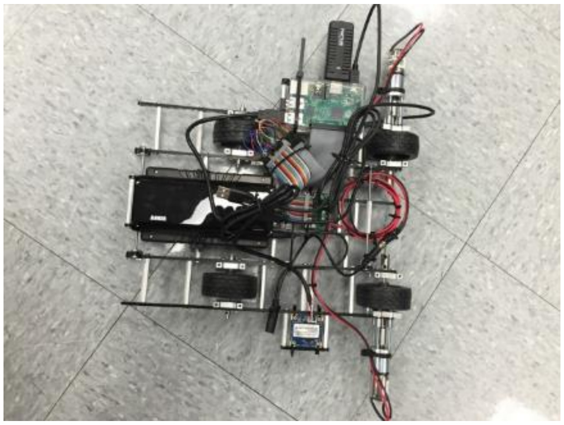
RECLAMATION

Managing Water in the West

Power System Diagnostics

Research and Development Office
Science and Technology Program
Final Report ST-2015-5040-1



Edges: [143, 206]
Center: 174
Location: 0

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

November 2015

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
T1. REPORT DATE 11 2015	**T2. REPORT TYPE** Research	**T3. DATES COVERED** 2014 - 2015
T4.		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. Eric Preston Eastment		**5d. PROJECT Z5040**
		5e. TASK NUMBER
		5f. WORK UNIT 86-68450
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research and Development Office U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007		**10. SPONSOR/MONITOR'S ACRONYM(S)** R&D: Research and Development Office BOR/USBR: Bureau of Reclamation DOI: Department of the Interior
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 words)*

Power system diagnostics responds to demonstrated problems in the Bureau of Reclamation's electrical facilities. This project has a broad focus on improving equipment diagnostic methods and techniques and developing/innovating new methods to reduce maintenance costs and equipment downtime in the areas of high-voltage insulation, rotating machine protection, and maintenance testing and diagnostics.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	**U**	25	**19b. TELEPHONE NUMBER** 303-445-2125

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

PEER REVIEW DOCUMENTATION

Project and Document Information

Project Name POWER SYSTEM DIAGNOSTICS WOID Z5040

Document RESEARCH - POWER SYSTEM DIAGNOSTICS

Document Author(s) ERIC P. EASTMENT Document date 9/30/2016

Peer Reviewer BENJAMIN FEW

Review Certification

Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer Benjamin F Date reviewed 9/30/2016
(Signature)

Disclaimer

Notices

****This research project contains intellectual property****

Acronyms and Abbreviations

DC	Direct Current
FY	Fiscal Year
HTC	High Thermally Conductive (insulation)
W	Watt
mK	meter-Kelvin
USBR	United States Bureau of Reclamation

Table of Contents

Executive Summary

Power system diagnostics responds to demonstrated problems in the Bureau of Reclamation's electrical facilities. This project has a broad focus on improving equipment diagnostic methods and techniques and developing/innovating new methods to reduce maintenance costs and equipment downtime in the areas of high-voltage insulation, rotating machine protection, and maintenance testing and diagnostics.

For Fiscal Year 2014 – 2015 the research project included the following topics:

1. DC Ramp Test Intelligent Analysis Software - Continue development of the FY13 program and incorporate intelligent analysis features.
2. Rotating Corona Probe - Continued from FY13, the rotating corona probe project is intended to create a universal corona probe sensor assembly that adapts to all machines within Reclamation (salient pole generators). This device will be used for insulation condition assessment of all generators.
3. Stator Winding Insulation Diagnostics – Determine the thermal conductivity of service aged insulation systems to better predict insulation life.
4. Increasing Hydrogenerator Output – Presently two technologies exist that have the capability to increase the output of any of Reclamations generators without redesigning the turbine. This would allow select Reclamation (and Corps of Engineers) units with excess turbine capability to utilize the extra power available in the turbine. Theoretical generator output increases of approximately 15% could be realized by utilizing High-Thermally Conductive (HTC) insulation and a stator coil, or bar, wedging system that promotes better heat transfer.

Below is a summary of the research problems/goals, outcomes/results, and the recommended next steps for each project individually.

DC Ramp Test Intelligent Analysis Software

This project was abandoned due to lack of personnel resources and also to allow evaluation of commercially available systems. No progress was accomplished in 2014-2015. Funding was reduced.

Rotating (Automated) Corona Probe System

The Problem:

The corona probe is a test instrument that measures partial discharge activity on a slot-by-slot basis and is regarded as one of the most useful analysis tools for in-depth condition assessment of stator windings. However, this test must be performed with the generator off-line and typically with rotor removed from the machine. Rotor in-situ testing is less useful because limited physical access to scan the stator slots often prevents obtaining error-free data. Additionally performing a rotor in-situ test presents a number of personnel high-voltage shock or potential electrocution hazards. Only highly trained personnel are permitted to perform this test. Because it is impractical to remove the rotor to obtain this data it is highly desirable to create a prototype device that can perform a scan of the stator with the unit off-line.

