Re-inventing the Rotor-mounted Scanner Hydro Condition Monitor

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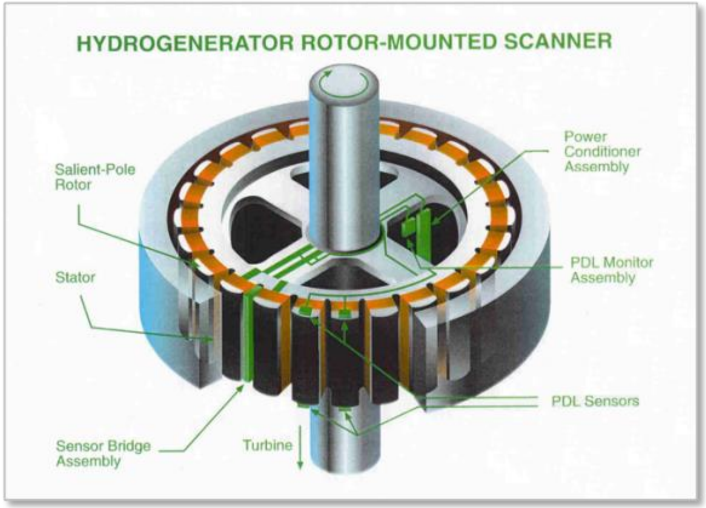
June 22, 2021

It's coming back☺

Permanent rotor-mounted sensing platform performing Condition Monitoring of the stator- StatorScan™

