Dielectric Frequency Response of Generator Stator Windings

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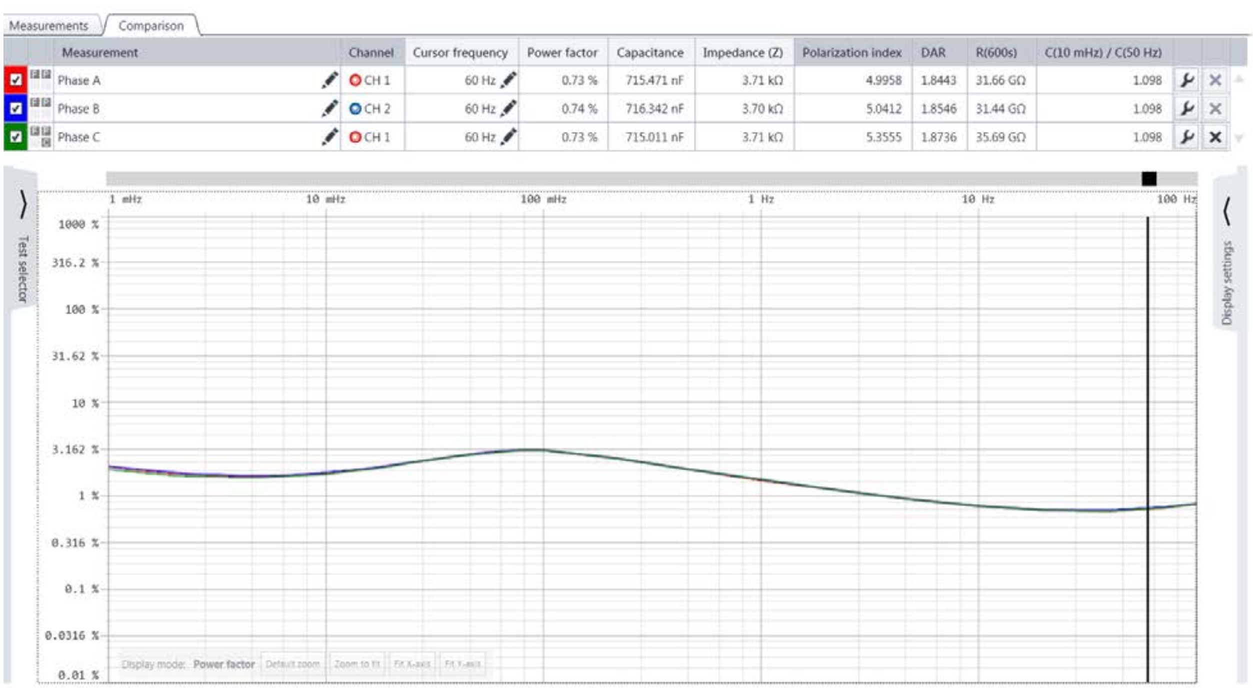

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14. ABSTRACT
Dielectric Frequency Response (DFR) testing has become an accepted test for analyzing oil filled power transformer insulation which has sparked interest in the rotating machine community. DFR testing provides similar test points compared to traditional test methods but performed at much lower test voltages. This study's primary goal was to determine if DFR testing could provide equivalent test results to traditional test methods. Results from the study are inconsistent with respect to aligning with traditional rotating machine test methods. At times the results would correlate well, and others would differ greatly. Additional data points and study would be required to determine if these inconsistencies continue, the data correlates, or differs from traditional methods.

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Dielectric Frequency Response, DFR, Rotating Machines, Stator Windings

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Disclaimer

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Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology Program

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Acronyms and Abbreviations

Reclamation	Bureau of Reclamation
DFR	Dielectric Frequency Response
FDS	Frequency Domain Spectroscopy
PDC	Polarization Depolarization Current
IR	Insulation Resistance
PI	Polarization Index
DAR	Dielectric Absorption Ration

Measurements

MVA	Megavolt-ampere
kV	Kilovolt
MΩ	MegaOhm
GΩ	GigaOhm
%PF	Dielectric Power Factor in percent

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Executive Summary

Dielectric Frequency Response (DFR) testing has emerged as an effective and industry accepted method for analyzing the health of oil filled power transformers. The effectiveness on power transformers has drawn my team's attention and questions of using DFR testing on rotating machines (generators and large motors) were raised. The usefulness of DFR testing on rotating machines is an area that this technology had not been given extensive attention but had potential for development.