Research Tasks:

Determine the physical parameters and test procedures/methodology to permit the use of a rotor mounted or stator mounted corona probe data acquisition system. Develop the algorithms and test a prototype carriage system, or semi-autonomous vehicle. Determine if the carriage system can be adapted to fit in the air gap of a fully assembled generator. Provide a report on the feasibility of this project.

Conclusions / Results:

Control and development of a carriage system is feasible at low cost as demonstrated by the simple prototype created under this research. However adapting the carriage system to a machine capable of fitting in a typical air gap (0.500” to 0.800”) is technically challenging and would require sophisticated manufacturing techniques which would result in high cost. A catalog of options was developed and considered. Based on hands-on experience with generator design characteristics and physical features none of the options offer ideal flexibility, universal adaptability, or ideal data collection means. In order to construct a system that obtains reliable data with flexibility to perform proper measurements requires a highly sophisticated robotic machine that would likely not be cost effective. The alternative is to accept a design that may not produce reliable or accurate data, or require operational flexibility of a generator that is under clearance that is not easily accomplished, i.e. is logistically difficult or not easily integrated into the unit outage. The original idea of an air-gap crawler, a semi-autonomous robot adhered to the stator core by magnetic attraction and driven by a magnetic track, is feasible for air gaps in excess of 0.750”. Technical difficulties of physical design for use in smaller air gaps would increase complexity and cost substantially requiring highly sophisticated designs. Additionally this would yield complications in design, construction, marketing, training, and maintenance of such a device. At this time the next best approach is to utilize a design that is rotor mounted and build a system that applies torque to the rotor to rotate it while a wireless rotor-mounted assembly collects data. This system is not ideal for data collection purposes because it reduces flexibility in acquiring measurements and may not use the standard corona probe measurement circuitry. If this system could not use the standard corona probe circuitry it would de-value the information because the data could not be compared to historical information for diagnostic guidance.

Next Steps / Recommendations:

A system that mounts to the rotor appears to be the simplest and likely the most cost effective method of obtaining corona probe data with a fully assembled machine. If a rotating corona probe system is to be developed the research should determine how to best control rotate and control the rotor and mount the sensors such that they are acquiring data in the same manner as the manual method.

Stator Winding Insulation Diagnostics

Thermal Conductivity of Delaminated Epoxy-Mica Based High-Voltage Stator Winding Insulation Systems for Large Power Generators

Background:

Stator winding insulation life is governed mainly by time operated and temperature during the period of operation. As the insulation system ages the epoxy material that bonds the layers of electrically insulating mica together begin to thermally age and degrade. One of the main degradation mechanisms is delamination of the mica layers thus leaving a gas void between layers where epoxy once existed. The term ‘insulation,’ when referring to stator windings, generally refers to the electrical ability of the insulation to successfully separate and withstand the electric field stresses imposed by the high-voltage conductors contained within. However, another very important parameter of stator winding insulation is its **thermal** insulation characteristics. The insulation system must electrically isolate the high-voltage conductors from the grounded stator core and also serve as a heat rejection medium for the conductors where it passes the thermal energy from the copper to the air-cooled stator core.

Thermal characteristics of newly manufactured insulation is well known; however, after service aging and onset of delamination, there is little known about effects of this delamination on the thermal conductivity.

If thermal conductivity decreases the copper conductors would then operate at a slightly higher temperature; thus, one would expect an increase in thermal decomposition. This, in turn, would accelerate thermal deterioration.

Research Tasks:

1. Obtain service-aged stator windings operated at high-voltage which are known to be delaminated.
2. Obtain service-aged stator windings operated at low-voltage which are not delaminated.
3. Obtain unused, spare stator windings which have never been in operation.
4. Instrument these windings with heat sinks and temperature sensors to measure the thermal conductivity of the insulation systems.
5. Inject high current to increase the temperature of the copper and measure the thermal conductivity of the insulation.

Conclusions / Results:

The stator windings samples, temperature measurement equipment and a power source were obtained. The windings were instrumented and some initial testing was performed. Testing was halted because of an urgent need for the high-power source for use at two USBR Powerplants. When the equipment returned it was then tasked on other research projects (metal fiber brushes). A substitute lower-power source was implemented but proved to be inadequate for the duty. The power source became available late in September at the conclusion of the metal fiber brushes research but there was not enough time to

Next Steps / Recommendations:

The power supply has returned from field use. Additionally we have secured an additional higher power supply that may also be used in case the primary supply is called to task in the field. Continue the research in FY17.