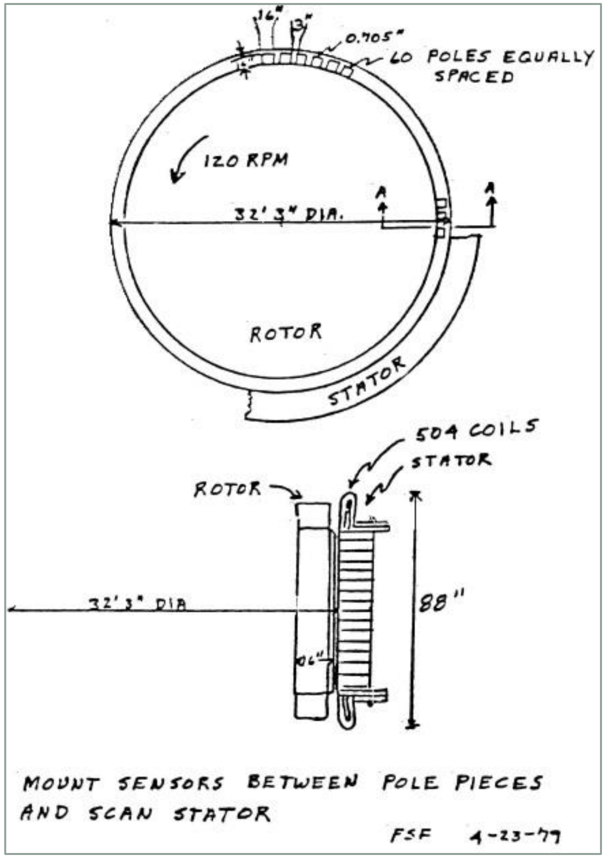


OUTLINE

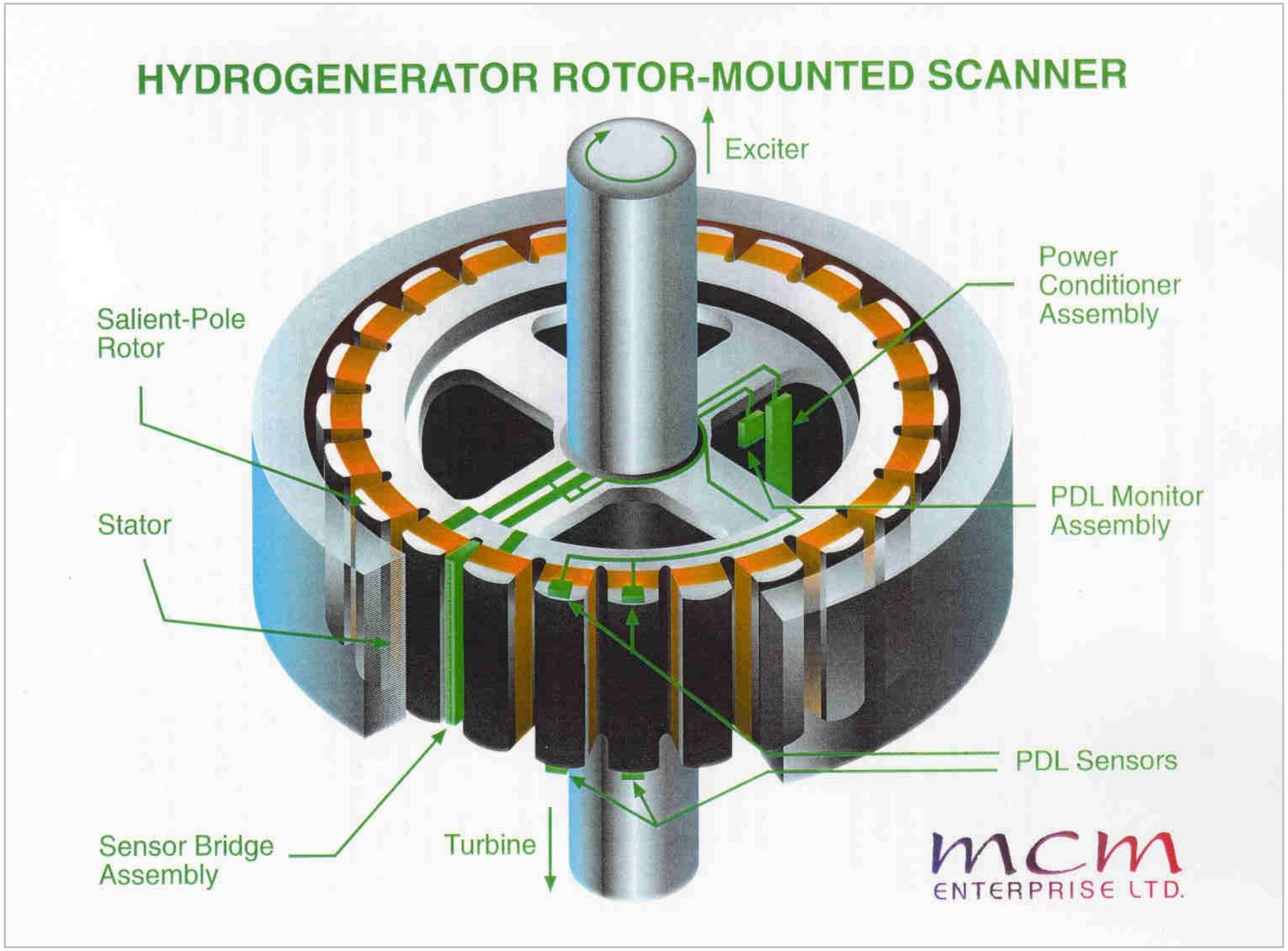
- History of Rotor-mounted Scanner
- RMS Technology
- Why Monitor from the Rotor?
- What is StatorScan?
- Active Failure Mechanism of Hydrogenerators
- StatorScan Capabilities
- 11 Benefits of StatorScan
- StatorScan Development

HISTORY OF ROTOR-MOUNTED SCANNER

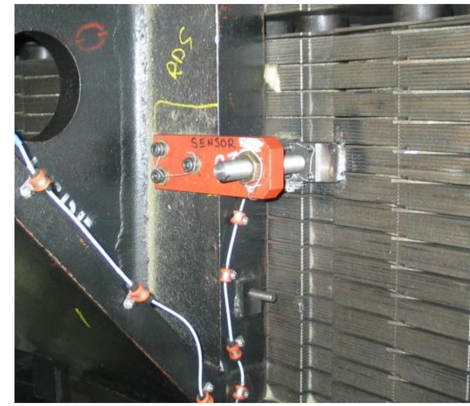
- 1979: Concept defined by Seattle City Light (Frank Ferry)
- 1985: EPRI-funded development began (STI Optronics)
- 1987: First prototype installed
- 1992: First commercial system "HydroScan" (MCM Enterprise)
- 1999: 56 HydroScan systems sold
- 2000: Bently Nevada purchased assets, hired key employees
- 2002: GE purchased Bently, discontinued RMS Program
- 2021: Currently 2 RMS systems operating in North America (2 Utilities)



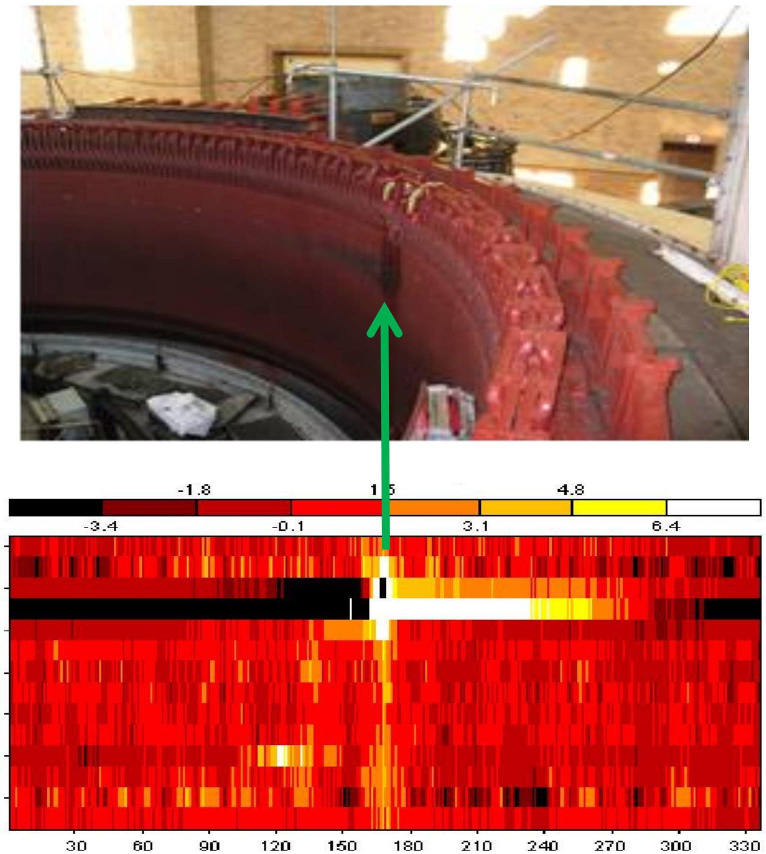
HISTORY OF ROTOR-MOUNTED SCANNER (continued)