DFR testing provides data points for many industry standard tests to include: Dielectric Power Factor/Dissipation Factor, Insulation Resistance, Polarization Index, and Dielectric Absorption Ratio. One major difference is that portable DFR test sets perform the tests at approximately 250 Volts where the standard tests are performed at voltages up to 12 kVac and 10 kVdc respectively. Discovering the differences in test results from DFR testing compared to traditional test methods was the primary goal of this research.

1.Introduction

Dielectric Frequency Response (DFR) testing has emerged as an effective and industry accepted method for analyzing the health of oil filled power transformers. The effectiveness on power transformers has drawn my team's attention and questions of using DFR testing on rotating machines (generators and large motors) were raised. The usefulness of DFR testing on rotating machines is an area that this technology had not been given extensive attention but had potential for development.

1.1 Project Background

DFR testing provides data points for many industry standard tests to include: Dielectric Power Factor/Dissipation Factor, Insulation Resistance, Polarization Index, and Dielectric Absorption Ratio. One major difference it that portable DFR test sets perform the tests at approximately 250 Volts where the standard tests are performed at voltages up to 12 kVac and 10 kVdc respectively.

1.2 Previous Work

Hydropower Diagnostics Team (86-68450) is well versed in all standard and advanced test methods used for rotating machine electrical insulation condition analysis. Previous work developed by Bert Milano (86-68450) is the creation of the Ramped High-Voltage DC Test Method. Ramp Testing automates the rate of the voltage output (ramp) and linearizes the portion of the test that would previously been performed by hand. Currently Ramp Testing is the best method for identifying the condition of stator winding insulation.

1.3 Problem the Study Addresses

Although Ramp Testing is the best method for testing stator insulation there is always areas for improvement. Ramp Testing is very sensitive and experienced test operators are required for valid/repeatable test results. Analysis of Ramp Test results requires practice and, in some cases, expert review.

Dielectric Power Factor/Dissipation Factor is another common test performed on stator windings but lacks the sensitivity to identify localized defects that the Ramp Test excels. Both test methods have areas that they perform well with, but most people will not take the time to perform both tests during normal maintenance intervals. We are always in search of ways to simplify or improve our test methods to reduce the demands of field personnel and reliance on expert review.

1.4 Study Objectives and Approach

Performing period literature searches related to DFR and rotating machines was one of the objectives of this study. This was to discover if any breakthroughs had been made and not to duplicate efforts. Following initial literature search it was decided to purchase a DFR test set to begin data collection. Once a DFR test set was purchased, field tests were performed periodically throughout the study when our team was contacted for generator testing. Discovering the differences in test results from DFR testing compared to traditional test methods was the primary goal of this research.

1.5 Partners and Contributors

The partners in this study were Eric Eastment and Jacob Lapenna, Electrical Engineers, Hydropower Diagnostics Team (86-68450). Eric Eastment gathered data and provided peer review. Jacob Lapenna performed field tests and gathered data.

Contributors to this study were facilities that allowed our team the time to perform extra testing on their generators. The contributors were Nicholas Lawrence, Electrical Engineer, Hungry Field Office and Andrew Trader, Electrical Engineer, Hoover Dam.

2 Methods

Methods used for this study were to perform standard electrical test methods to generators in addition to DFR testing to compare results. The DFR test set that was purchased for this study is an Omicron Dirana FDS-PDC+ dielectric insulation analyzer. DFR test methods for rotating machines can be seen in Figure 1 below.

