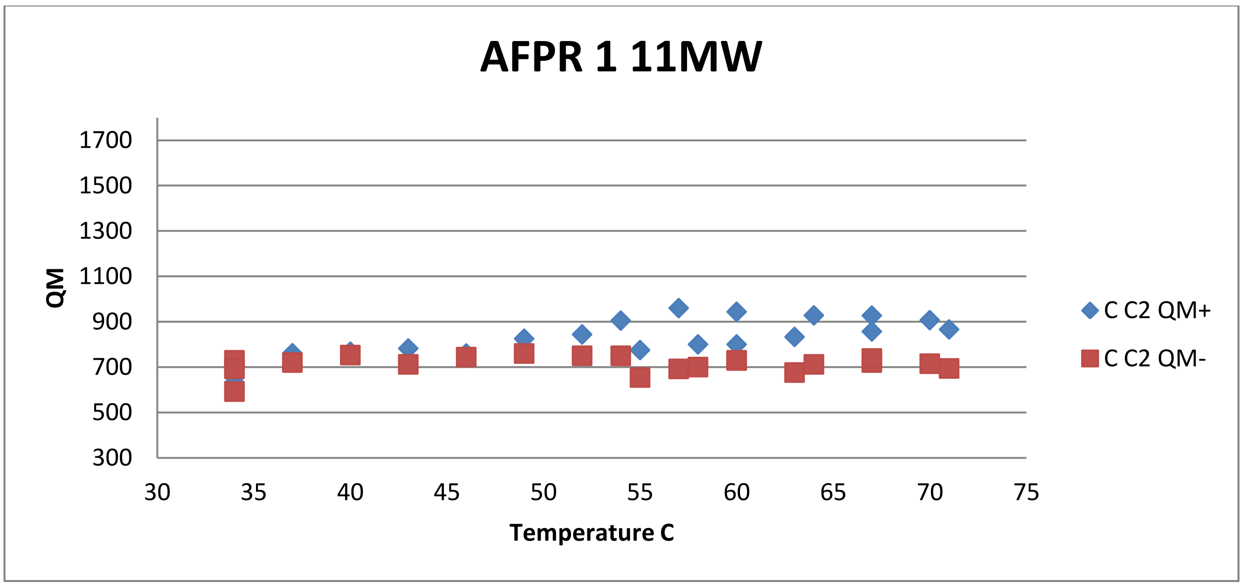





AFPR 1 11 MW
1700
1500
1300
1100
900
700
500
300
QM
30
35
40
45
50
55
60
65
70
75
Temperature C
B C1 QM+
B C1 QM-


AFPR 1 11 MW
1700
1500
1300
1100
900
700
500
300
QM
30
35
40
45
50
55
60
65
70
75
Temperature C
B C2 QM+
B C2 QM-



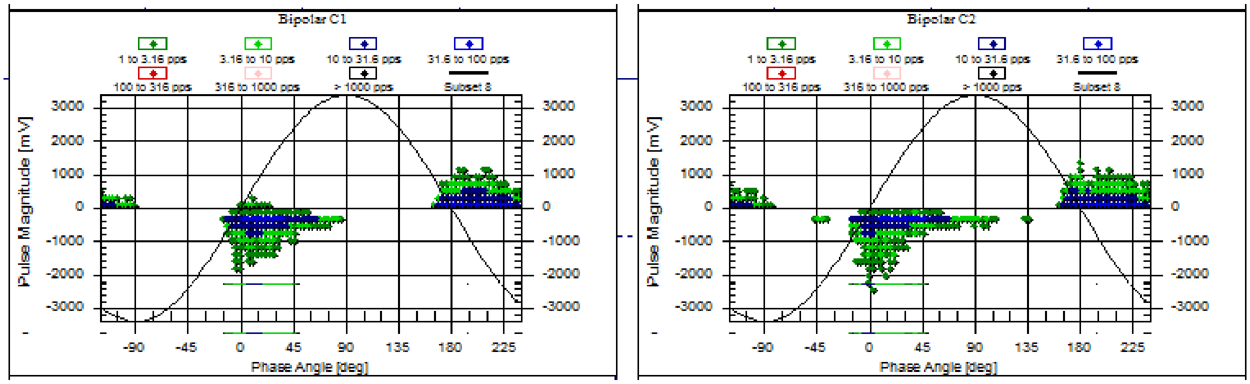


The phase A C1 results show a decrease in Qm+, which is consistent with loose windings. Qm- remains constant. C2 remains constant but what is of note is how low the PDA is on that coupler.

Both couplers on B phase increase with temperature. The only failure mechanism that normally increases with temperature is PD in the Semicon/Grading coating interface (SGCI). However it normally has a positive predominance and this phase has a negative predominance.

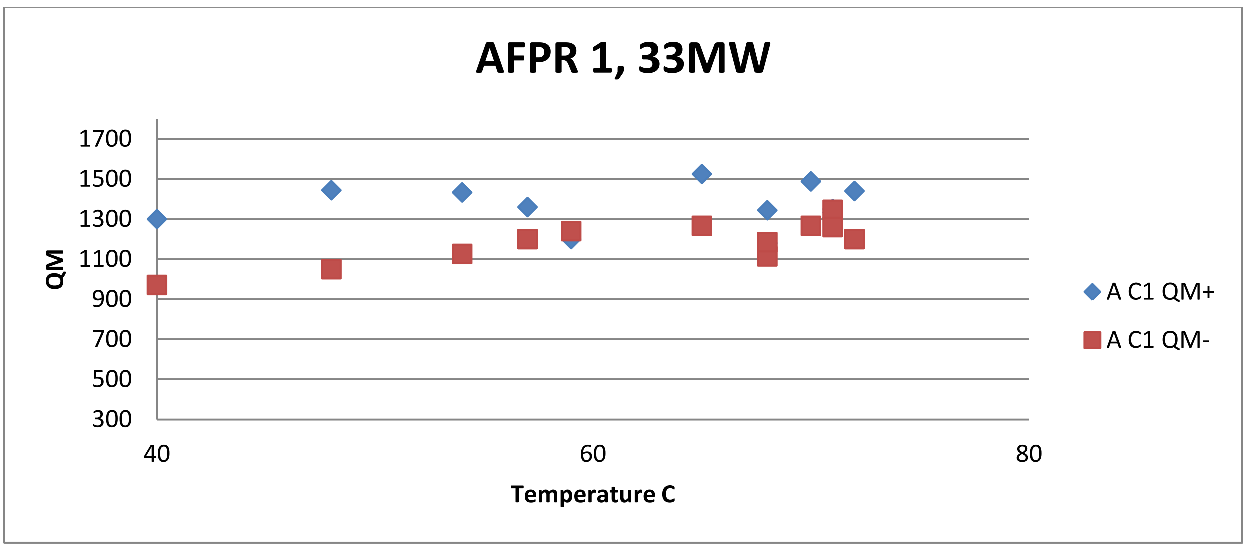
Phase C C1 has a decrease with temperature and goes to Qm+ predominance. C C2 has a constant Qm- with an increase in Qm+. Both of these couplers show some SGCI is occurring as the temperature increases.

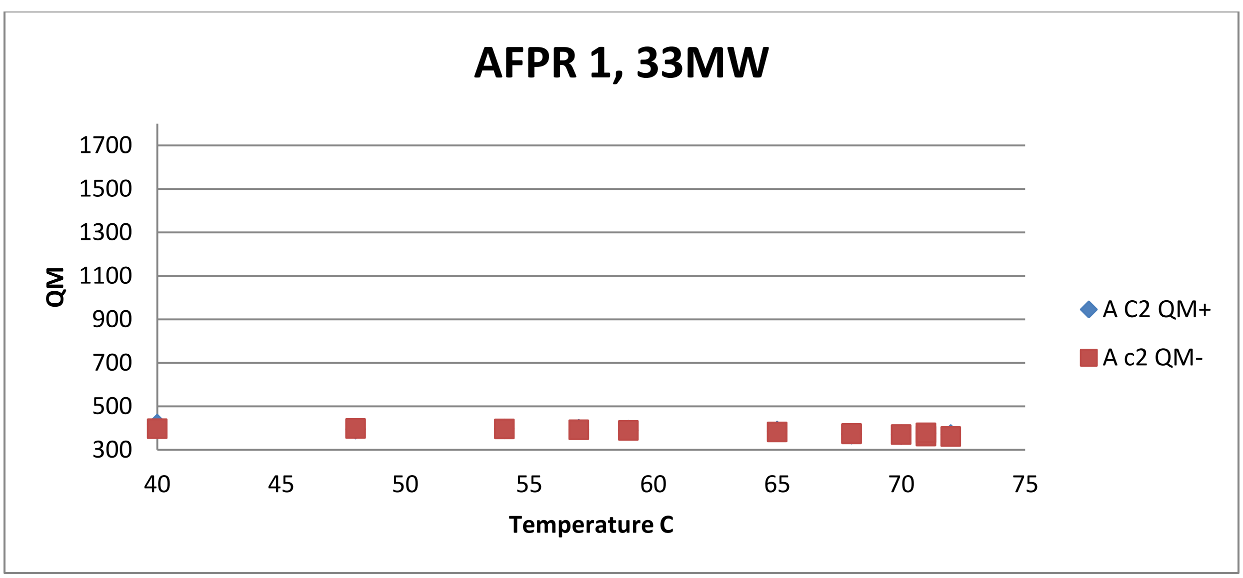
Of note is the phase B PPA shown below.

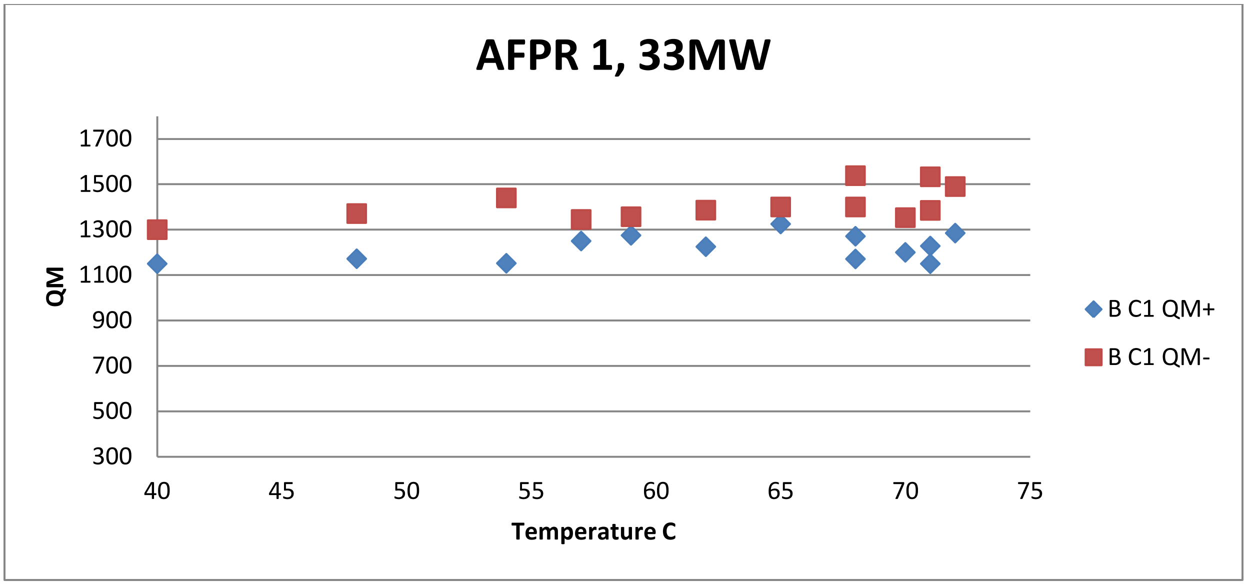


If the SGCI is severely deteriorated this may show up as pulses at 0 and 180 degrees. (1) This also could be a combination of contamination, inadequate spacing, and SGCI.