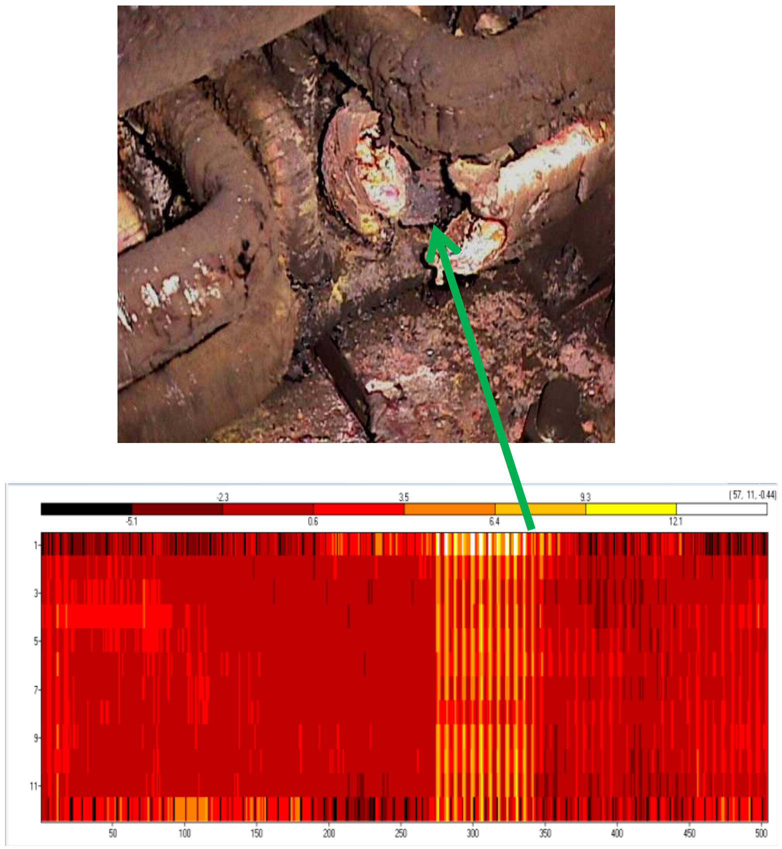


HISTORY: RMS Rotor COMPONENTS



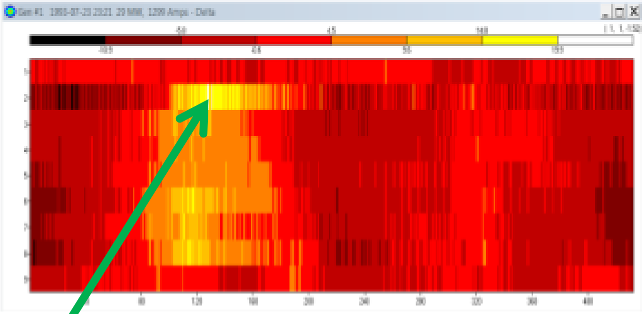
Why Monitor from the Rotor?

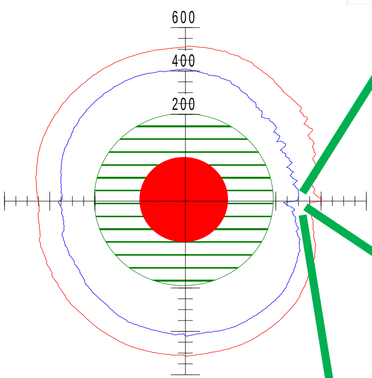




Real Examples from the Rotor-Mounted Scanner

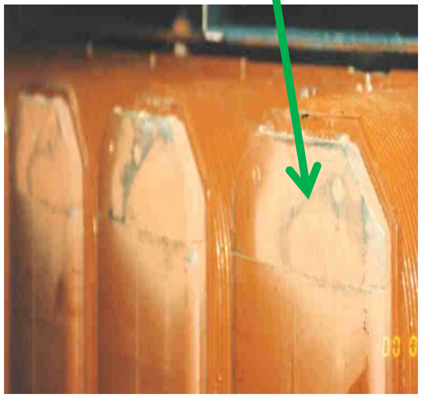
Why Monitor from the Rotor?

