ELECTRIC MACHINERY

26TH IRIS ROTATING MACHINE CONFERENCE

AVR Controller Function in an Excitation System and Unique Failure and Resolution

June 19, 2024

ESTABLISHMENT OF MATHIMATICAL PRINCIPLES

26	26
12	1
12 divided by 26	1 divided by 26
.46153846	.03846154
46.153846%	03.846154%

TOPICS FOR REVIEW

- WEG Electric Machinery Company Information
- Basic Elements and Operation of Excitation System
- Unique failure, trouble shooting and resolution of AVR problem
- User Path Forward

WEG ELECTRIC MACHINERY COMPANY INFORMATION

EM Facility

- Located Minneapolis Minnesota
- 425,000 ft²
- 215 factory/office employees
- All motor/generator core competencies on premises
- Full VPI capability with WEG EM's Duraguard™ Insulation System

LRQA
Business Assurance

CERTIFICATE OF APPROVAL

This is to certify that the Quality Management System of:

Electric Machinery
800 Central Avenue NE
Minneapolis, Minnesota 55413, USA

has been approved by Lloyd's Register Quality Assurance to the following Quality Management System Standards:

ISO 9001:2008

The Quality Management System is applicable to:

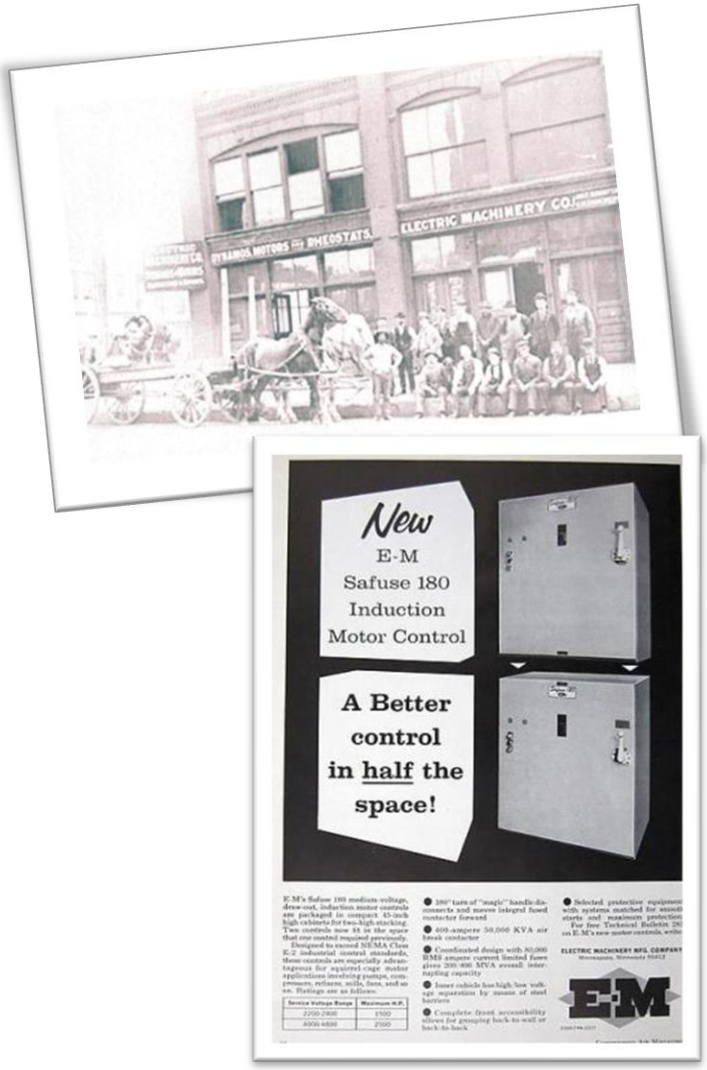
Design, Manufacture and Technical Support of Electric Motors, Electric Generators, and Magnetic Couplers.

EM Quality Assurance

- Total Quality Process - Since 1989
- Focused on total customer satisfaction through continuous improvement.
- ISO-9001 (2015 Standard)
  - Lloyd's Register Quality Assurance
- ASME NQA - 1 - 10CFR50 – 10CFR21

WEG ELECTRIC MACHINERY COMPANY INFORMATION

- 1891
  - Electric Machinery founded as a service shop
- 1897
  - Electric Machinery Manufacturing Company (EM) began manufacturing direct current motors & generators
- 1921
  - EM develops its first synchronous motor and following year its first induction motor
- 1944 – 2011
  - Various owners of EM
- 2011
  - GE required to sale off EM as ordered by the DOJ in order for GE's acquisition of ConverTeam to proceed.
- 2011
  - **WEG Group purchases EM from GE**, becoming WEG's first manufacturing facility in North America.