Increasing Hydrogenerator Output

The Problem:

In an electric generator, the copper conductors (coils) generate heat (via I^2R copper losses), the heat must be transferred through the coil insulation to the air-cooled stator core (heat sink). Materials required to make a good quality, long lasting, high-voltage electrical insulator are unfortunately a very poor conductor of heat. Typical stator winding insulation has a thermal conductivity of 0.27 W/mK [Watts per meter-Kelvin]. For reference, steel is 80 W/mK and copper is 400 W/mK. The high resistance to heat transfer limits the power production/output of the electric generator and plays a dominant role in the reliable life of the stator winding. It is for this reason High Thermal Conductivity (HTC) insulation technology is being sought. HTC insulation technologies have been around for at least 10 years. It has been successfully implemented by several manufacturers in some limited production and test phase programs but still is not mainstream technology.

Research Tasks:

Review industry standards (if present), papers, and query current industry peers in HTC insulation technology. Determine why HTC insulation and synergy with stator wedging (slot fixing) systems have not been utilized in parallel.

Conclusions / Results:

1. HTC insulation technology utilizes nano-particles mixed with conventional sized fillers to achieve better thermal conduction. These particles are introduced into the epoxy that would be used in a typical stator winding insulation system.
2. When uniformly distributed spherical nano-particles of approximately 40 nm (nano-meters) are into a host epoxy at approximately 5% (by weight) dramatically increase the interfacial area meaning that heat conduction now has a much larger path through the epoxy media.
3. Nano-particles mixed with conventional fillers of various types have been researched by others [1], [2], [3] may utilize:
   a. Magnesium Oxide
   b. Boron Nitride/nano-silica
   c. Silicon Dioxide
4. Increases in thermal conductivity varies depending on the percent of the nano-filler in the epoxy. Formulations up to 60% silica nano-filler have been attempted in epoxy resins.
5. Introduction of nano-particles has demonstrated a reduction in electrical treeing and an increase in voltage required to breakdown the epoxy mixed with these particles. Both of these properties would tend to increase the life of stator windings.
6. Laboratory stator bars produced with various nano-silica particle content have shown an increase in accelerated voltage breakdown testing of 5 – 10 times standard technology [2].
7. Voltage Endurance – Nano-composite stator bars produced in a standard 13.8 kV design and tested at 2.5 rated voltage lasted 13 times longer than the standard non-nano composite designs [2].
8. Because increases in breakdown voltage and reduction in tree propagation have been realized this may allow designers to reduce the thickness of the insulation system. This, in turn, will increase the thermal conductivity because the insulation can now be made thinner. This is an added benefit on top of the already increased thermal conductivity due to better per-unit thickness thermal conductivity.
9. Additional qualifications should be performed on nano-composite insulating systems such as mechanical and multifactor aging.

HTC insulation systems and improved stator coil/bar thermal wedging systems exist and have demonstrated promising increases in heat transfer capability (increased thermal conductivity). Several discussions with Dr. Nancy Frost (formerly with Von Roll) have indicated that HTC systems are being integrated at some project levels but obviously insulation system lifespans and actual service time have not been established for this technology. Generation owners may resist adoption of this technology because there is risk of the unknown. Siemens AG in cooperation with Voith Hydro GmbH Germany has successfully integrated nano[1]-particles[2] into insulation (nanocomposite insulation) and performed laboratory testing with very promising results [2]. Several unsuccessful attempts were made to discuss these topics with the authors. This technology likely needs additional time to develop to the point where it can be married with slot fixing systems that also promote better heat transfer.

Next Steps / Recommendations:

Contact Siemens and set up a meeting to discuss the state of the art. Determine if Voith-Siemens may is already be integrating this into their mainstream product.

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[1] ~40 nano-meters

[2] Aluminum oxide, magnesium oxide, Boron Nitirde and nano-silica particles, ~2% by weight of the epoxy used in stator coils.

Main Report

DC Ramp Test Acquisition and Analysis Program

Refer to the executive summary.

Stator Winding Insulation Diagnostics

Thermal Conductivity of Delaminated Epoxy-Mica Based High-Voltage Stator Winding Insulation Systems for Large Power Generators

Background:

Stator winding insulation life is governed mainly by time operated and temperature during the period of operation. As the insulation system ages the epoxy material that bonds the layers of electrically insulating mica together begin to thermally age and degrade. One of the main degradation mechanisms is delamination of the mica layers thus leaving a gas void between layers where epoxy once existed. The term ‘insulation,’ when referring to stator windings, generally refers to the electrical ability of the insulation to successfully separate and withstand the electric field stresses imposed by the high-voltage conductors contained within. However, another very important parameter of stator winding insulation is its **thermal** insulation characteristics. The insulation system must electrically isolate the high-voltage conductors from the grounded stator core and also serve as a heat rejection medium for the conductors where it passes the thermal energy from the copper to the air-cooled stator core.

Thermal characteristics of newly manufactured insulation is well known; however, after service aging and onset of delamination, there is little known about effects of this delamination on the thermal conductivity.