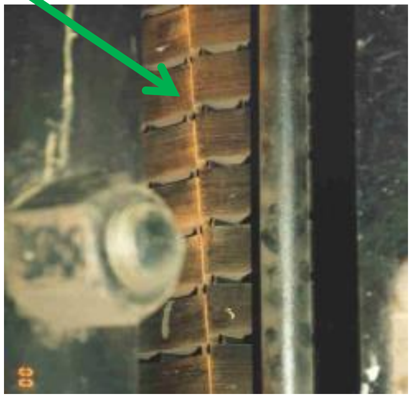


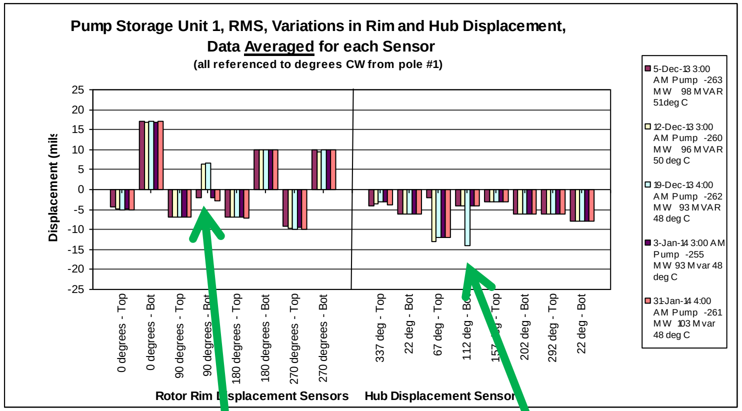


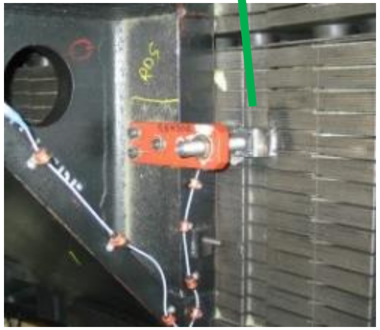
Stator Profile Analysis

	Stator AG 1	Stator AG 2
Minimum	234 at 108	348 at 108
Maximum	422 at 2	515 at 216
Average	372	475
Offset	31 at 136	32 at 107
Bimodal	49 at 125	46 at 112
Trimodal	7 at 129	12 at 104
Quadmodal	8 at 5	12 at 3







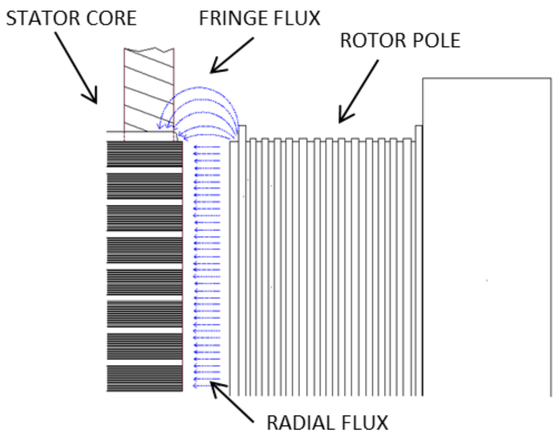


Real Examples from the Rotor-Mounted Scanner

The Evolution of RMS Technology

Key Finding from 28 years of RMS Operation

- Monitoring the full height of the stator is not necessary.
- Detrimental electrical conditions within a hydro generator stator can be detected by monitoring only the ends of the core and adjacent portions of the endwinding from the vantage point of the rotor



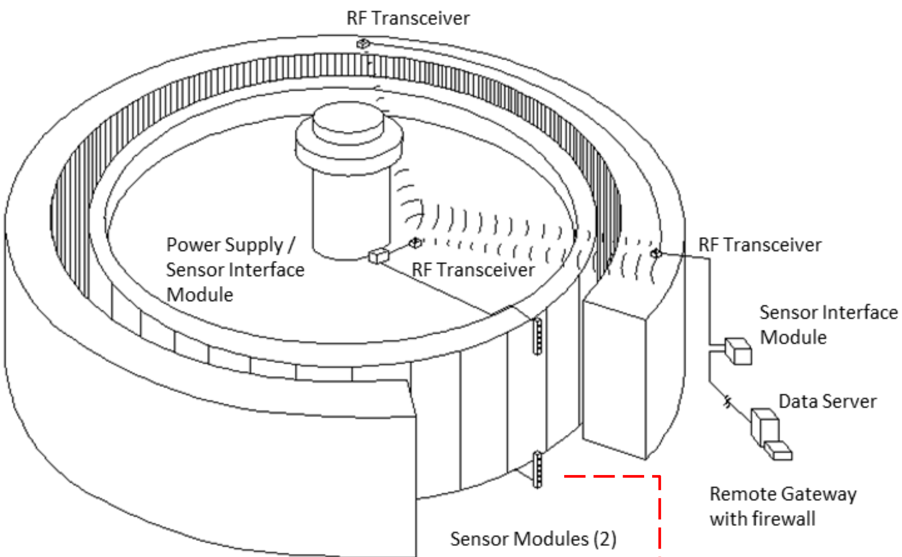
Why?