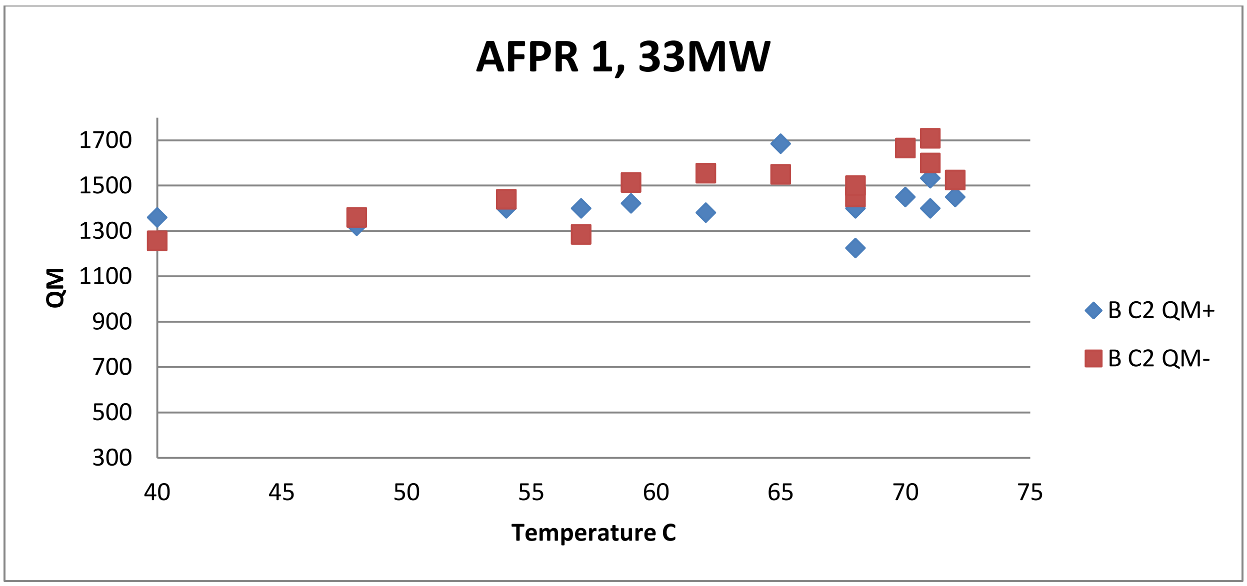
High Load Test



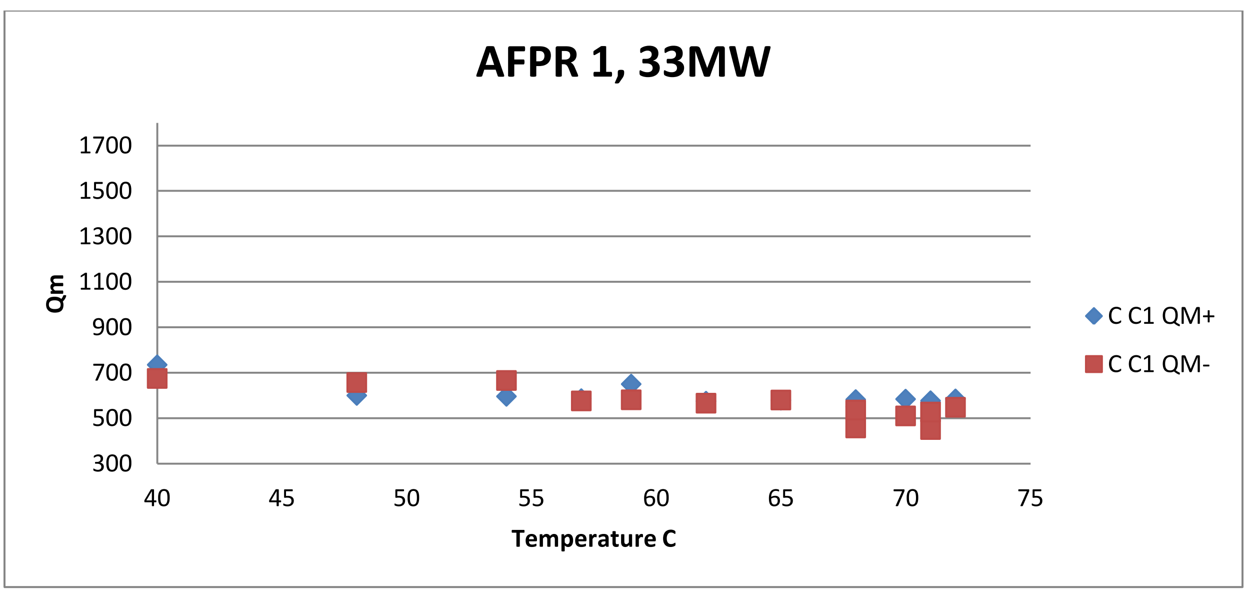




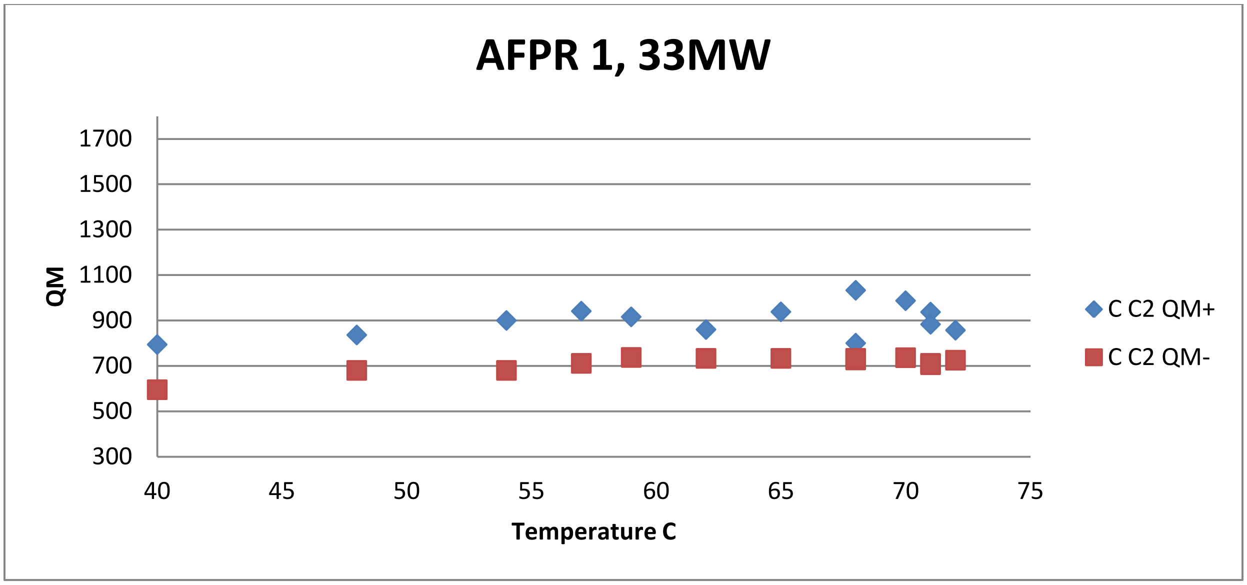
AFPR 1, 33MW
QM
1700
1500
1300
1100
900
700
500
300
40
45
50
55
60
65
70
75
Temperature C
B C1 QM+
B C1 QM-



AFPR 1, 33MW
QM
1700
1500
1300
1100
900
700
500
300
40
45
50
55
60
65
70
75
Temperature C
B C2 QM+
B C2 QM-



AFPR 1, 33MW
Qm
1700
1500
1300
1100
900
700
500
300
40
45
50
55
60
65
70
75
Temperature C
C C1 QM+
C C1 QM-



Under high load A C1 now has an increase with temperature. C2 remains constant, which is interesting with the load change.

Phase B still increases with temperature but starts at a higher initial level.

C phase reacts the same under high load and the PPA's also look the same.

General Conclusion

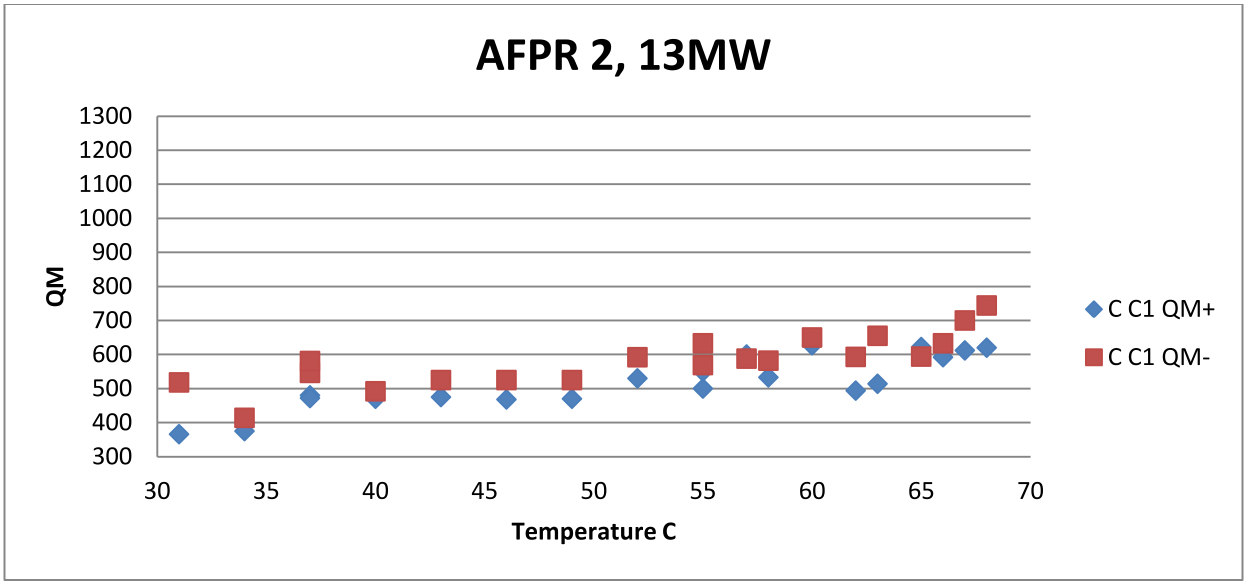
On this unit loading is not a major factor on the level of PDA. Temperature is a major factor only on phase B with more of an influence at low loading levels. This phase shows severe SGCI at low loading levels. There is indication of loose windings on several couplers at low load conditions. There is probably a combination of failure mechanisms occurring in this unit.

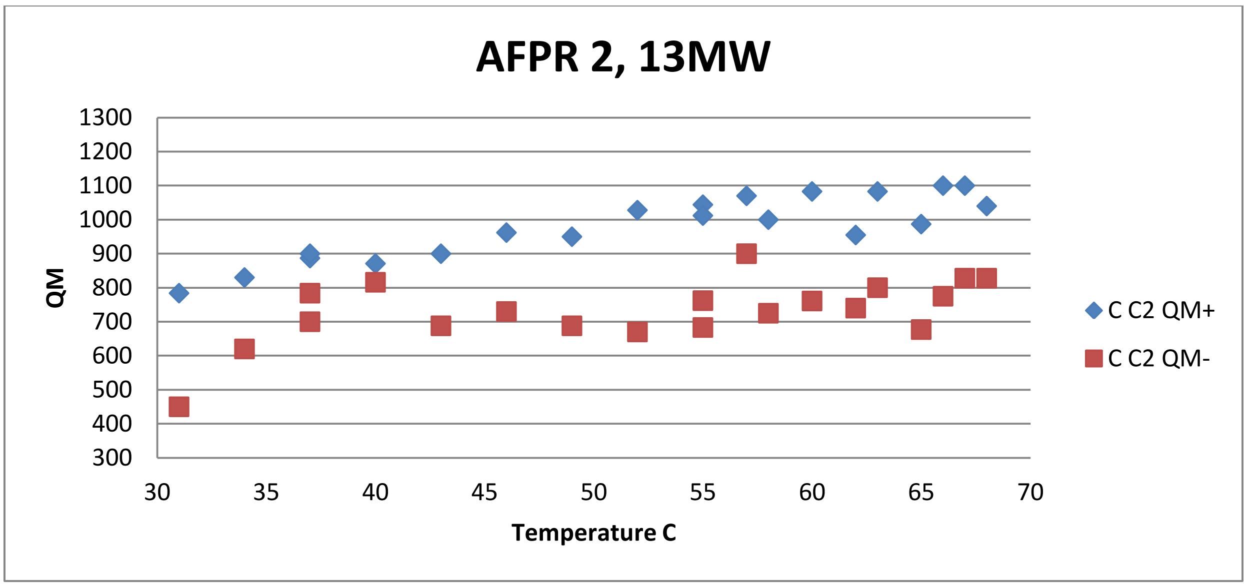
Unit 2

The tests on unit 2 were conducted at 13 MW and 25 MW. The temperature ranges are as shown in the graphs. The remainder of the operating parameters were held constant.