WEG ELECTRIC MACHINERY COMPANY INFORMATION

PRODUCTS

- Synchronous Motors
- Induction Motors
- Brushless Exciters
- Turbo Generators
- Synchronous Generators
- Magnetic Drives

WEG ELECTRIC MACHINERY COMPANY INFORMATION

SYNCHRONOUS MOTORS

- **Output:** 300 to 150,000 HP
- **Speed:** 150 to 3600 RPM
- **Voltage:** 2.3 kV to 14.4 kV
- **Typical Applications:**
  - Compressors, Pumps, Mills, Grinders, Refiners, Chippers

WEG ELECTRIC MACHINERY COMPANY INFORMATION

INDUCTION MOTORS

- **Output:** 2000 to 25000 HP
- **Speed:** 180 to 3600 RPM
- **Voltage:** 2.3 to 14.4 kV
- **Typical Applications:**
  - Pumps, Compressors, Extruders

WEG ELECTRIC MACHINERY COMPANY INFORMATION

SYNCHRONOUS GENERATORS

- **Output:** 5000 to 25000 kW *
- **Speed:** 150 to 1800 rpm
- **Voltage:** 2.3 kV to 14.4 kV
- **Typical Applications:**
  - Diesel Engines, Hydro Turbines, MG sets
  - 438/500 kVA Control Rod Power MG sets for Nuclear PWR plants

WEG ELECTRIC MACHINERY COMPANY INFORMATION

2-POLE TURBO GENERATORS

- **Speed:** 3000 & 3600 RPM
- **Output:** 6 to 180 MW
- **Voltage:** 2.3 to 14.4 kV
- **Applications:**
  - Gas & Steam Turbines
- **Installed Base of over 1000 units**

WEG ELECTRIC MACHINERY COMPANY INFORMATION

ENGINEERING SERVICES

Field Service
- Turnkey On-Site PM & Repairs
- Installation & Commissioning
- On-Site Testing

Factory Repair
- Rewinds & Refurbishments
- Rectifier Rebuilds
- Factory Testing

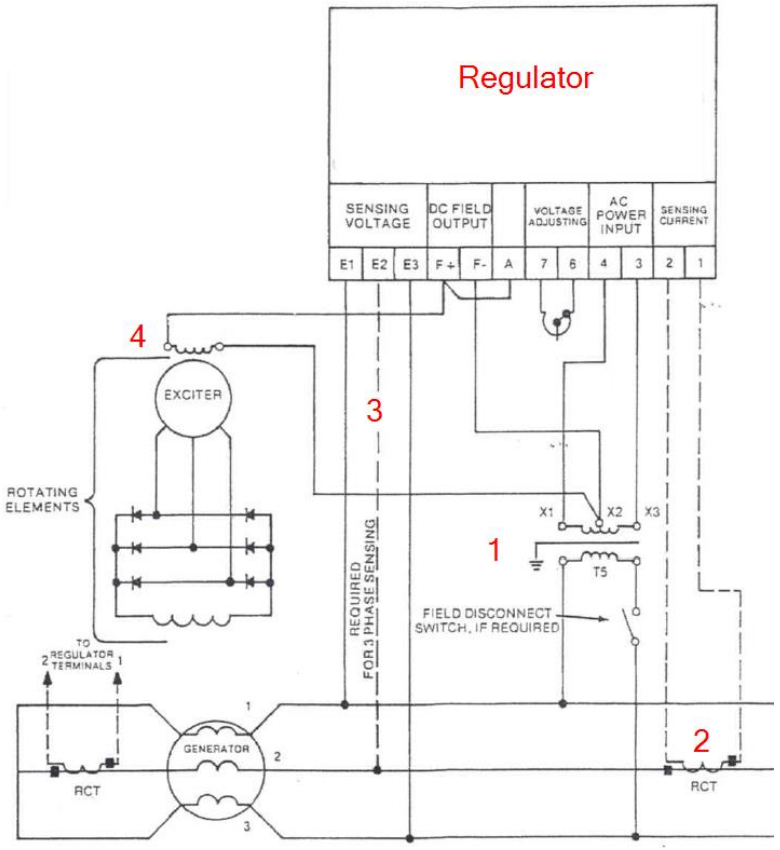
Parts
- Replacement Parts
- Major Components
- Brushless Exciters