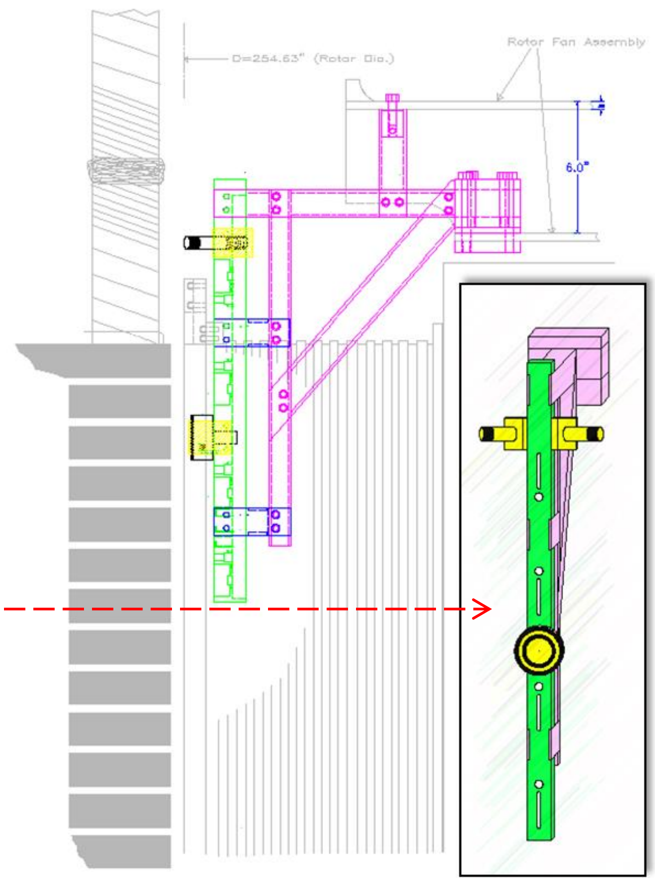
These "end regions" of the stator are where unbalanced forces exist that often cause component failure primarily due to:

- Eddy Current (inductive) heating from fringing magnetic fields (flux)
- Non-uniform cooling air flow
- Limited mechanical support of endwinding components

NEW CRITERIA = LOOK AT THE ENDS OF THE STATOR ONLY

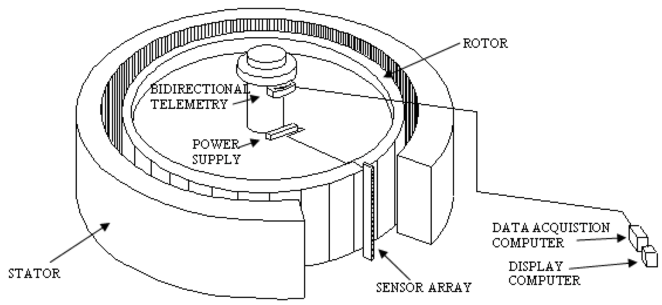
What is StatorScan?

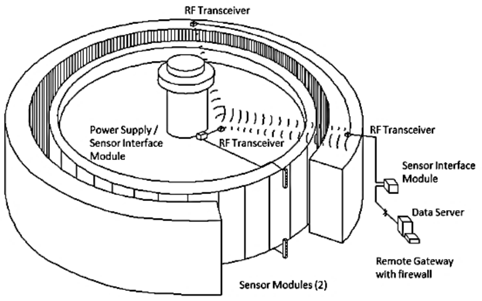




- *Rotor-Mounted* Condition Monitoring System
- Real-time / Continuous Monitoring
- Analyzes / Records Stator Behavior under all Operating Conditions
- Sensor Arrays Mounted between Rotor Poles

The Evolution of RMS Technology (cont.)