Low Load Test

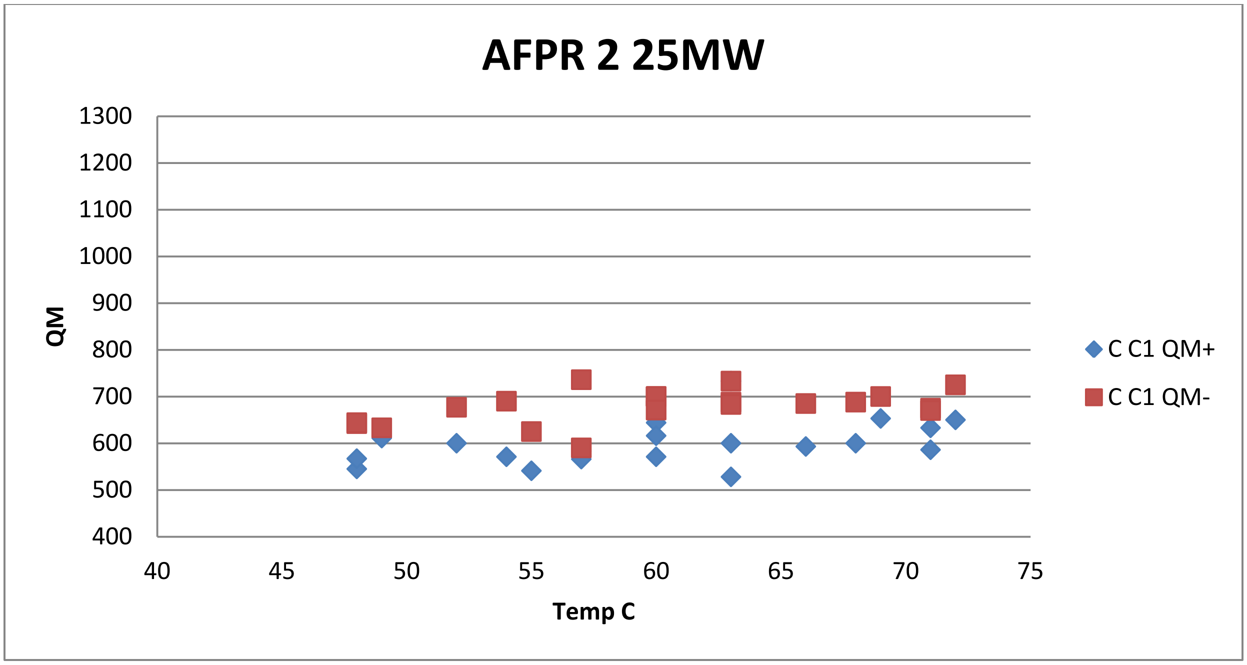
The results below show the minimum changing coupler and the maximum changing coupler. They happen to be the couplers on C phase.

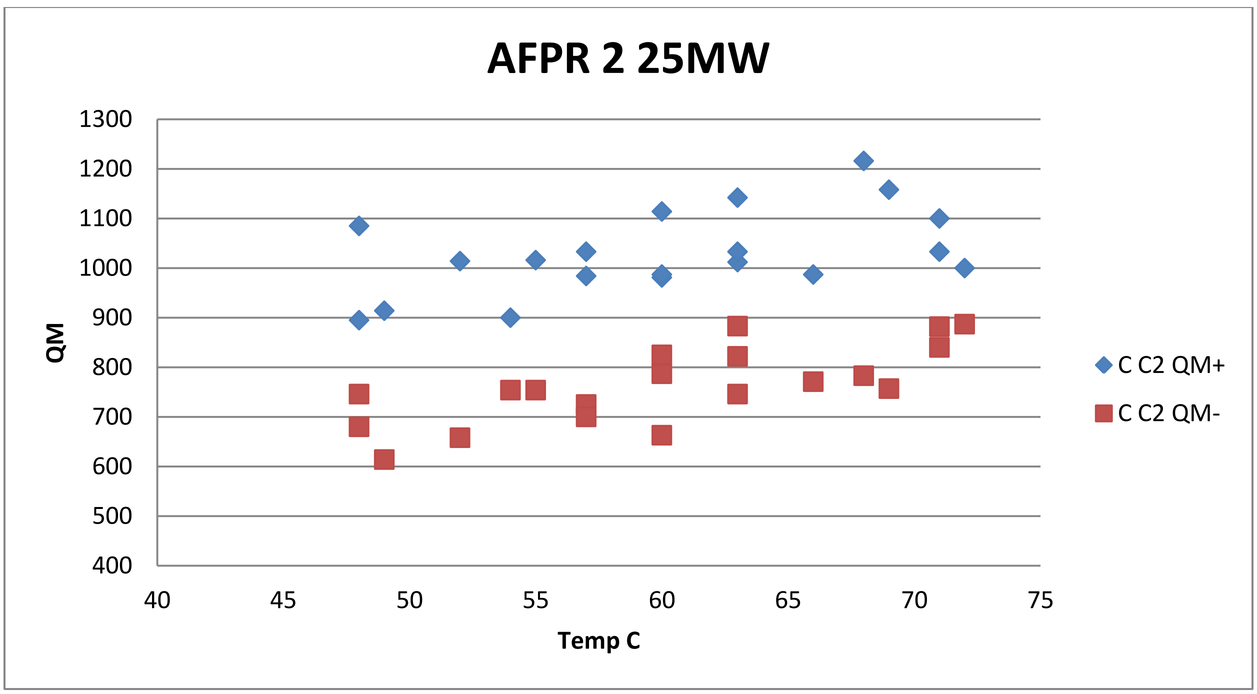




High Load Test

Phase C's couplers are again the minimum changing coupler and the maximum changing coupler at high load.

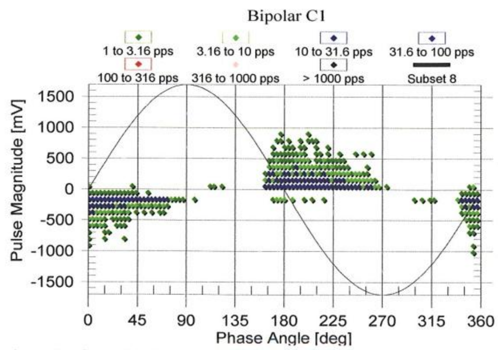

AFPR 2 25MW
1300
1200
1100
1000
900
800
700
600
500
400
QM
40
45
50
55
60
65
70
75
Temp C
C C1 QM+
C C1 QM-


AFPR 2 25MW
1300
1200
1100
1000
900
800
700
600
500
400
QM
40
45
50
55
60
65
70
75
Temp C
C C2 QM+
C C2 QM-

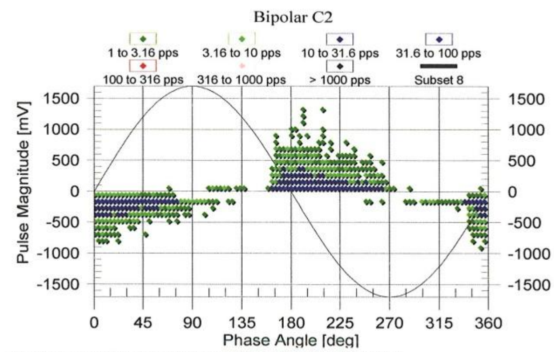
Pulse Phase Analysis (ABC)

Folder: Idaho Power\American Falls\, Asset Class: Hydro Generator
Asset Name: Unit # 2, Class: Differential (PDA), Sensor Type: End-Cap

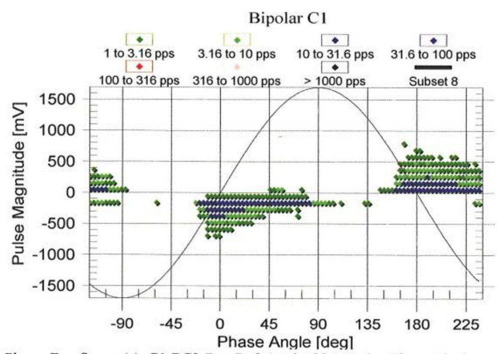
Operating Load: 25.70 MW, Reactive Load: -0.70 MVAr, Operating Asset Temp: 22 deg C, Operating Voltage: 13.87 kV
Operating Gas Pressure: N/A, Ambient Temp: -7 deg C, Ambient Humidity: 24.00 %, Freq. (Test Duration): 60 Hz, (1 sec.)



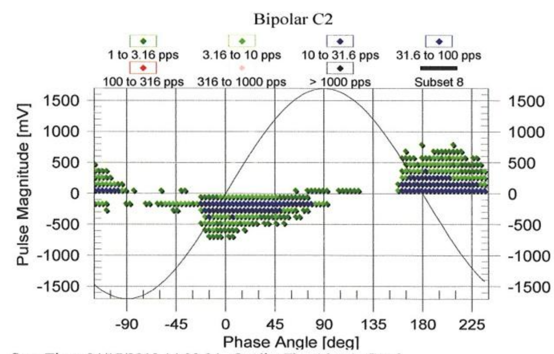
Phase: A, Sensor(s): C1-AC2-A, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1808, NQN- 1412, Qm+ 925, Qm- 700



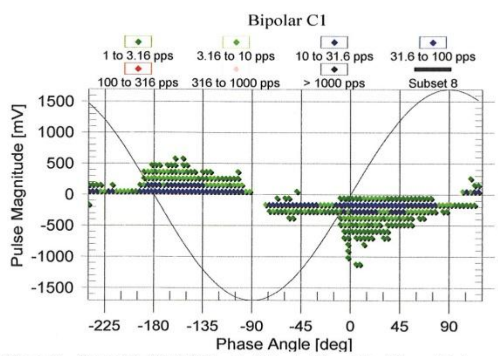
Start Time: 04/17/2013 14:32:50, Quality Flag (short): OVR
C2: NQN+ 2198, NQN- 1628, Qm+ 1037, Qm- 775



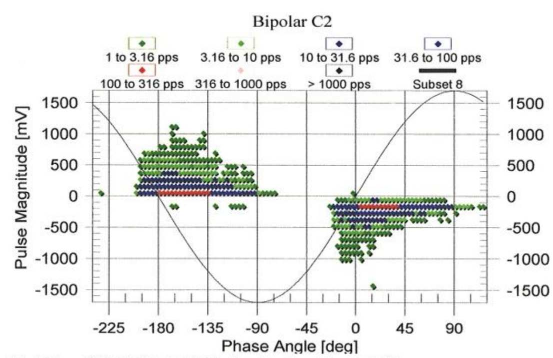
Phase: B, Sensor(s): C1-BC2-B, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1500, NQN- 1139, Qm+ 740, Qm- 580



Start Time: 04/17/2013 14:33:34, Quality Flag (short): Good
C2: NQN+ 1928, NQN- 1372, Qm+ 833, Qm- 664



Phase: C, Sensor(s): C1-CC2-C, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1357, NQN- 1580, Qm+ 650, Qm- 725