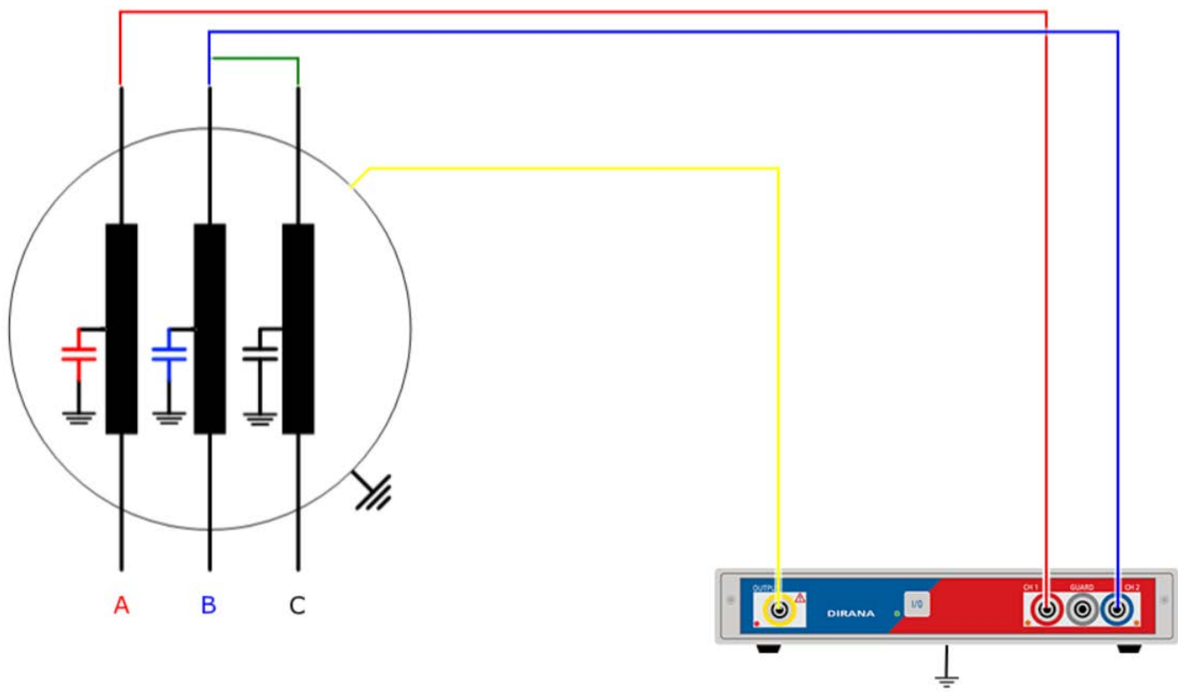

Figure 1 DFR Test Connection Method

Measurements were made by connecting the input to the frame of the generator and measuring the return current on the winding conductors. With the Omicron Dirana test set, two phases can be measured simultaneously, and the third phase can be connected to guard circuit. Connecting the third phase to the guard circuit gives it a ground reference and directs any leakage current traveling through it to stay out of the measurement.

Although DFR testing provides the data points of several traditional tests that are performed on rotating machines, it was determined that the Dielectric Power Factor results would be compared against the DFR data for stator winding tests. DFR tests performed on field windings were compared with traditional IR tests. The Dielectric Power Factor testing was performed with Doble M4100 and Omicron CPC100/TD1 test sets. The IR tests were performed with a Megger MIT430 Megohmmeter. Two traditional tests are performed with this Megohmmeter, the IR and the PI. The IR test is the Insulation Resistance after 1-minute of applied voltage. Polarization Index (PI) tests are the Insulation Resistance (MΩ) results after 10-minutes of applied voltage divided by the 1-minute Insulation Resistance (MΩ). The decision to use these tests was based on workload, outage time, and already scheduled tests.

3 Results

Gathering field data was more difficult than anticipated. Due to the COVID-19 pandemic a whole outage season was disrupted and only two outage seasons were part of this study. Data from three generator stator windings and three generator field windings were gathered over the two seasons. A table of the units tested is provided below.

Table 1 Details of units tested

Facility	Unit	Voltage	Output	Type	Manufacturer/ Year
Hoover	N6	16,500	133 MVA	Stator–Epoxy Mica	Marine Industrie Limtee/1989
Chandler	G1	4,1600	6.3 MVA	Stator-Asphalt Mica	Electrical Machine Manufacturing Company/1956
Hungry Horse	G1	250	262 kW	Field Winding	General Electric/ 1953
Hungry Horse	G3	13,800	112 MVA	Stator–Epoxy Mica	General Electric/ 1991
Hungry Horse	G3	250	262 kW	Field Winding	General Electric/ 1953
Hungry Horse	G4	250	262 kW	Field Winding	General Electric/ 1953

The results correlated well with traditional testing for some field winding parameters and there were large discrepancies with the stator winding tests. Some field winding test results are close to the traditional Insulation Resistance (IR) testing results while others are not. Stator winding tests had greater discrepancies and in general did not correlate well with traditional Dielectric Power Factor testing. The table below shows the comparison of DFR and traditional test methods.