Service Engineer-ing
- Technical Support
- Engineering Studies
- Field Analysis & Troubleshooting
- Aftermarket Design

Monitoring Service (future)
- Future Revenue Stream
- On-line Motor and Generator Monitoring
- Sales Avenue for Other Service

ELEMENTS AND OPERATION OF EXCITATION CONTROL SYSTEM (REGULATOR)

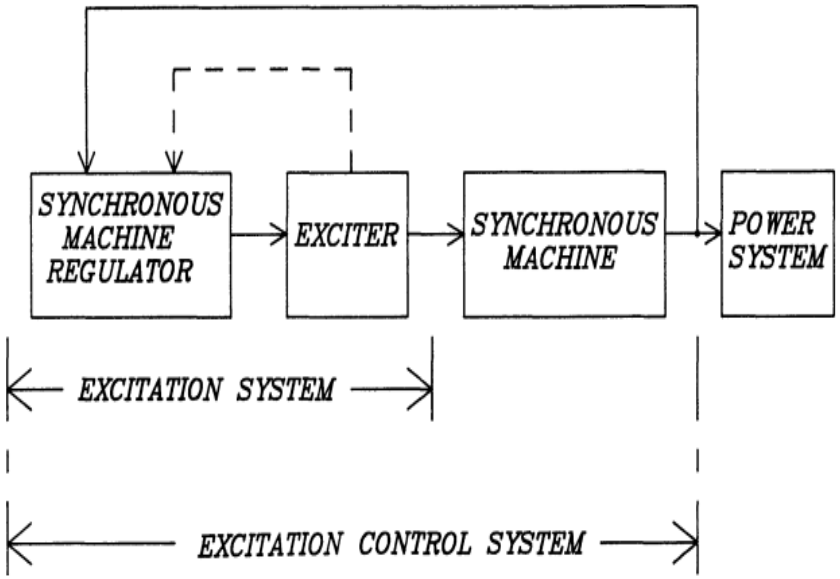
- An Automatic Regulator (AR) system for a generator maintains output set point stability. Key components include operating power from a Permanent Magnet Generator (PMG) or auxiliary source(1), Current Transformers (CTs) (2), and Potential Transformers (PTs) (3) to monitor system performance. The brushless exciter (4) receives signals from the excitation regulator, adjusting the field current to ensure the generator maintains stable operational parameters under varying load conditions.



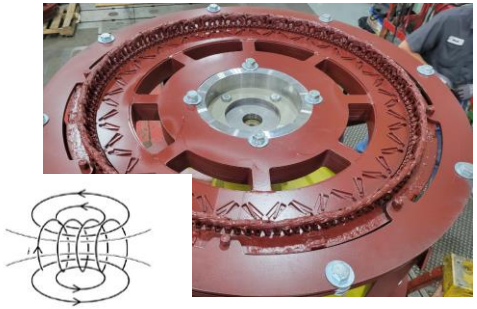
ELEMENTS AND OPERATION OF EXCITATION CONTROL SYSTEM BRUSHLESS EXCITER THEORY

Elements of a excitation System
(Per IEEE 421-2 Definition)

- Synchronous Machine
  - Generator Stator
  - Generator Rotor
- Excitation System
  - Exciter Stator
  - Exciter Rotor
  - Rotating Rectifier
  - Automatic Regulator



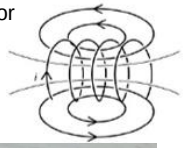
ELEMENTS AND OPERATION OF EXCITATION CONTROL SYSTEM BRUSHLESS EXCITER OPERATION



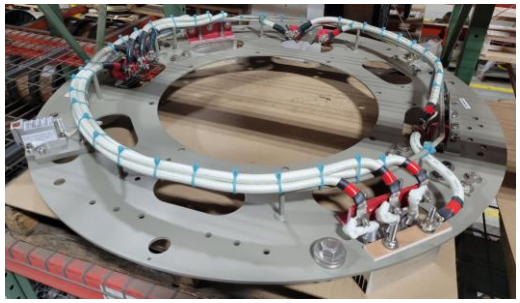
Permanent magnet rotor induces current in the PMG stator and supplies AC power to the AVR