Start Time: 04/17/2013 14:34:18, Quality Flag (short): OVR
C2: NQN+ 2427, NQN- 1854, Qm+ 1000, Qm- 887

Iris Power LP, 3110 American Dr., Mississauga, On, Canada L4V 1T2, Phone: (905)-677-4824, Fax: (416) 620-1995

General Conclusion

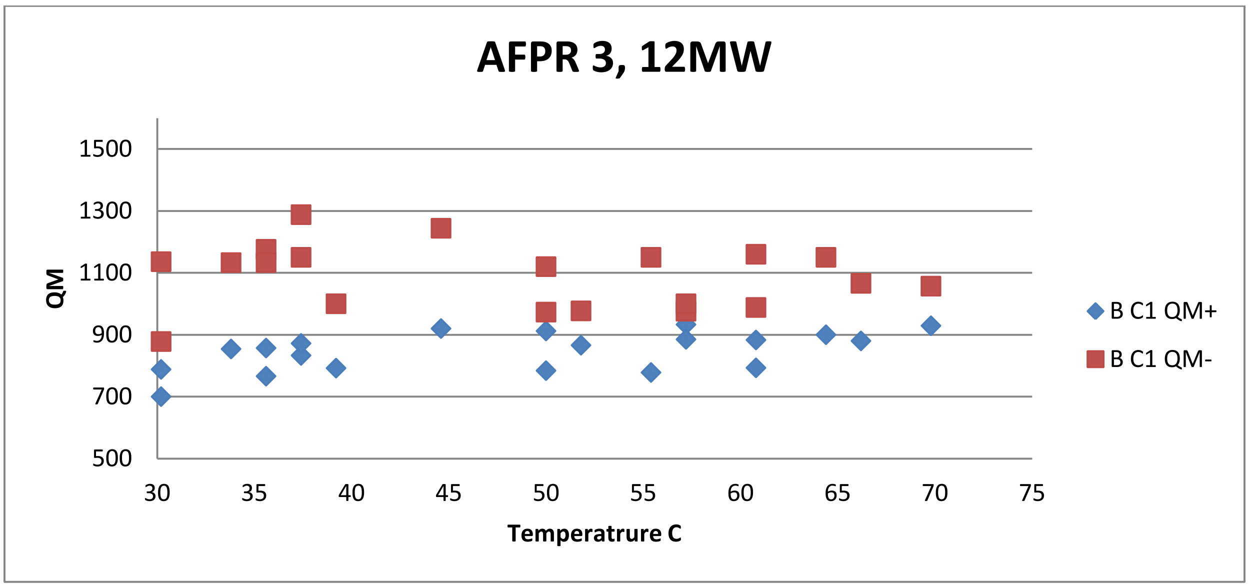
The above data would seem to correspond to the failure mechanism at the SGCI at most of the couplers. This failure mechanism has positive polarity predominance. Phase C coupler C1 was the only one that had a negative predominance. The other 5 couplers had a positive predominance. All couplers had an increase in both Qm's as temperature increased. This failure mechanism is one of the few that has a positive increase with temperature. Loading did increase the PDA but only by 10 or 20 percent. As with unit 1, this also could be a combination of contamination, inadequate spacing, and SGCI.

Unit 3

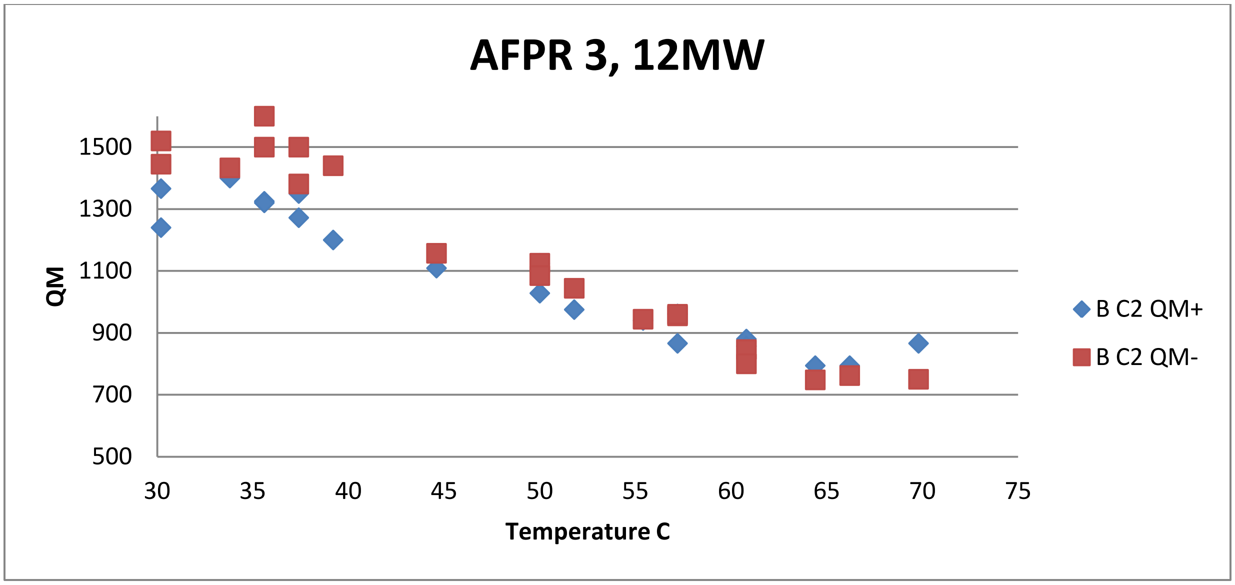
The tests on unit 2 were conducted at 12 MW and 33 MW. The temperature ranges are as shown in the graphs. The remainder of the operating parameters were held constant.

Low Load Test

The couplers on unit 3 show a marked difference between them. The phases do not show any significant difference so we will show the two couplers on one phase.



On this coupler, the positive increase in Qm with temperature is an indication of deterioration of the semicon/grading coating. The Qm- bias and then its decrease is indicative of voids near the copper surface normally seen with load cycling. Even though the average Qm is basically constant, the general decrease in Qm- compared to the increase in Qm+ would be a considered a good thing as a deterioration of the semicon/grading coating area can be repaired, insulation near the copper cannot.



On this coupler, the decrease in Qm is very large. That both Qm+ and Qm- decrease by such magnitude indicates the temperature increase tightens up the windings a large amount where this coupler can see. At low temperatures, there is again a slight Qm- bias and then it decreases until it turns into a Qm+ bias. In general, the tightening of the coils transfers the PD from near the copper to the surface. The Qm- predominance along with a slight 45 degree predominance would indicate the load cycling failure mechanism. The large drop in both Qms indicates that the coils are very loose at low temperatures.

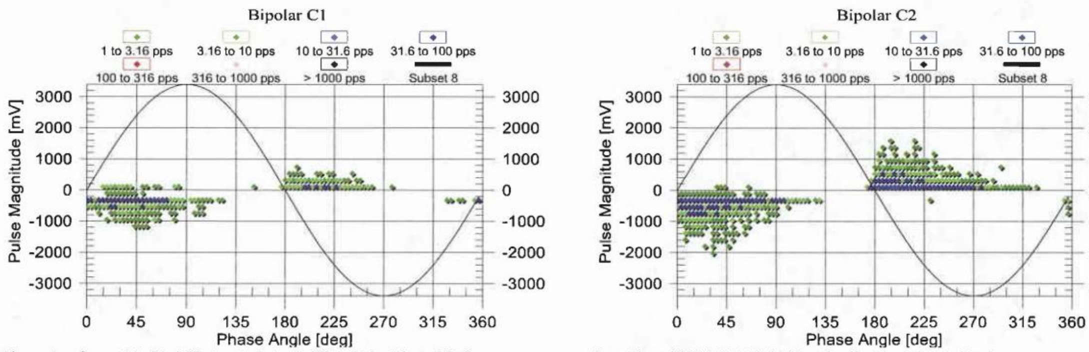
Unit 3 30C 12 MW results.

Pulse Phase Analysis

IRIS POWER
www.irispower.com

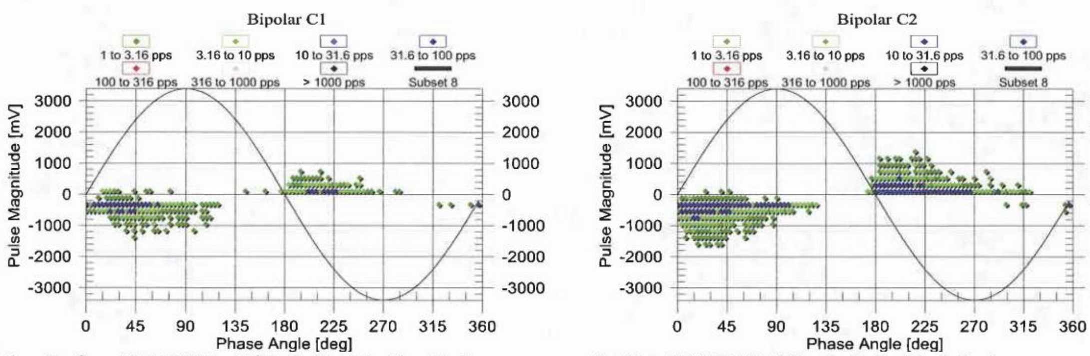
Folder: Idaho Power\American Falls\, Asset Class: Hydro Generator
Asset Name: Unit # 3, Class: Differential (PDA), Sensor Type: End-Cap

Operating Load: 11.90 MW, Reactive Load: -1.30 MVAr, Operating Asset Temp: -1 deg C, Operating Voltage: 13.92 kV
Operating Gas Pressure: N/A, Ambient Temp: -8 deg C, Ambient Humidity: 43.00 %, Freq. (Test Duration): 60 Hz, (1 sec.)



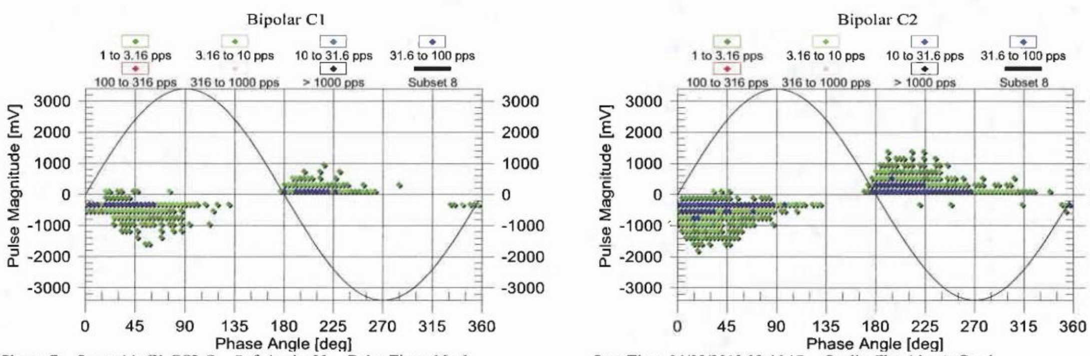
Phase: A, Sensor(s): C1-AC2-A, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1384, NQN- 2149, Qm+ 750, Qm- 1033

Start Time: 04/08/2013 09:44:49, Quality Flag (short): Good
C2: NQN+ 2817, NQN- 3071, Qm+ 1400, Qm- 1533



Phase: B, Sensor(s): C1-BC2-B, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1421, NQN- 2135, Qm+ 788, Qm- 1136

Start Time: 04/08/2013 09:45:33, Quality Flag (short): Good
C2: NQN+ 2734, NQN- 2921, Qm+ 1366, Qm- 1520



Phase: C, Sensor(s): C1-CC2-C, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1456, NQN- 2208, Qm+ 825, Qm- 1112

Start Time: 04/08/2013 09:46:17 , Quality Flag (short): Good
C2: NQN+ 2719, NQN- 3125, Qm+ 1425, Qm- 1520

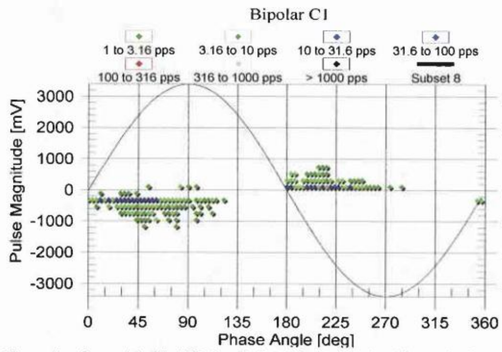
Unit 3 69C 12 MW results.