Table 2 Comparison of test results

Facility	Unit	Phase	DFR Method	Traditional Method	Type	%Δ
Hoover	N6	A	%PF @0.25kV 0.60%	%PR @2.4kV 0.39%	Stator–Epoxy Mica	53.8%
		B	%PF @0.25kV 0.61%	%PR @2.4kV 0.40%	Stator–Epoxy Mica	52.5%
		C	%PF @0.25kV 0.65%	%PR @2.4kV 0.41%	Stator–Epoxy Mica	58.5%
Chandler	G1	A	%PF @0.25kV 0.72%	%PR @0.6kV 2.98	Stator–Asphalt Mica	-76.24%
		B	%PF @0.25kV 0.65%	%PR @0.6kV 2.98	Stator–Asphalt Mica	-78.55%
		C	%PF @0.25kV 0.64%	%PR @0.6kV 2.97%	Stator–Asphalt Mica	-78.60%
Hungry Horse	G1	N/A	IR @0.25kV 270 MΩ@1min 991 MΩ@10min PI = 3.7	IR @0.5kV 240 MΩ@1min 453 MΩ@10min PI = 1.88	Field Winding	12.5% 118.8% 105.5%
Hungry Horse	G3	A	%PF @0.25kV 0.73%	%PR @2kV 0.99%	Stator–Epoxy Mica	-26.26%

	B	%PF @0.25kV 0.74%	%PR@2kV 0.99%	Stator–Epoxy Mica	-25.25%
	C	%PF @0.25kV 0.73%	%PR@2kV 0.99%	Stator–Epoxy Mica	-26.26%
Hungry Horse G3	N/A	IR @0.25kV 325 MΩ@1min 1.4 GΩ@10min PI =4.3	IR @0.5kV 336 MΩ@1min 1.2 GΩ@10min PI =3.6	Field Winding	-3.27% 16.7% 19.4%
Hungry Horse G4	N/A	IR @0.25kV 243 MΩ@1min 1.19 GΩ@10min PI =4.8	IR @0.5kV 290 MΩ@1min 1.4 GΩ@10min PI =4.7	Field Winding	-16.2% -15.0% 2.13%

%PF = Dielectric Power Factor in percent
MΩ = MegaOhm
GΩ = GigaOhm

Green = Acceptable
Red = Unacceptable Deviation

4 Discussion

The test results from this limited study have many variations. When traditional Dielectric Power Factor in percent (%PF) tests are performed on stator windings it is performed at 25% and 100% line to ground rated voltage. It was expected to see the DFR %PF results align with the 25% line to ground voltage. The %PF results for the stator winding tests did not correlate with the DFR tests. DFR test sets that are field portable have a reduced voltage output to keep the power demand low. The power requirement to operate up to 100 Hertz (Hz) and 10 kilovolt (kV) on stator windings with approximately 1 microfarad (µF) of capacitance to ground would be substantial (~63 kilovolt-ampere (KVA)). Operating the DFR test set at 250 Volts keeps the power demand for the same 1 µF stator to 40 VA or 40 Watts assuming 1.0 power factor.

Typical Power Factor testing at higher voltages applies greater stress to electrical insulation and provides a better representation of the actual condition. DFR testing appeared to provide good results for all the various test that were performed even when the traditional tests showed fair results. The opportunity did not present itself to test extremely poor stator winding insulation to confirm the behavior. More research and comparisons are required.

DFR could be very useful for diagnosing wet field and/or stator windings. Water molecules are polar and if there are enough of them present in an insulations system the current required to polarize the water laden insulation molecules will be appreciable. Field windings can get wet when bearing cooling water pipes leak onto the generator rotor and significant work must be performed to dry them out. IR and PI testing is the most common method to determine if a field winding is dry enough to operate, but it is possible to use DFR testing in this application. At times there have been stator windings contaminated with water after excessive water was used to cool brazed electrical connections during assembly. DFR testing has the potential to be useful during water ingress instances and would pose no threat of failure or damage to the insulation system due to the low applied voltage.

Currently DFR is not a suitable replacement for traditional Power Factor test methods on rotating machines. More research would need to be performed to validate using DFR testing to identify wet electrical insulation. The next steps for further testing would be to integrate this testing into another project that is analyzing the effects of moisture on generator stator windings. DFR testing has the potential to more accurately evaluate the presence of moisture in solid electrical insulation compared to traditional methods.

5 Data

The data gathered in this study can be found in *Table 1 Details of units tested* and *Table 2 Comparison of test results* in addition to the figures in Appendix A. For electronic files, contact Benjamin Few at bfew@usbr.gov.