If thermal conductivity decreases the copper conductors would then operate at a slightly higher temperature; thus, one would expect an increase in thermal decomposition. This, in turn, would accelerate thermal deterioration.

The majority of power-generating rotating machine assets in the world are manufactured with class B (130 °C) or class F (155 °C) thermally rated insulation systems. The temperature class/rating of an insulation system is sometimes referred to as the temperature index or Relative Temperature Index (RTI). IEEE Std. 100 describes RTI as an index that allows relative comparisons of the temperature capability of insulation systems.

When developing an electrical insulation system, the temperature class/rating is based on the temperature it can withstand over 20,000 hours (2.28 years) while retaining at least 50 percent (%) of its original mechanical strength. Almost all large rotating machine winding assets within Reclamation use temperature class B or F insulation systems, which correspond to absolute temperature ratings of 130 °C and 155 °C, respectively.

Example: To classify an insulation system it is heated to 155 °C for 20,000 hours and then subjected to a mechanical strength test.

- If the mechanical strength is equal to or greater than 50% of the un-aged value, it is allowed to be defined as Class F.
- If the mechanical strength is less than 50% after thermal aging, it is not allowed to be defined as Class F.

If the insulation system reaches the 20,000-hour mechanical limit at 20,000 hours at any temperature between 130–154 °C, it must be rated as Class B. The insulation thermal aging rate (rate of chemical decomposition) can be modeled with an acceptable degree of accuracy by the Arrhenius rate law {1}, which essentially states that the rate of aging will be cut in half for each 10 °C drop in temperature; alternately, the aging rate will double for every 10 °C above the insulation temperature rating. Using this information and the temperature class letter of the insulation, one can simply construct the plots shown in Figure 1, which are life versus operating temperature plots for class B and F insulation, indicating where the insulation mechanical strength has been reduced to 50% of original mechanical strength.

Arrhenius Rate Law: $k = Ae^{\frac{-Ea}{RT}}$ .... {1}

Where:

- k is the rate constant
- Ea is the activation energy
- R is the gas constant
- T is temperature in Kelvin
- A is frequency factor constant or also known as pre-exponential factor or Arrhenius factor. It indicates the rate of collision and the fraction of collisions with the proper orientation for the reaction to occur.