Pulse Phase Analysis

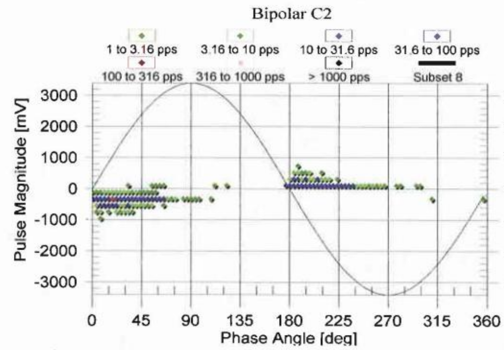
IRIS POWER
www.irispower.com

Folder: Idaho Power\American Falls\, Asset Class: Hydro Generator
Asset Name: Unit # 3, Class: Differential (PDA), Sensor Type: End-Cap

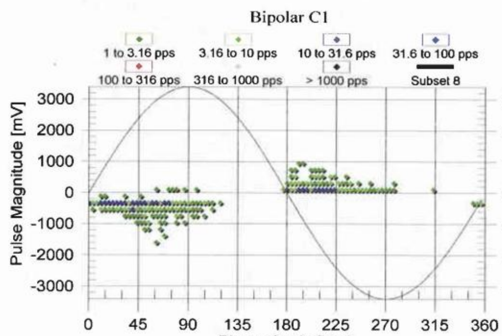
Operating Load: 12.00 MW, Reactive Load: -0.30 MVAr, Operating Asset Temp: 21 deg C, Operating Voltage: 13.89 kV
Operating Gas Pressure: N/A, Ambient Temp: -7 deg C, Ambient Humidity: 37.00 %, Freq. (Test Duration): 60 Hz, (1 sec.)



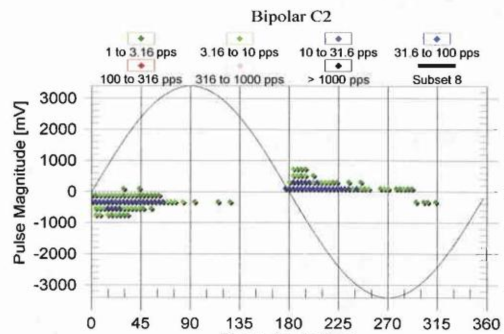
Phase: A, Sensor(s): C1-AC2-A, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1424, NQN- 1941, Qm+ 789, Qm- 972



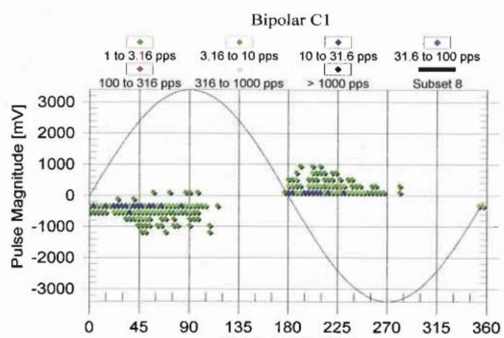
Start Time: 04/08/2013 16:01:42, Quality Flag (short): Good
C2: NQN+ 1357, NQN- 1444, Qm+ 736, Qm- 736



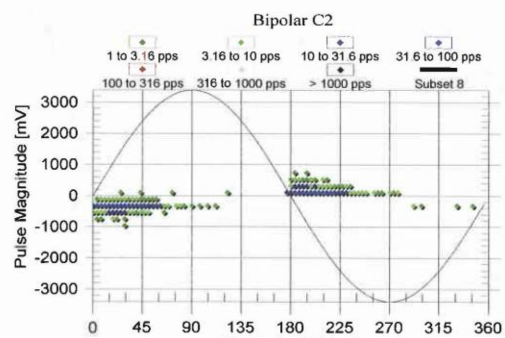
Phase: B, Sensor(s): C1-BC2-B, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1525, NQN- 1983, Qm+ 929, Qm- 1057



Start Time: 04/08/2013 16:02:26, Quality Flag (short): Good
C2: NQN+ 1606, NQN- 1383, Qm+ 866, Qm- 750



Phase: C, Sensor(s): C1-CC2-C, Ref. Angle: 90, Delay Time: 6 [ns]
C1: NQN+ 1623, NQN- 1840, Qm+ 1033, Qm- 1040

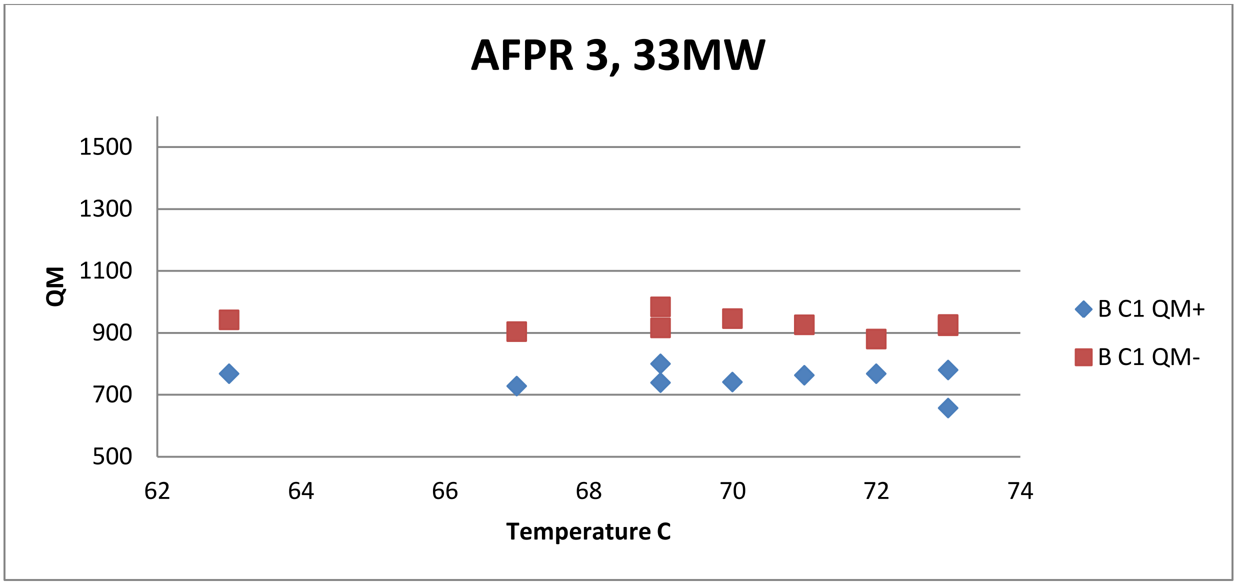


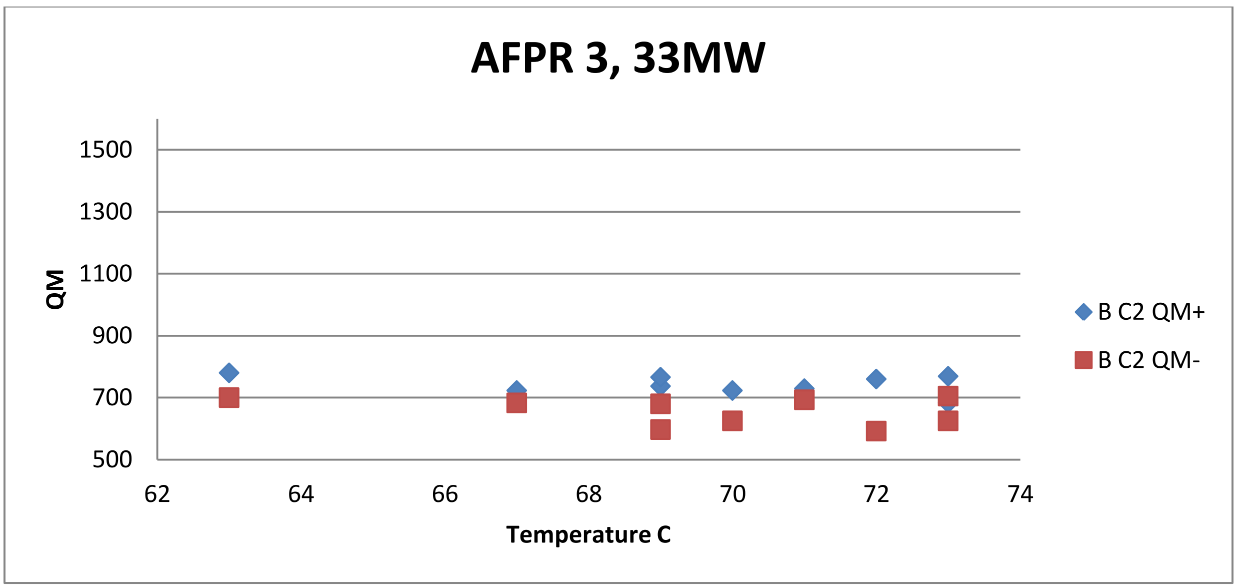
Start Time: 04/08/2013 16:03:10 , Quality Flag (short): Good
C2: NQN+ 1494, NQN- 1388, Qm+ 780, Qm- 707

Iris Power LP, 3110 American Dr., Mississauga, On, Canada L4V 1T2, Phone: (905)-677-4824, Fax: (416) 620-1995

High Load Test

Unfortunately the unit started at a relatively high temperature.





Both couplers remain relatively constant over this temperature range. The item of note between the high and low load readings is that the PDA drops on C1 by 20% to 30% on an increase in load. This combined with the negative predominance points toward the load cycling failure mechanism. This mechanism is a deterioration of the bond between the groundwall and turn insulation.

General Conclusion

This unit has loose windings on the C2 side that are highly affected by temperature at low loads. The C1 side is relatively tight but shows indications of a deterioration of the bond between the groundwall and turn insulation.

Phase 2 Results

The phase 2 testing showed a complex picture of the failure mechanisms occurring in the units. The question that was to be answered is how operating temperature was affecting PDA and if controlling the temperature could be of benefit.

On unit 1 there is a large increase in PDA on phase B as the temperature is increased. Phases A and C could benefit by increasing the temperature at low loading levels but not at high loading levels due to the SGCI failure mechanism.

On unit 2 the SGCI failure mechanism looks to be present on all phases. Thus an increasing temperature increases the PDA in the unit.

Unit 3 has a split personality. One side of the unit shows loose windings, the other side shows a deterioration of the bond between the groundwall and turn insulation. Both of these mechanisms would benefit from keeping the unit at a higher operating temperature, especially the side with the loose windings.

Conclusion

The testing of these units produced a very good picture of how the PDA changes with the change of the stator temperature. It showed that there are several different failure mechanisms occurring in the units. Units 1 and 2 have failure mechanisms that would be considered normal for units of this age. Unit 3's one side has a normal failure mechanism but the other side shows loose windings which could be from insufficient packing when they were installed.

Unit 3 could benefit from maintaining the operating temperature at a constant 70C. Unit 1 and 2 are actually better off being run at lower temperatures due to the failure mechanisms present.