Test results did not correlate well with traditional test methods and there were expectations at the beginning of this study that the lower voltage tests would be comparable. Results from the field winding tests for the 1-minute IR tests correlated well with traditional tests and is expected as the applied test voltage is within 250 Vdc. Unexpectedly the 10-minute IR test results had large variations. It is possible that the differences in test set accuracies caused the variations as the DFR test set is more accurate than most typical IR test sets used. Further testing with a more accurate IR test set will help to verify this.

References

Anglhuber, M, Bohler, S, Ottl, F 2017. Measuring and analyzing the dielectric response of rotating machines. https://my.omicronenergy.com/knowledge-library/. Date accessed 09/25/2020.

Appendix A

Measurements | Comparison

Measurement	Channel	Cursor frequency	Power factor	Capacitance	Impedance (Z)	Polarization index	DAR	R(600s)	C(10 mHz) / C(50 Hz)
Phase A	CH 1	60 Hz	0.60 %	907.221 nF	2.92 kΩ	6.6950	1.9060	16.33 GΩ	1.069
Phase B	CH 2	60 Hz	0.61 %	907.834 nF	2.92 kΩ	6.7140	1.9070	16.37 GΩ	1.069
Phase C	CH 1	60 Hz	0.65 %	904.929 nF	2.93 kΩ	7.4801	1.9453	19.41 GΩ	1.068