Rotor-Mounted Scanner

- $$M's Development over 6 years
- Full Stator Coverage
- Off-rotor data acquisition computer
- Custom Infrared Telemetry system
- Custom Mechanical Mounting and Enclosures
- Basic Mechanical Analysis and FEA
- Custom hardware and software for Data Acquisition and HMI
- No networking capability
- Remote access using dial-up modem
- Minimum alarming capability

StatorScan

- <$M Development over 2-3 years
- Top and Bottom Stator coverage
- On-rotor data acquisition
- RF Telemetry
- Generic modules and support components
- Fracture Mechanics and FEA for critical mechanical components
- NI hardware with LabView software for data server and displays
- Standardized data communication protocol with network and VPN remote access
- Enhanced data alarming and analysis techniques

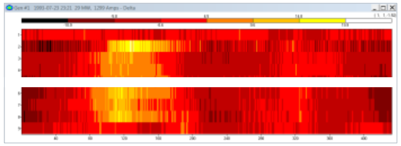
Hydrogenerator Active Failure Mechanisms

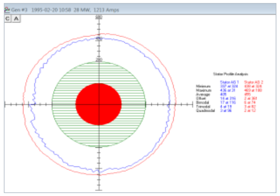
Active Mechanism (1^{st} = Primary; 2nd = Secondary)
Table 1: Stator and Rotor Failure Mechanisms;
Modified from Tom Churchill- ERPI Report

	CONDITION / SENSOR TYPE >	INFRARED	RF	MAGNETIC	AIR GAP	VIBRATION	DISPLACEMENT	DETECTABLE FROM CORE ENDS?
1	Bad Ring Bus/Coil Joint	1^{st} ; excess I^2R						yes
2	Bad Coil/Knuckle Joint	1^{st} ; excess I^2R						yes
3	Loose Coil	2^{nd}; poor cooling	2^{nd}; slot discharge					yes
4	Loose End Bracing		2^{nd}; corona /part. disch.					yes
5	Broken Coil Strand(s)	2^{nd}; burning	2^{nd}; arching	1^{st} ; erratic I				yes
6	Shorted Coil Strand(s)	1^{st} ; excess I^2R		1^{st} ; excess I				yes
7	Shorted Coil Turn(s)	1^{st} ; excess I^2R		1^{st} ; excess I				yes
8	Expelled Coil				1^{st} ; migration			yes
9	Damaged Coil Ground Wall	2^{nd}; displaced I^2R	1^{st}; slot discharge					yes
10	Damaged Coil Grading Paint		1^{st}; corona /part. discharge					yes
11	Delaminated Coil Insulation		1^{st}; partial discharge					yes
12	Shorted Core Laminations	1^{st}; burning		2^{nd}; eddy I				only if located at ends
13	Loose Core Laminations	2^{nd}; poor cooling			2^{nd}; uneven gap			yes
14	Deformed /Poorly Supported Core	2^{nd}; variable heating		2^{nd}; variable mmf envelope	1^{st}; uneven gap			yes
15	Loose Clamping Fingers	1^{st}; poor cooling						yes
16	Blocked Ventilation Ducts	1^{st}; poor cooling						only if located at ends
17	Trapped Air in Cooler	1^{st} ; excess I^2R						yes
18	Blocked Air Cooler	1^{st} ; excess I^2R						yes
19	Misaligned Rotor	2^{nd}; variable heating		2^{nd}; variable mmf envelope	1^{st}; uneven gap			yes
	Dynamic Flexing of Rotor Rim				2^{nd}; uneven gap		1^{st}; dynamic displacement	na
	Shifting Rotor Hub Sections						1^{st}; static displacement	na
	Loose Rotor Pole					1^{st} ; f= power harmonics		na
	Loose Rotor Hub Section					1^{st} ; f= very low freq		na

StatorScan Capabilities

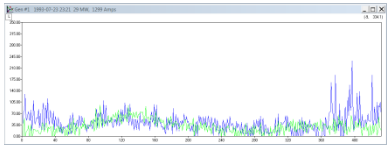
Infrared Thermal Imaging of Stator Surface and Endwinding

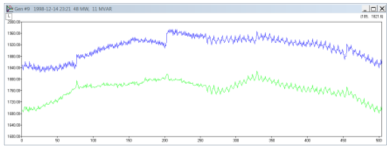




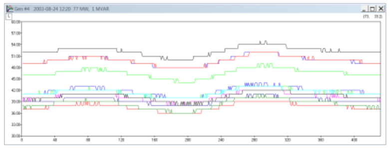
"Actual" Stator Air Gap of stator core referenced from the rotor (not inferred from stator-mounted sensors)

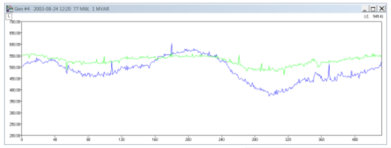
Localized and Global Partial Discharge Analysis using 5MHz Corona Probe





AC/DC Magnetic Field Sensors reflect imbalances in stator winding electrical circuit





Rotor Integrity Sensors monitor static and dynamic movement of Rotor Components- Displacement Sensors /Strain Gauges /Accelerometers

11 Benefits of StatorScan

1. Defer stator rewinds and core replacements
2. Provide multi-unit rewind/replacement prioritization
3. Prevent stator failures by providing early warning
4. Monitor progress of active failure mechanisms
5. Evaluate the design and manufacturing quality of new windings and cores.