References

1, IRIS Partial Discharge Course, 6.1.2, 2004

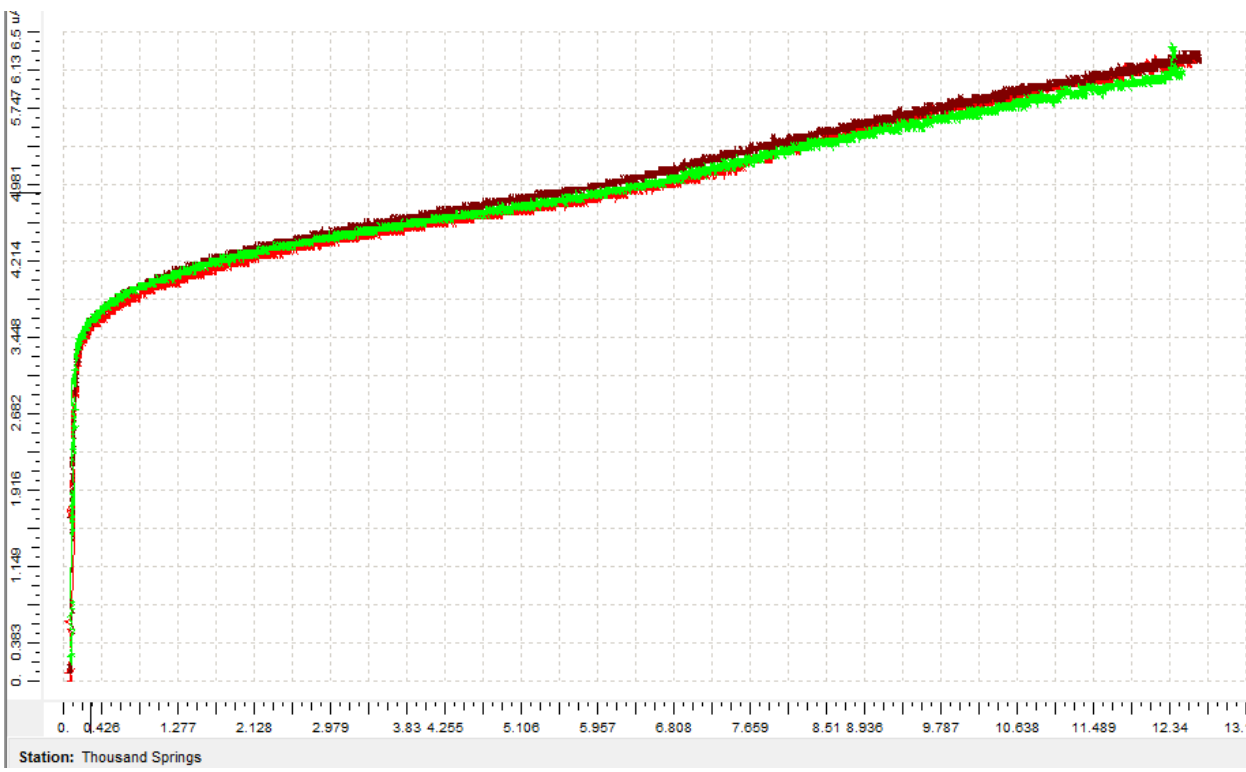
DC Ramp Testing on 6.9 kV Generators

Introduction

While there has been much written and results shown for DC Ramp testing on 13.8 kV and higher machines, there is little information about using this test on 6.9 kV machines. At Idaho Power we have 6 hydro plants with a total of 11 units of this voltage. The vintages are from 1920 to 1994. Due to concerns with the age of the windings, and with planned refurbishment of runners to occur on some of the units, we have been conducting DC Ramp testing on several units to assess the health of the windings. This report presents the results from the different units, possible interpretations of the results, and any actions taken to improve the test results.

Thousand Springs Unit 3

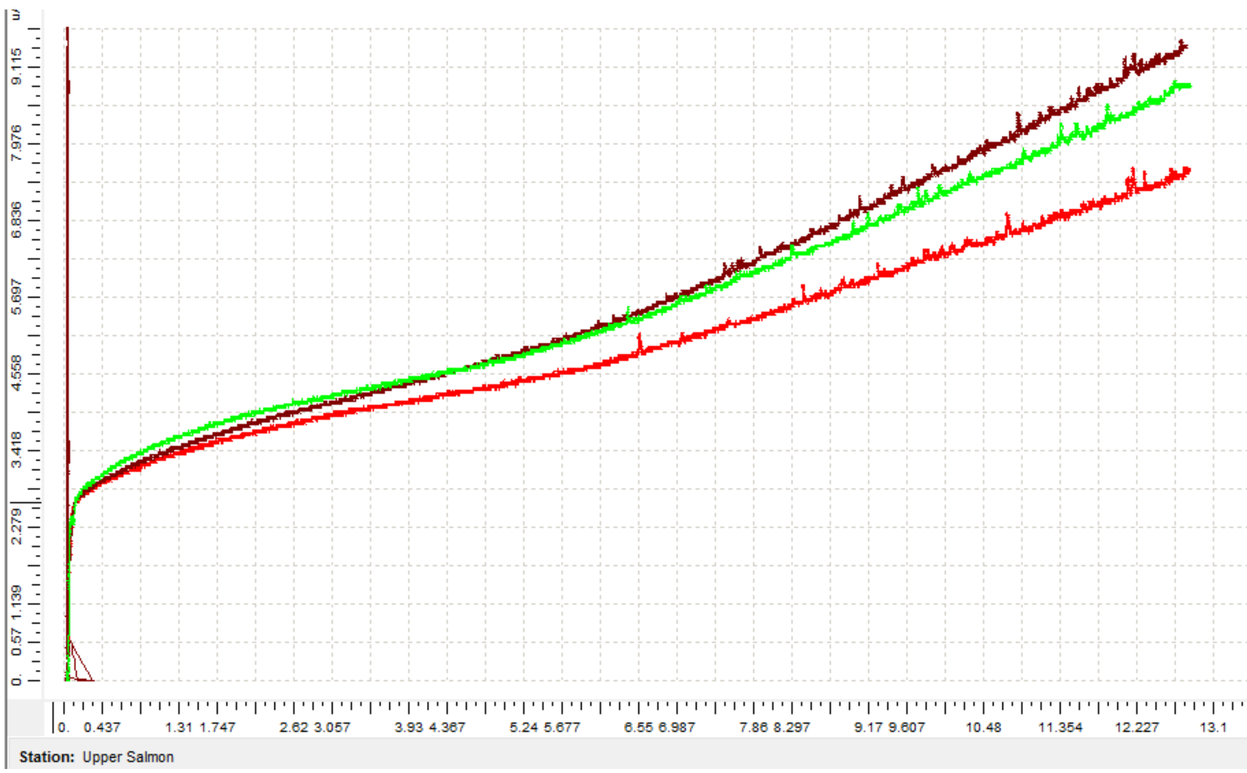
This was the first 6.9 kV machine tested. The Thousand Springs unit 3, TSPR 3, windings are 1960 vintage asphalt. The unit itself is a 1920 8.5 MVA General Electric vertical unit. The unit was isolated with very few external connections. TSPR 3 has very few starts and stops and runs at an almost constant loading level across the year. TSPR 3 can be looked at as a best case with asphalt windings. Below is a plot of the results.



The results show a slight shift in slope around 6 kV. In some studies this shift is attributed to deteriorated insulation. Others have found that contaminated end windings can also cause this. We will see this shift in all the 6.9 kV machines tested. While these machines are hard to clean and most are fairly old, it is seen on asphalt, polyester, and epoxy windings of varying ages.

Upper Salmon Unit 2

The Upper Salmon unit 2 is a 9 MVA 1937 General Electric vertical unit. The exact nature of the windings in this unit is unknown. It is known that a rewind occurred in 1969. It is probable that there are polyester-mica coils in the unit as the Lower Malad generator had them installed in 1968. This unit has several connections that cannot be wrapped or cleaned well. This can be seen by the noise in the below results.

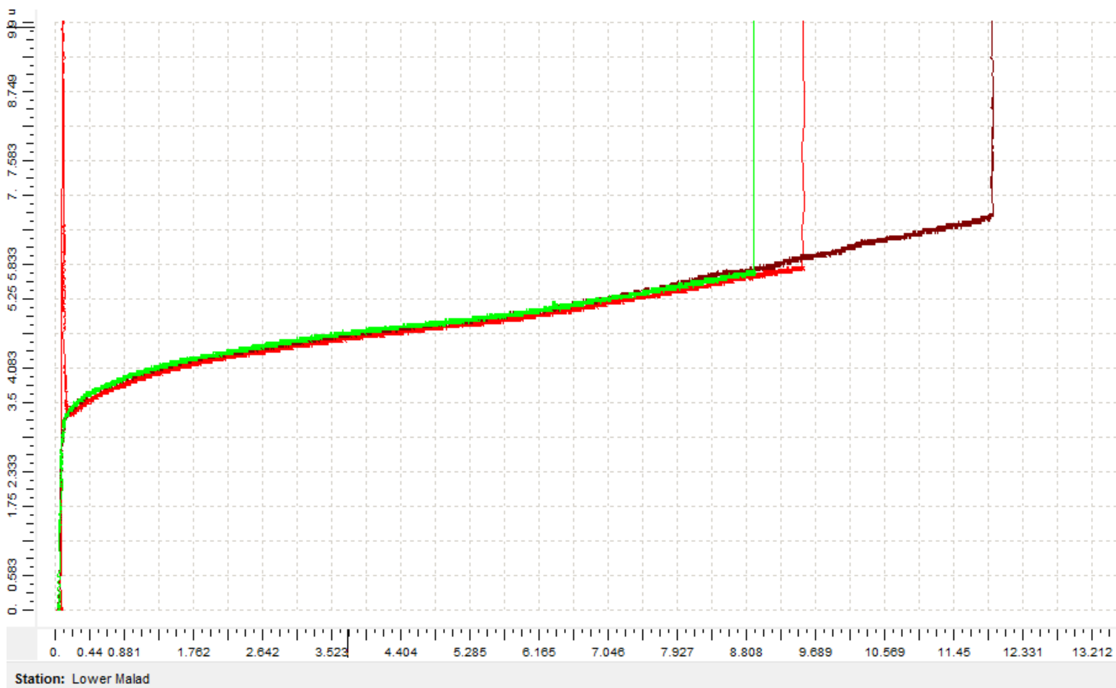


The results show marked differences between the phases. Assessable connections were inspected and cleaned but the results remained constant. With the age of the unit there could be different types of materials used in different places that could cause these results.

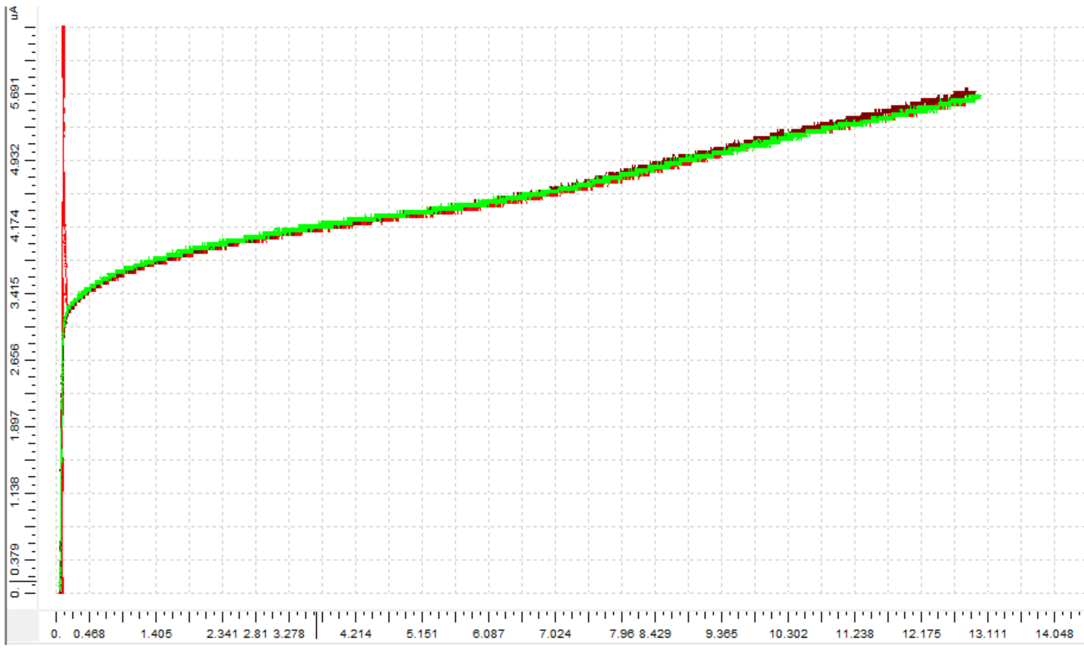
The leakage is higher than Thousand Springs 3, but is not excessive.