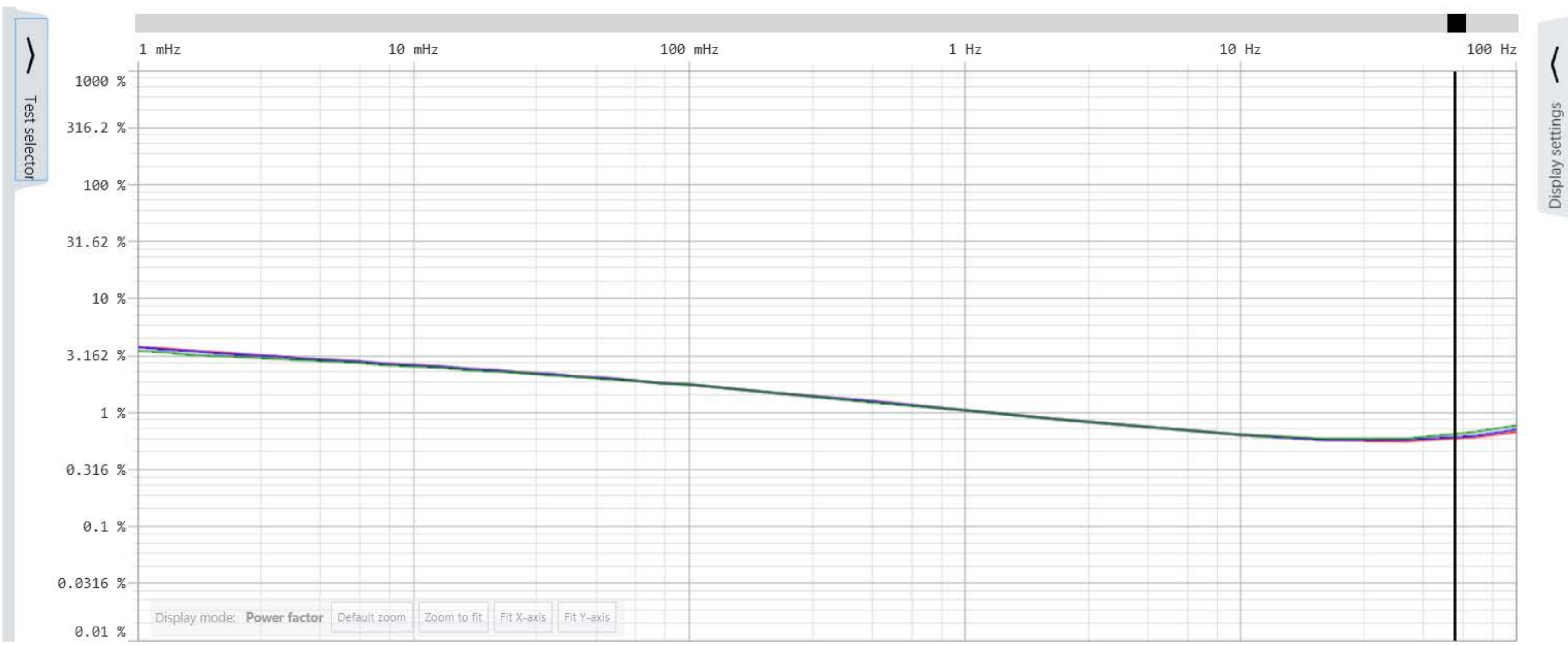

Figure 2 Hoover N6 Stator DFR Test Results

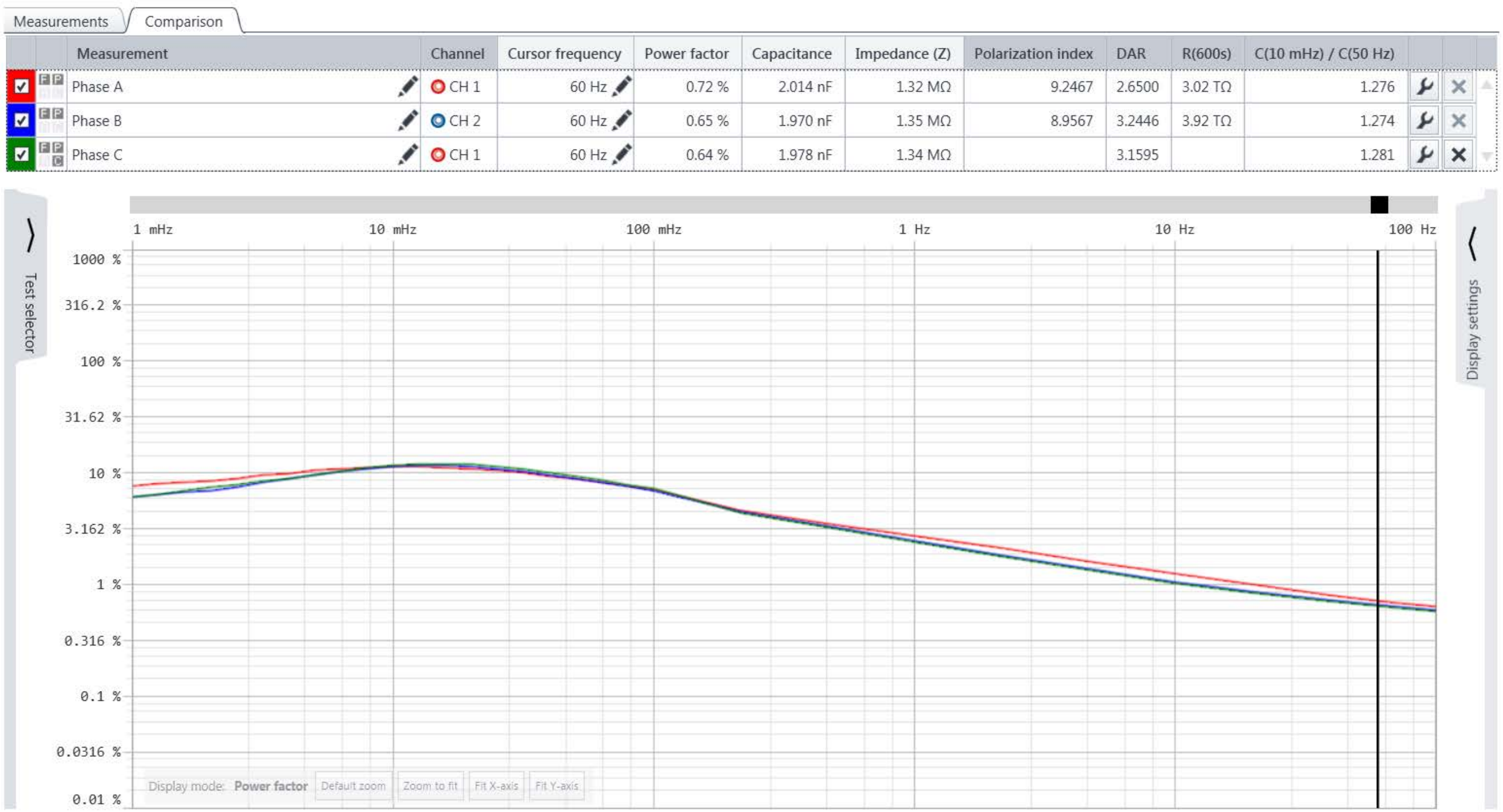

Figure 3 Chandler G1 Stator Winding DFR Test Results

Figure 4 Hungry Horse G1, G3, and G4 Field Winding DFR Test Results

Measurements | Comparison

	Measurement	Channel	Cursor frequency	Power factor	Capacitance	Impedance (Z)	Polarization index	DAR	R(600s)	C(10 mHz) / C(50 Hz)