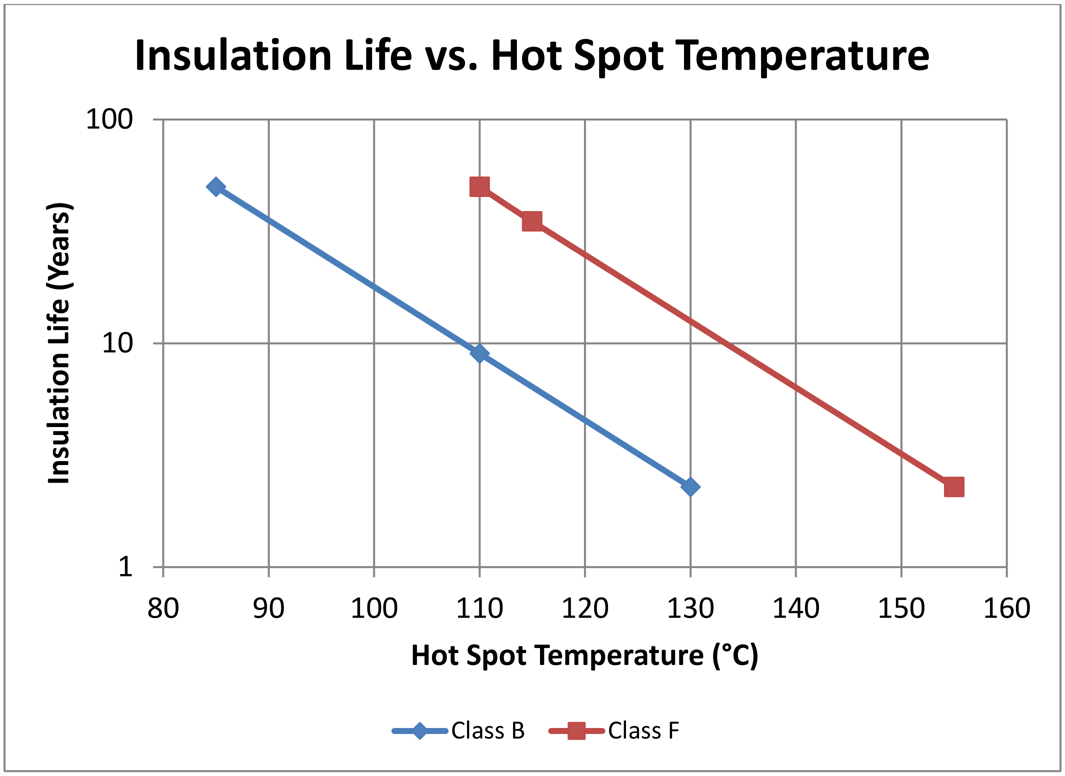

Figure 1. Insulation life vs. hot spot temperature

Mica-based stator winding insulation is a very poor heat conductor (i.e., a good **thermal insulator**). "The range of thermal conductivity of mica insulation is between 0.25 and 0.30 Watts per meter Kelvin (W/m · K), whereas values for copper or steel are 1,500 or 300 times higher, respectively…" [5]. It is for this reason any changes, even small, may result in a substantial change in thermal conductivity which could have severe consequences and ultimately reduce the service life of the insulation. A brief review of industry articles, papers, and general knowledge revealed a complete lack of information on the topic of thermal conductivity of service-aged insulation systems. Previous Stator Winding Insulation Diagnostics research efforts have often observed thermally deteriorated conditions that have led to bulk delamination and elevated temperatures inside the coil body. These conditions have not been detected by traditional Resistance Thermal Detectors (RTDs). Observations of many dissected windings have yielded observations of severe thermal degradation and yet temperatures, as recorded by traditional Resistance Thermal Detectors (RTDs), have yielded no correlation. Figure 2 is an example of the result of severe

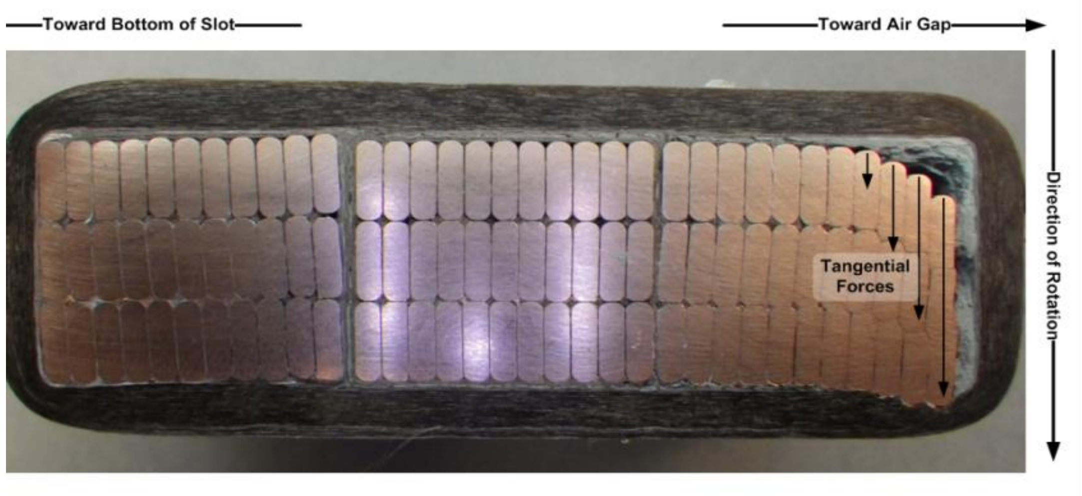

Figure 2. Actual example of tangential forces acting on coil conductors.

thermal deterioration which obviously affected thermal conductivity. The question is by how much?

Research Tasks

1. Obtain known-delaminated service-aged stator windings operated at high and low voltage.
2. Obtain unused, spare stator windings which have never been in operation.
3. Instrument these windings with heat sinks and temperature sensors to measure the thermal conductivity of the insulation systems.
4. Inject high-current to increase the temperature of the copper via I^2R losses and measure the thermal conductivity of the insulation.

All items listed above were obtained from a rewind that occurred at a USBR powerplant. Service-aged low-and-high-voltage coils along with spare coils were shipped to the Denver Federal Center for instrumentation and analysis. The stator coils were instrumented (Figure 3, Figure 4 and Figure 5) and an initial test run was performed; however, the equipment providing the power source was urgently needed at two of Reclamations powerplant facilities and the research was halted. The equipment was shipped to the field office and research on this task was halted.

Equipment

Thermocouple Wire

Type T Special Limits of Error (SLE) Twisted-Pair Shielded thermocouple wire: advertise temperature accuracy of ± 0.5 °C

Data Acquisition:

I/O Tech/MCC Personal DAQ 3000 (with attached PDQ 30 expansion module): advertised[3] accuracy of ±1.8 °C and ±0.2 °C typical noise. Both units are Cold-Junction-Compensated at the terminal blocks.