Lower Malad

The Lower Malad unit is a 15.5 MVA 1948 Allis-Chalmers vertical unit. It has a set of 1968 General Electric coils, probably polyester mica as they are rated as class F insulation. Below are the first tests run in October of 2012.

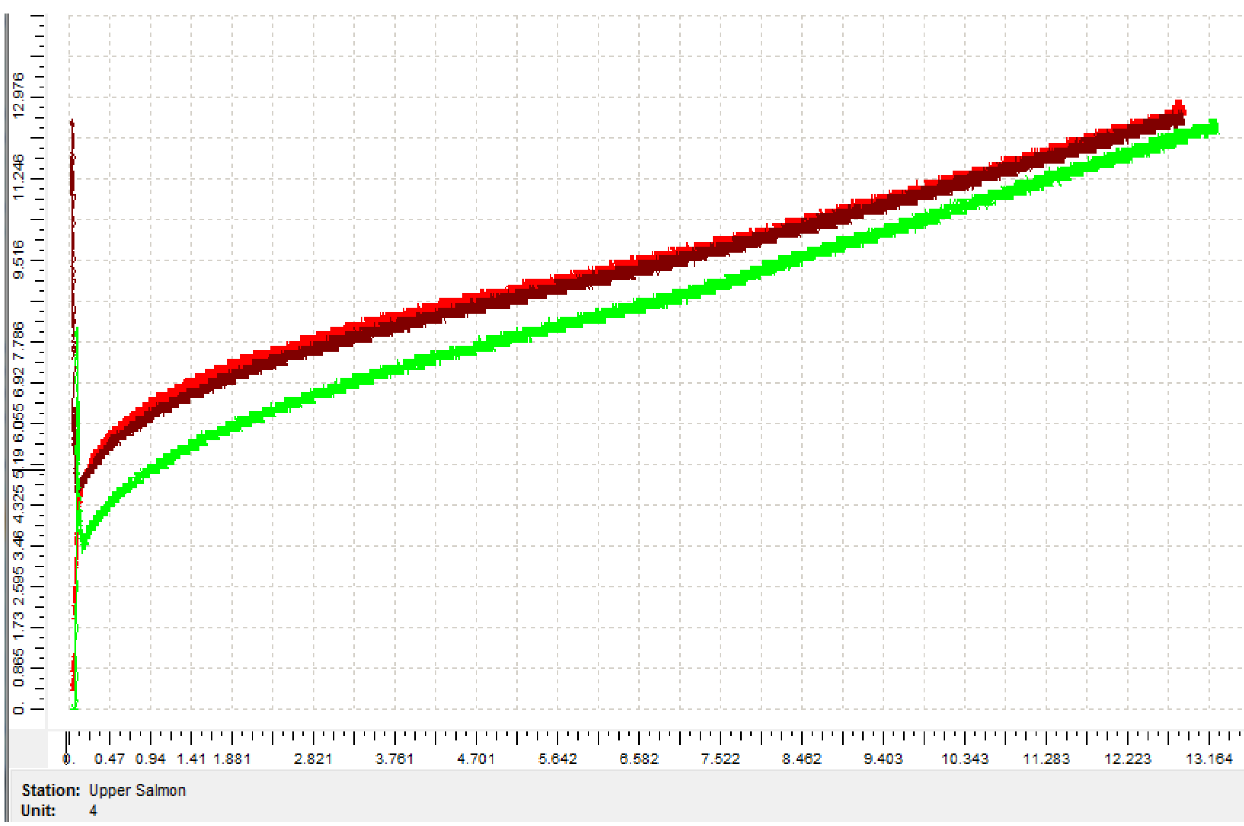


As can be seen, the unit had some issues. This type of result is indicative of a crack in insulation. This unit has had a troubled life and had recently burned up a set of main cables to the transformer as well as had a fire in the lightning arrester compartment. The only external component that not had been recently replaced were the neutral leads and the insulation was known to be in bad shape on them. Since the results up until the point of flash over were consistent with little noise, it was felt that the neutral leads were indeed the problem. It was then planned to replace the neutral leads at the next outage. When the old leads were removed, the DC Ramp test would be run before the new leads were installed to isolate the windings as much as possible. The below results are from the second test.



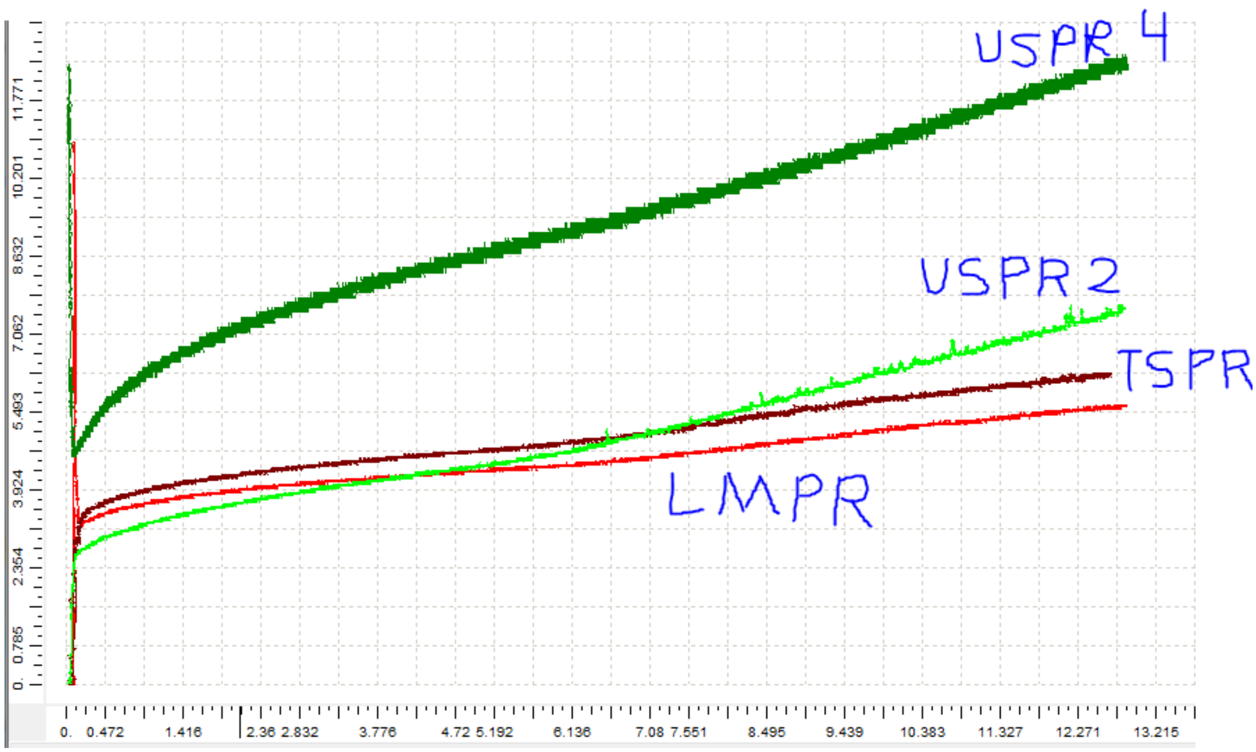
Upper Salmon Unit 4

The Upper Salmon unit 4 is a 9 MVA 1947 General Electric vertical unit with original asphalt windings. Below are the results.



Phase 1 and 3 are the higher results, phase 2 is the lower result. The cause for the differences in the phases is unknown. There is no indication of noise due to tracking on the graphs. Due to how consistent that both sets of curves are, it would seem that there has been something changed on phase 2 compared to the other phases. As old as these machines are, there is a good possibility that some piece of the system was changed over the years. Insulation repairs at external connections, changing of a cable, insulators, etc. could all change the leakage in the system. The unit's isolation was verified and the system where it could be cleaned had been cleaned before testing. Retest showed the same results. It is interesting that both of the Upper Salmon units tested had differences between the phases.

At this point, for comparison, is a single phase from the four above tests on one graph.



The USPR 4 windings are known to have been severely overheated in the past. While asphalt windings are forgiving to temperature changes since they are more flexible than the polyester or epoxy windings, severe overheating with loss of asphalt will compromise them. These windings are also 13 years older than the TSPR windings.

Of note is that the leakage rates, or slope, of USPR 2 and 4 are very similar after about 6 kV, 0.5 micro amps per kV for USPR 4 versus 0.433 micro amps per kV for USPR 2. This would indicate that there is a physical similarity between the units that is causing this.

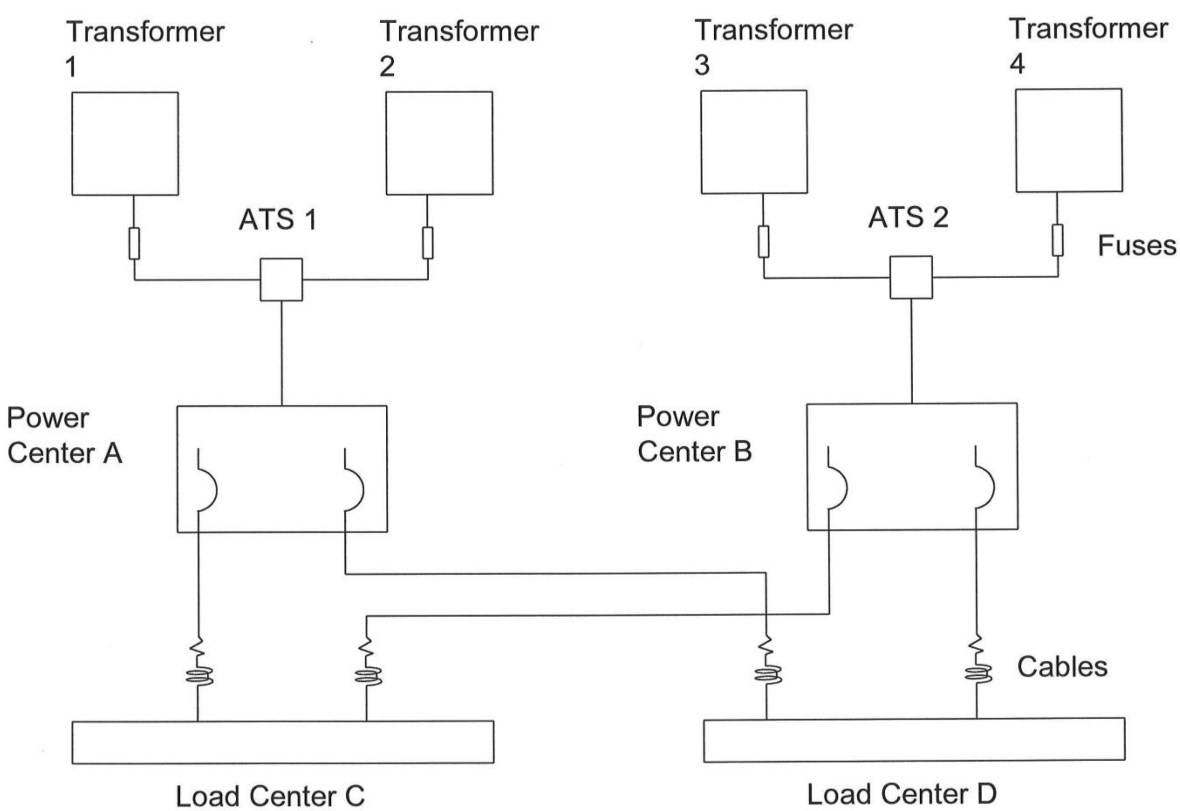
Summary

The DC ramp test has proved valuable in evaluating 6.9 kV windings in various machines. These machines normally have no other testing except for insulation resistance. The DC ramp test allows for a single test to show the relative health of the insulation in the machine based on the leakage rate and the characteristics of the leakage rate as well as a proof test of the withstand capability of the insulation. The testing to date has shown that these units are in good shape for their age and should continue in service for many more years.