11 Benefits of StatorScan (cont.)

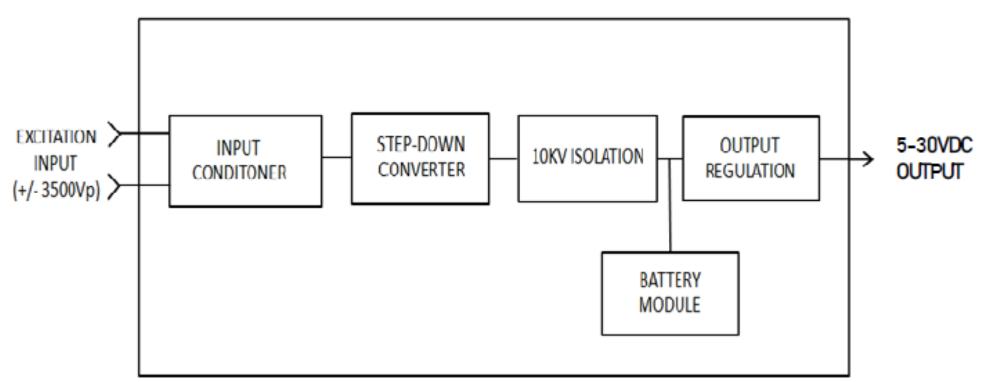
6. Gives operational insight to avoid winding stress
7. Complements existing Predictive Maintenance systems
8. Improves generator Condition Assessment processes
9. Allows for incorporation of various rotor integrity sensors such as displacement (proximity), strain gauges, accelerometers, RTDs, etc.
10. Enhances existing 3rd party Rotor Air Gap systems providing “True Air Gap”
11. Endwinding Inspection Camera can allow for remote visual stator inspections with the unit running

STATORSCAN DEVELOPMENT

- Underway in August 2020
- Led by the Hydropower Research Institute (HRI) in Chelan County, Washington.
- Funding provided by Chelan County PUD and the United States Bureau of Reclamation
- Project split into three phases:
  - Phase 1: Rotor Power Supply
  - Phase 2: Rotor Data Acquisition Platform
  - Phase 3: Primary Sensing Module and Camera

Phase 1: Rotor Power Supply (RPSM)

- Underway beginning in 2020
- Phase 1 complete on July 15, 2021.
- Prototypes delivered to project sponsors on completion date
- Design is based on the RMS Power Conditioner; however with significant improvements



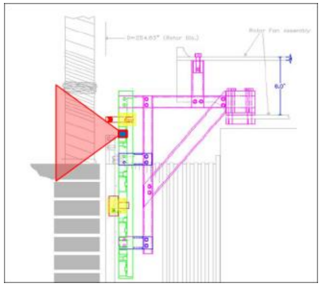
RPSM Block Diagram

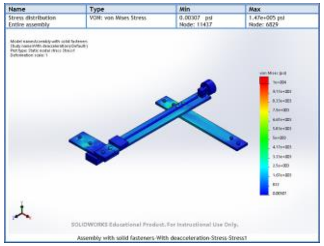
Phase 2: Rotor Data Acquisition Platform

- Targeted to start in August 2021
- Development to include:
  - The Rotor and Stator Data Acquisition platforms
  - Wireless Telemetry system
  - Stationary Data Server and Display Software
  - Selected rotor integrity sensors including proximity sensors (to capture dynamic rim flexing), strain gauges, and accelerometers
  - Rotor Thermocouples/ RTDs for pole winding monitoring
  - Stationary thermocouple sensors and plant process sensors (MW, MVAR)
  - Input for 3rd party Air Gap sensors and Key Phasor

Phase 3: Primary Sensing Module

- Anticipated to begin in latter 2022 or 2023
- Development to include:
  - Sensor Module (SM) pair and generic Mounting Brackets
    - Modules mounted on the top and bottom perimeter of the rotor, between poles viewing the end of the core and endwinding
    - Sensors include infrared Thermal Imaging, Air Gap, 5MHz Corona Probe, AC/DC Magnetic Fields, and diagnostic Accelerometers
    - Rated for 1,000 G's
  - Endwinding Inspection Camera
    - Mounted between poles, top and bottom
    - Images can be viewed remotely by a Generator Expert with the unit running
    - Intended to replace visual stator enwinding inspections
    - Acquires sharp, color images in a stepped sequence around the stator





Comparing the Original RMS Power Conditioner and the StatorScan Rotor Power Supply Module

RMS Power Conditioner

- Taps into rotor excitation
- Different versions for AC or DC Excitation
- Input = +/- 40 to +/- 600VDC for DC version
- Input = 1,500Vpp for AC version
- 10KV isolation
- Transient filtering
- Soft start, overcurrent and overvoltage protection
- 60W, +/-15VDC output
- 120 lbs. with mounting bracket
- 60 °C operation
- 266 G's (overspeed)