The AVR controls excitation current and supplies DC power to the exciter stator

The exciter stator induces current in the exciter rotor



Exciter rotor supplies AC output to the diode wheel

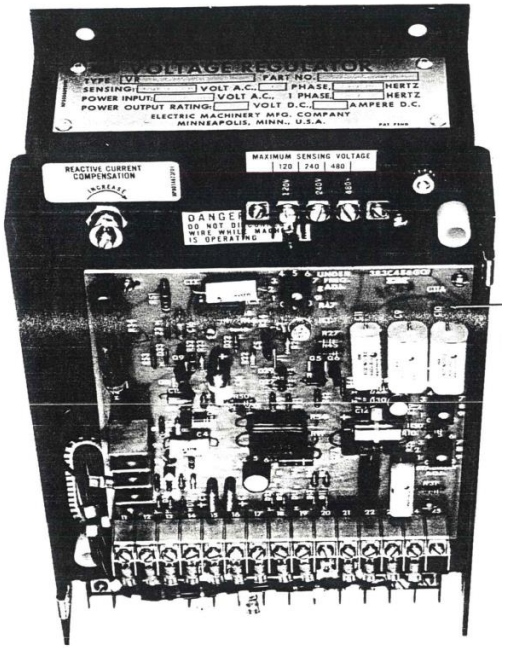


Diode wheel rectifies AC to DC and supplies DC power to the main rotor field

COMPARISON OF TYPES OF REGULATORS (ANALOG – PRE 1990'S)

- The brain of the brushless excitation system.
- Converts AC power to DC power.
- DC power output will determined according to system requirements.
- Can run in two different modes.
  - Manual (Field Current Regulate).
  - Auto (Voltage Regulate).