Cable Testing at the Lower Salmon Plant

Introduction

The Lower Salmon power plant is a hydro generation power plant and dam on the Snake River in Idaho. The plant was built in 1948-1949 and consists of four 17.5 MVA generators. The cable testing that is of interest was conducted on main power cables in the local service electrical system operating at 240 volts. Each generator has an associated local service transformer. The feed of two transformers are fed through an automatic transfer switch to a power center. The two power centers then feed two load centers via breakers and 2 parallel 4/0 copper cables. A simplified diagram is shown below.



Sequence of Events

In the spring of 2012, during a rainy period, the plant lost local service due to a blown fuse during an operation to shift local service from Unit 3 to Unit 1. The local service was shifted back to unit 3 and a fuse blew on this feed also. Unit 2 was down for maintenance. Unit 4 was brought up to try and supply local service. A fuse blew and all local service was lost. Personnel started to pull the fuse holders to replace fuses.

About this time, your humble engineer who had specified the fuses be installed in the system walked into the plant. He was a very popular guy!

There were several things going on in the plant but eventually the fuses were replaced and a unit was brought on line to supply local service and local service was restored. It was determined that only one fuse had blown on each feed. At the time of the event it is not entirely clear what the configuration of the breakers were in the system. In this system the two set of cables from the load centers are live back to the power centers if the load center is energized, making it hard to troubleshoot the cables. I was also informed that they had blown a fuse the previous spring. There was also a slight burning smell coming from the power center B end of the plant but the source could not be found and it quickly went away.

Using information from a recorder on the generator protection, further investigation of the incident showed a 2000 amp 240 volt fault occurring for 15 to 20 seconds. This corresponds to the time current curve for the fuse installed.

Theory for Cause of the Fault.

This plant is known for its wet conditions and is also known for having conduit that is embedded in the concrete structure shift and pinch cables. It was theorized that one of the sets of cables had been crushed in the conduit leading to a partial failure of the insulation. When dry or under non transient conditions wet, there is no current flow. When wet and a transient condition on the system causes the voltage to rise above the breakdown voltage, a fault will occur. The fault stays there until the water is evaporated by the heat of the fault. Then the fault disappears.

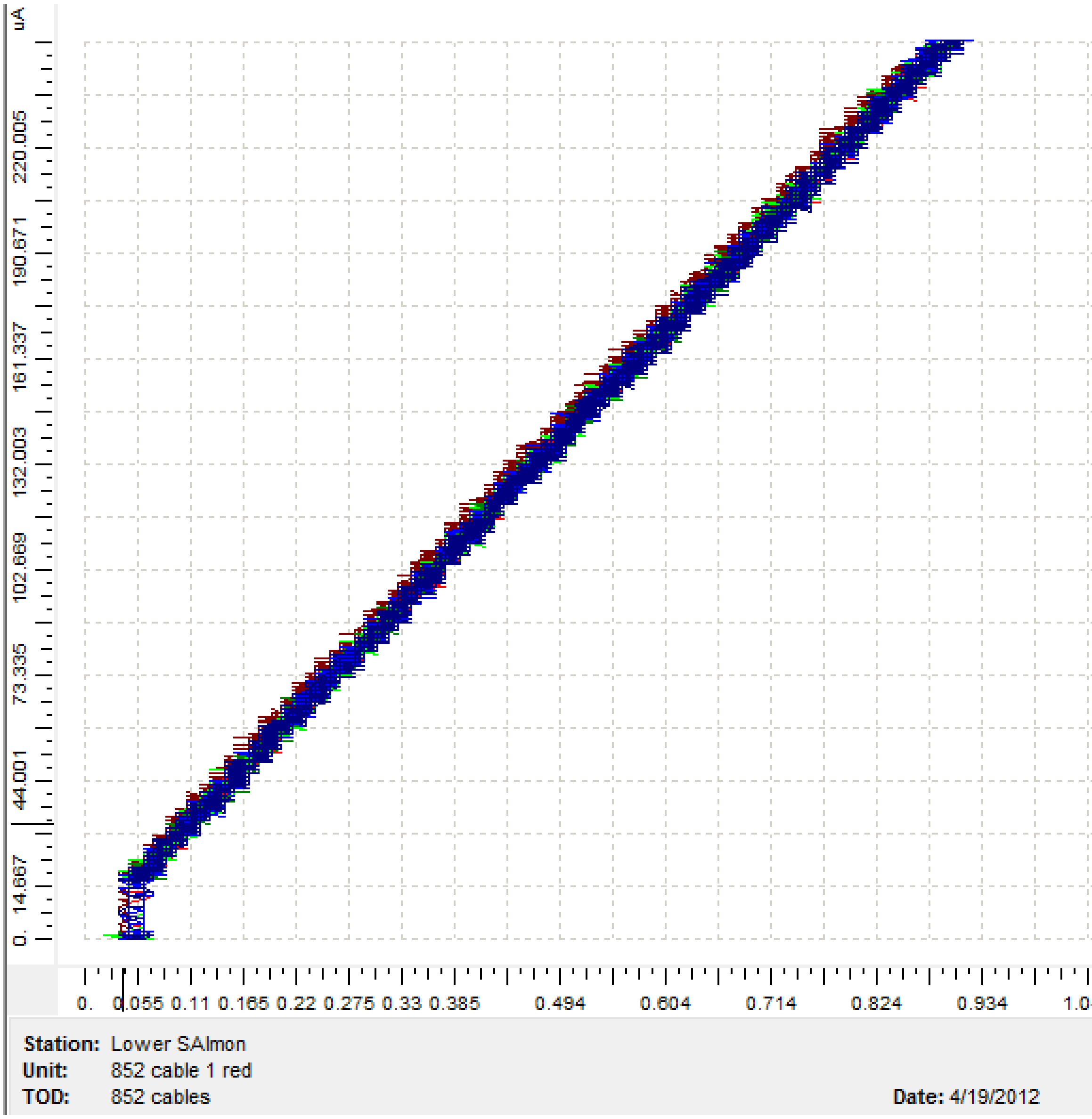
Test procedure

To test the cables a power center was taken out of service. Then one at a time the load centers were de-energized and the cables to the de-energized power center disconnected and then the load center energized from the other power center. The cables to be tested were then subjected to an insulation resistance test and then a DC Ramp test.

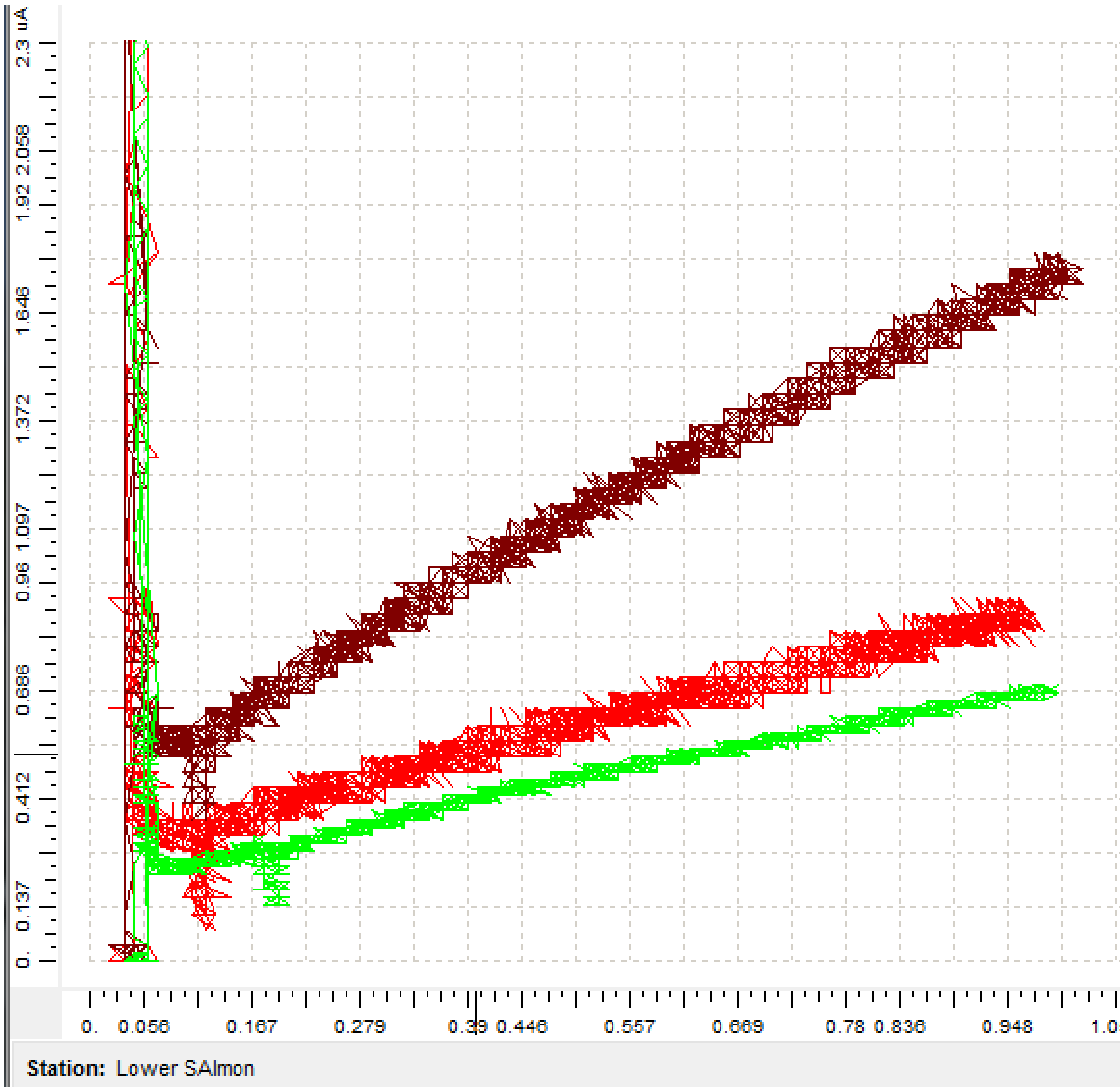
Results

The first cables to be tested were the cables from power center B (PC B) to load center D (LC D). An initial 500V insulation resistance test on the cables failed at just over 250 volts. The 2 parallel cables were then split at the breaker and an individual test of each cable conducted. The cables again failed. The system was rechecked to insure there were no unnoticed connections or anything else to explain the very low resistance readings. None could be found. The cables to load center C from power center B were then tested and easily passed the insulation resistance test.

The DC Ramp tester was then connected to each cable from PC B to LC D with the other cables grounded. The test was at 250 volts per minute to a final voltage of 1000 volts. In the graph below, all 6 cables are shown. The test was stopped when the current reached 250 micro amps, which is the limit of the machine.



The other three sets of cables were then DC Ramp tested in the parallel configuration. The graph below shows tests from one phase of each of the three other cable sets.



Conclusion

As can be seen in the above test results, the PC B to LC D set of cables had an obvious insulation failure. This failure may have been there for years before the fuses were installed. The fuses were initially blamed for causing an outage when they were doing their job and interrupting a fault.

This testing showed that the DC Ramp tester can be used as a precise insulation tester for cables as well as windings in machines. The other three sets of cables showed being in very good condition for their age and could continue on in service. The testing highlighted how damaged an insulation system can become before it gives an obvious physical indication.

This whole episode did help educate plant and repair personnel on the reasons for protective devices and the importance of contacting engineering if the devices operate for unknown reasons.