System Accuracy:

System Accuracy will be the square-root of the sum-of-the-squares for each accuracy component, thus:

$System\ Accuracy = \sqrt{0.5^2 + 1.8^2 + 0.2^2} = 2\ °C$ ....[1]

- Desired ΔT across insulation: 20 °C
- Realistic ΔT across insulation: 10 °C (given experiment setup, power limitations)

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[3] **Assumes 16384 over-sampling applied, CMV = 0.0V, 60-minute warm-up, still environment, and 25˚C ambient temperature; excludes thermocouple error; TC_{IN} = 0 ˚C for all types except B (1000 ˚C), TR-2 for External Power.**

Calculations:

Choosing Temperature Offset & Determining Needed Current to Maintain this Temperature Offset

Ryan Hogg - 10/8/15

T_{offset}	**20.0**	**°C**	*set this box*

Where T_{offset} is the difference in temperature between the coil temp and ambient air temperature

Power to maintain T_{offset}	91.0	W
Current to maintain T_{offset}	**308**	**A**

Power Equations

$P = I^2 \cdot R_{CALCULATED}$	**914**	**W**	At 1000A
P (using $R_{MEASURED}$)	**960**	**W**	At 1000A

I	**1000**	**A**

$R = \rho \cdot L / A$

ρ	1.68E-08	Wm	(resistivity)
L	14.64	m	(length)
A	2.69E-04	m^2	(cross sectional area of 20 strands)

$R_{CALCULATED}$	0.000914	Ω	914 μΩ
$R_{MEASURED}$	0.000960	Ω	916 μΩ

Conduction through insulation

$Q_{R1} = -k_{ins} \cdot A_{cu} \cdot (T_{cu} - T_s) / \Delta x$ *(in Watts)*

k_{ins}	Conductivity of Insulation	0.3	W/mK	(range of 0.25-0.30 W/mK possible)
A_{cu}	Surface area of copper to insulation	0.781	m^2	
	Length of conduction	*4.88*	*m*	
	Base of conduction	*0.160*	*m*	
T_{cu}	Temp of Copper	40.0	°C	
T_s	Temp of the outside surface of the insulation	38.6	°C	(calculated below)
Δx	Thickness of insulation	0.003683	m	

Convection from insulation to air

$Q_{R2} = h \cdot A_{ins} \cdot (T_s - T_{air})$ *(in Watts)*

h	Heat transfer coefficient	25	W/m^2K	(5 to 25 for natural convection, 25 to 250 for forced convection)
A_{ins}	Surface area of insulation to air	0.196	m^2	
Ts	Temp of the outside surface of the insulation	38.6	°C	(calculated below)
T_{air}	Temp of the air surrounding the coil	20.0	°C	

Assuming $Q_{R1} = -Q_{R2}$

Therefore

T_s	38.6	°C

Q_{R1}	91.0	W
Q_{R2}	91.0	W

See Fundmentals fo Thermodynamics, by Borgnakke & Sonntag, p. 107-9

Conclusions / Results

The stator windings samples, temperature measurement equipment, and a power source were obtained. The windings were instrumented and some initial testing was performed. Testing was halted because of an urgent need for the high-power source for use at two USBR powerplants. When the equipment returned it was then tasked on other research projects (metal fiber brushes). A substitute lower-power source was implemented but proved to be inadequate for the duty. The original power source became available late in September at the conclusion of the metal fiber brushes research but there was not enough time to complete any remaining testing.

Next Steps / Recommendations

The power supply has returned from field use. Additionally we have secured an additional higher power supply that may also be used in case the primary supply is called to task in the field. Continue the research in FY17.