☑	Phase A	CH 1	60 Hz	0.73 %	715.471 nF	3.71 kΩ	4.9958	1.8443	31.66 GΩ	1.098
☑	Phase B	CH 2	60 Hz	0.74 %	716.342 nF	3.70 kΩ	5.0412	1.8546	31.44 GΩ	1.098
☑	Phase C	CH 1	60 Hz	0.73 %	715.011 nF	3.71 kΩ	5.3555	1.8736	35.69 GΩ	1.098

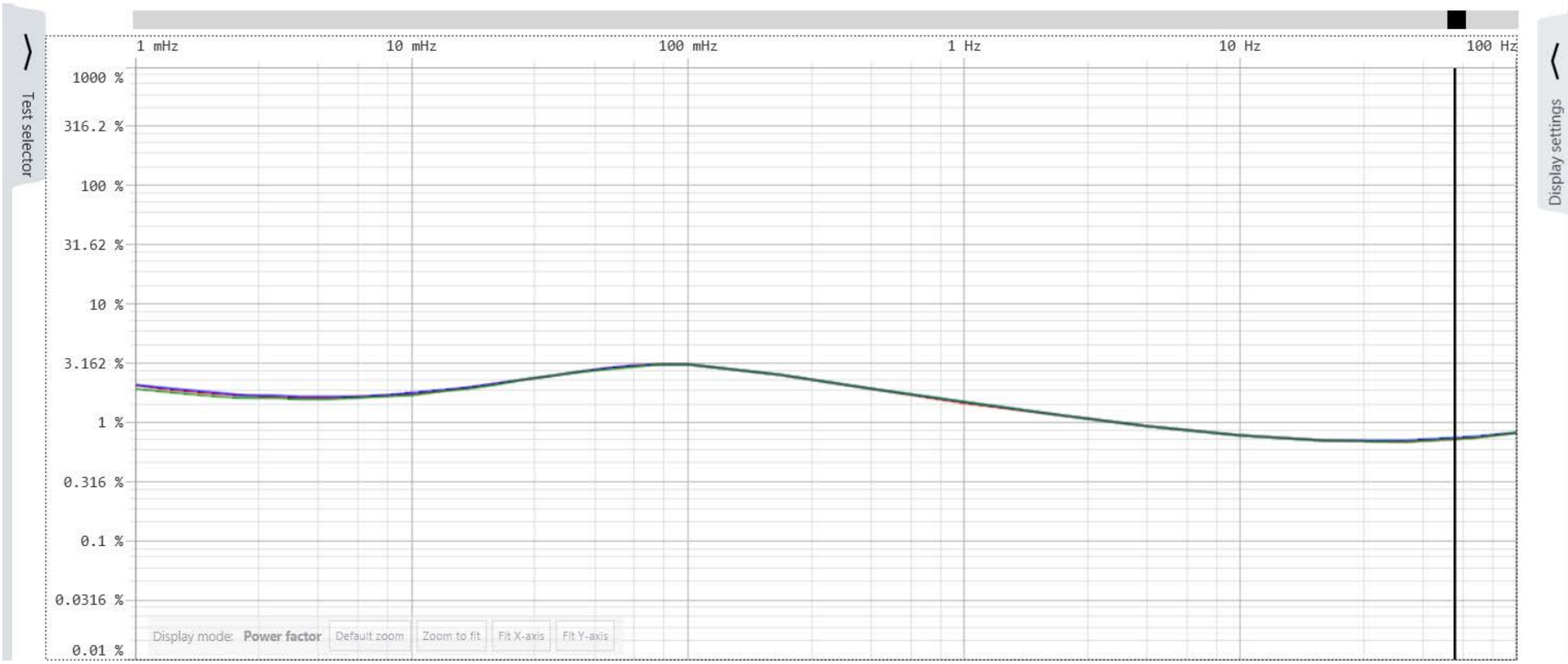

Figure 5 Hungry Horse G3 Stator DFR Test Results