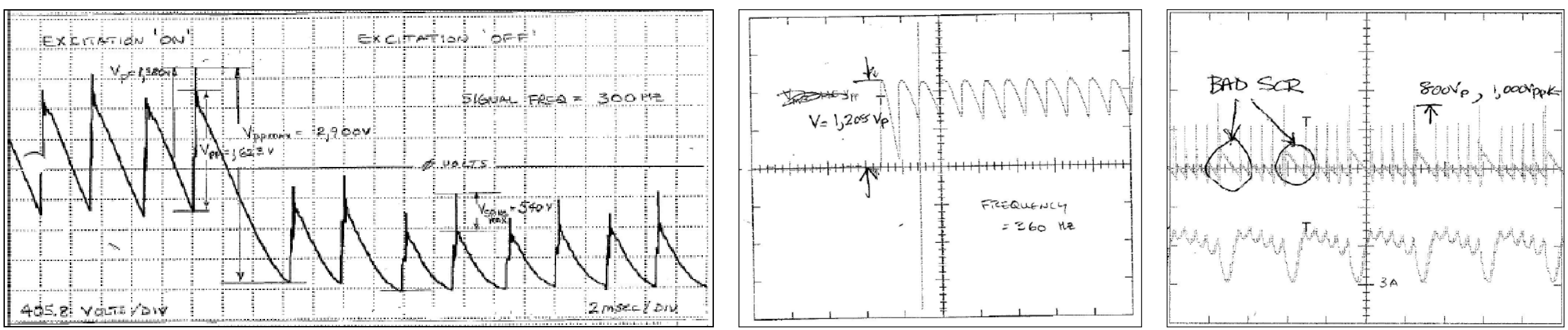
StatorScan RPSM

- Taps into rotor excitation
- Single version for AC and DC Excitation
- Input = +/- 40 to +/- 3,500Vpk
- 10KV isolation
- Transient filtering
- Soft start, overcurrent and overvoltage protection
- 20W, 5-30VDC output
- <40 lbs.
- 60 °C operation
- 300 G's (overspeed)
- Battery backup for operation during startup and shutdown

RSPM DEVELOPMENT PROCESS

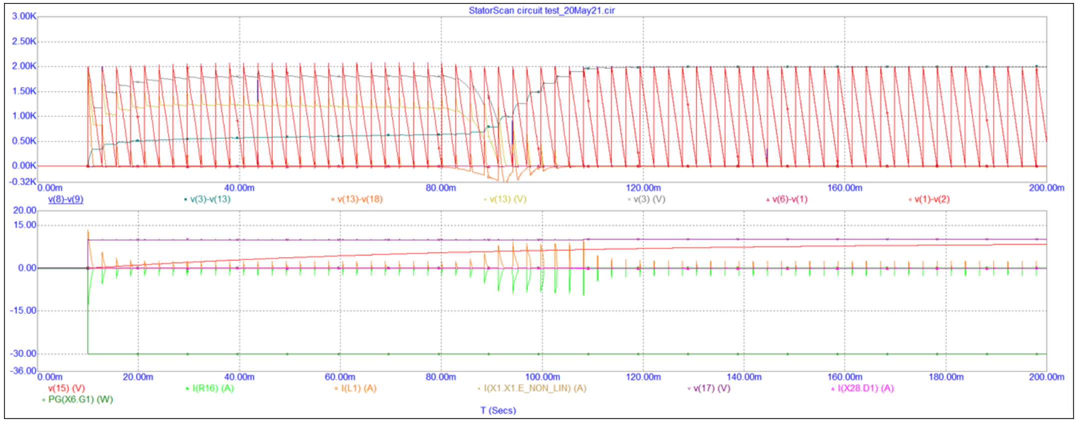
Challenges

- Extremely wide range of input voltage (using single Flyback Converter)
- Optimizing filter components for wide input range without blowing fuses
- Packaging to keep a small footprint for high G’s operation



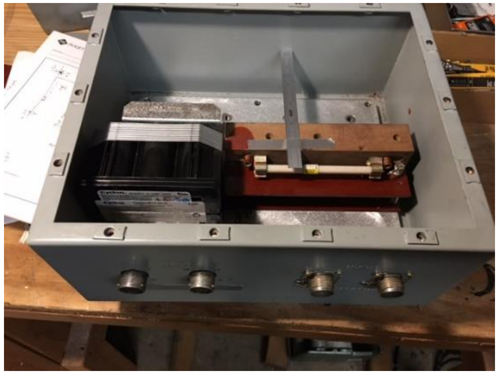
Worst case static excitation waveforms from RMS

RPSM DEVELOPMENT PICTURES



Spice Circuit Analysis of Input Filter Circuit with Simulated Excitation

O-scope Traces of Flyback Converter during Startup



Questions?