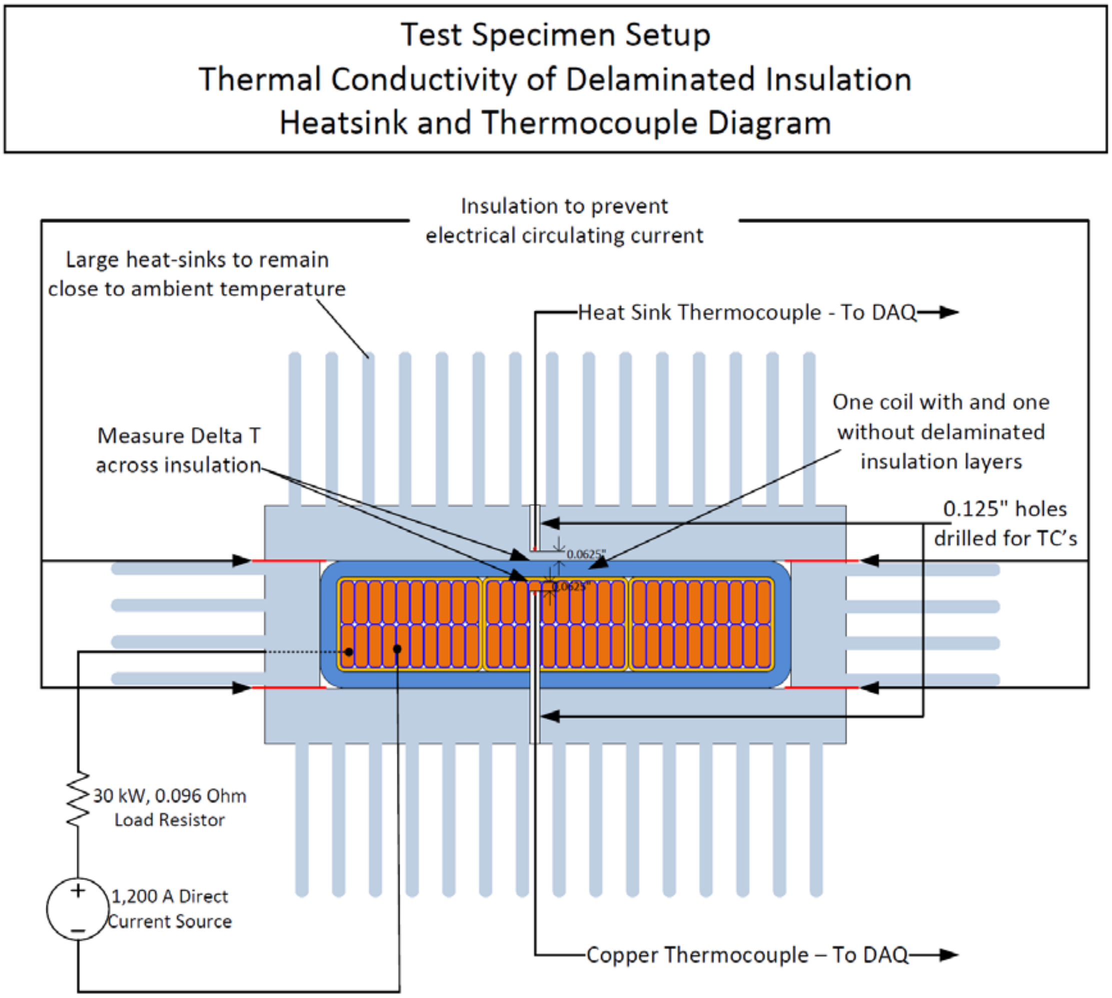
Test Specimen Setup
Thermal Conductivity of Delaminated Insulation
Heatsink and Thermocouple Diagram

Figure 3: Diagram of Stator Coil Instrumentation

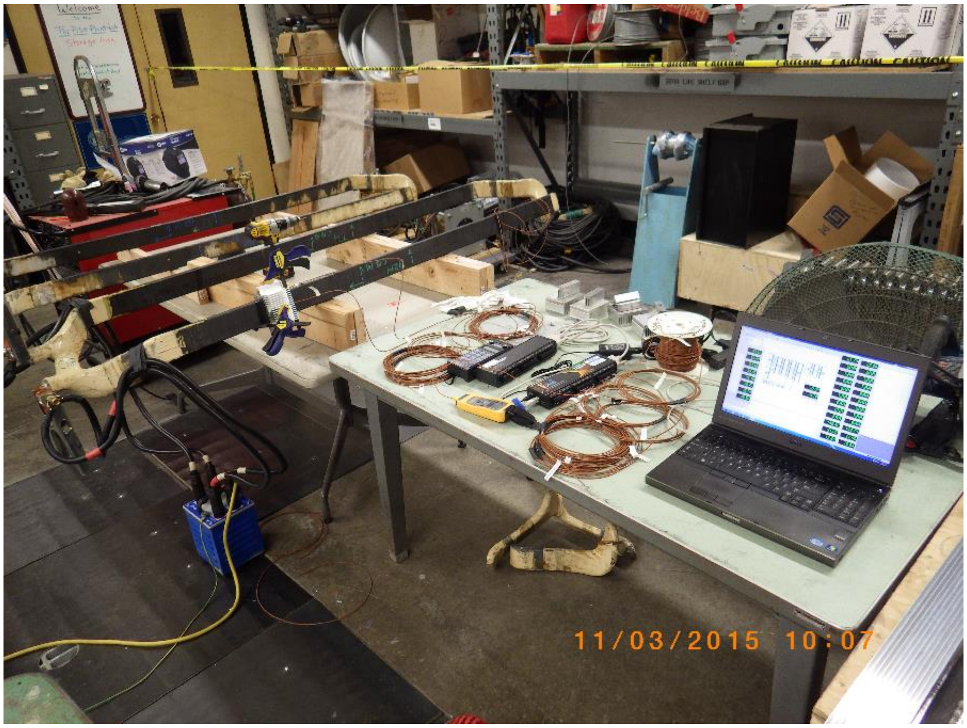

Figure 4: Instrumentation Installation and Monitoring During Initial Testing

Figure 5: Close-up of Heatsink and Thermocouple Installed on Non-Delaminated Low-Voltage Coil Removed from USBR Generator after 30 Years of Service

Increasing Hydrogenerator Output

The Problem:

In an electric generator, the copper conductors (coils) generate heat (via I^2R copper losses), the heat must be transferred through the coil insulation to the air-cooled stator core (heat sink) to cool the coils. Due to the materials required to make a good quality, long lasting, high-voltage electrical insulation the insulation itself becomes a very poor conductor of heat (on the order of 0.27 W/mK [Watts per meter-Kelvin], steel is 80 W/mK, copper is 400 W/mK), the amount of heat that the insulation can transfer limits the ultimate power production/output of the electric generator and plays a dominant role in the reliable life of the stator winding.

Increasing the heat transfer capability of the insulation would allow an up-rating of existing generator without changing physical design. If the prime mover (turbine) cannot deliver any more power the winding would simply run cooler and potentially last longer (i.e. same power output but longer life). High Thermal Conductivity (HTC) insulation systems have existed for many years, these systems approximately double the heat transfer capability of the insulation, however, this alone is not enough to realize full benefit. The contact surface between the stator coil and core is often poor, and is one of the major limiters of heat transfer from coil to core, thus HTC insulation may not provide full benefit. Recently one generator OEM has developed a coil installation system that improves contact between the coil and core which increased heat transfer. The solution is a research project to marry these two technologies. The benefit is extended winding life or up-rating output of the generator.

Simply combining HTC insulation design with recently improved coil installation methods. This will realize the benefits of both systems (synergy between improved thermal conductivity of insulation and improved coil-to-core heat transfer). HTC insulation alone has the potential to reduce copper temperatures by up to 10 degrees Celsius.

Newer coil-to-core installation systems have the potential to reduce copper temperatures by up to 4 degrees Celsius. Total theoretical benefit: reduce coil temperatures by 14 degrees Celsius, increase winding output or increase winding life significantly.

Theoretical reduction in copper temperatures of up to 14 degrees Celsius by combining these two technologies. Theoretically this would allow an existing generator to last twice as long as existing/current technologies, or if the turbine has more output the generator could be up-rated and the winding could produce more power, hypothetical uprate of 15% may be possible. Realistically the life extension of a stator winding may be up to 5 to 8 years. Either way significant improvement is possible, but research is necessary to quantify this benefit. High Thermal Conductivity (HTC) insulation technology has been around for at least 10 years. It has been successfully implemented in generators but still is not mainstream technology.

Conclusions / Results:

The literature searches have found the following:

1. HTC insulation technology utilizes nano-particles mixed with conventional sized fillers to achieve better thermal conduction. These particles are introduced into the epoxy that would be used in a typical stator winding insulation system.
2. When uniformly distributed spherical nano-particles of approximately 40 nm (nano-meters) are into a host epoxy at approximately 5% (by weight) dramatically increase the interfacial area meaning that heat conduction now has a much larger path through the epoxy media.
3. Nano-particles mixed with conventional fillers of various types have been researched by others [1], [2], [3] may utilize:

    a. Magnesium Oxide
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    c. Silicon Dioxide
4. Increases in thermal conductivity varies depending on the percent of the nano-filler in the epoxy. Formulations up to 60% silica nano-filler have been attempted in epoxy resins.
5. Introduction of nano-particles has demonstrated a reduction in electrical treeing and an increase in voltage required to breakdown the epoxy mixed with these particles. Both of these properties would tend to increase the life of stator windings.
6. Laboratory stator bars produced with various nano-silica particle content have shown an increase in accelerated voltage breakdown testing of 5 – 10 times standard technology [2].
7. Voltage Endurance – Nano-composite stator bars produced in a standard 13.8 kV design and tested at 2.5 rated voltage lasted 13 times longer than the standard non-nano composite designs [2].
8. Because increases in breakdown voltage and reduction in tree propagation have been realized this may allow designers to reduce the thickness of the insulation system. This, in turn, will increase the thermal conductivity because the insulation can now be made thinner. This is an added benefit on top of the already increased thermal conductivity due to better per-unit thickness thermal conductivity.
9. Additional qualifications should be performed on nano-composite insulating systems such as mechanical and multifactor aging.

Initially this research effort was to ideally have an agreement for testing of such systems in place by end of FY15. However, attempts to contact personnel with direct knowledge in this field have been unsuccessful. HTC insulation systems and improved stator coil/bar thermal wedging systems were proven to exist based on industry papers. Several discussions with one industry expert, Dr. Nancy Frost, indicated that the systems are tested but not yet fully integrated. Generation owners may resist adoption of this technology because there is risk of the unknown. Siemens AG in cooperation with Voith Hydro GmbH Germany has successfully integrated nano-particles into insulation and performed laboratory testing with very promising results [2]. Several unsuccessful attempts were made to discuss these topics with the authors. Additionally Mr. Lance Crow (Von Roll) and Sean Banagan (IsoVolta) could not be reached on the topic.

Next Steps / Recommendations:

Contact Voith-Siemens and set up a meeting to discuss the state of the art. Determine if Voith-Siemens may is already be integrating this into their mainstream product.

References Cited

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