System receive feedback from CT/PT and adjust according to that



COMPARISON OF TYPES OF REGULATORS

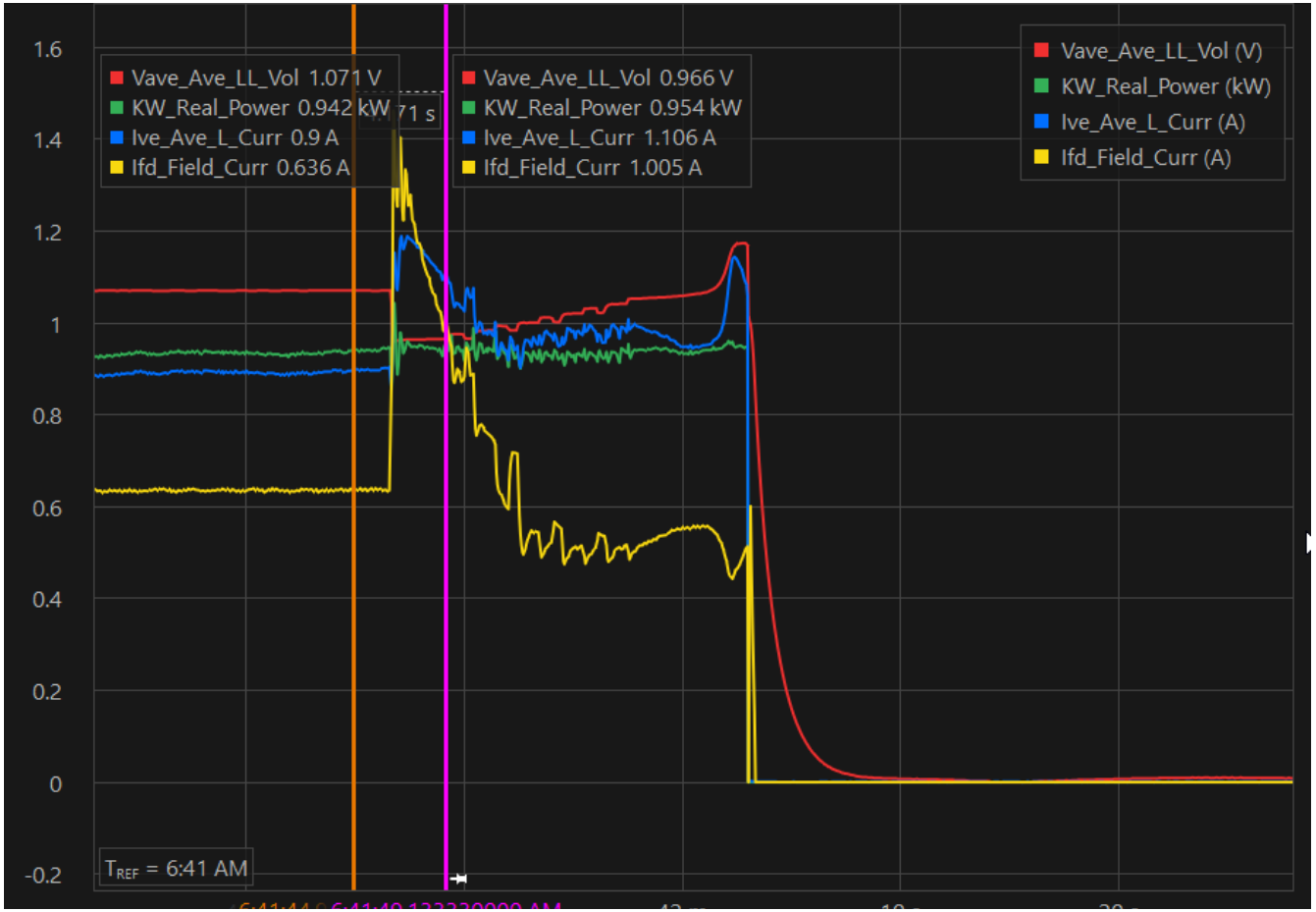
DIGITAL

- The brain of the brushless excitation system.
- Converts AC power to DC power.
- DC power output will determined according to system requirements.
- Can run in Five different modes.
  - Manual (Field Current or Field Voltage Regulate).
  - Auto (Voltage, PF or VAR Regulate).

System receive feedback from CT/PT and adjust according to that

Functionality of a Digital Excitation Controller Cont.

- The event logs also offer precise records of the primary parameters' performance, aiding in troubleshooting trip scenarios and providing a logical explanation for a precise root cause analysis.

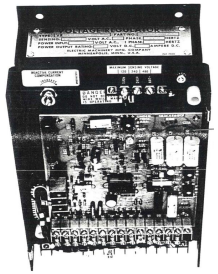


Functionality of an Digital Excitation Controller Cont.

- In addition to its primary function, the digital excitation system fulfills the requirements of both the operation and maintenance teams by offering operating parameters through various communication options, as well as event logs that aid in troubleshooting and minimize downtime.

	A	B	C	D	G
2834	2023-03-31 07:37:21.178		DECS PREPOSITION	On	
2835	2023-03-31 07:37:21.178		DECS START STOP	On	
2836	2023-03-31 07:37:21.178		Softstart Active	On	
2837	2023-03-31 07:37:25.274		EXCITTION_ON	On	
2838	2023-03-31 07:37:25.274		START	Off	
2839	2023-03-31 07:37:25.278		PMG_POWER THRESH2 PICKUP	On	
2840	2023-03-31 07:37:25.278		Softstart Active	Off	
2841	2023-03-31 07:37:25.278		Loss Of Sensing-Pickup	On	
2842	2023-03-31 07:37:25.487		Power Input Failure-Pickup	On	
2843	2023-03-31 07:37:25.491		PMG_POWER THRESH2 TRIP	On	
2844	2023-03-31 07:37:25.491		Alarm Output	On	
2845	2023-03-31 07:37:25.491		Loss Of Sensing-Trip	On	
2846	2023-03-31 07:37:25.591		TransferWatchdogTrip	On	
2847	2023-03-31 07:37:32.737		MAJOR_TROUBLE	On	
2848	2023-03-31 07:37:32.741		MINOR_TROUBLE	On	
2849	2023-03-31 07:37:32.949		WatchdogOutput	Off	
2850	2023-03-31 07:37:32.953		GenBelow10Hz - Pickup	On	
2851	2023-03-31 07:37:42.666		GenBelow10Hz - Trip	On	
2852	2023-03-31 07:37:42.670		Manual Mode Enable	Off	

AUTOMATIC EXCITATION CONTROL SYSTEM (VOLTAGE REGULATOR)



Feature	Analog AVR	Digital AVR
Regulation Technology	Analog components (resistors, capacitors, transformers)	Microprocessor
Response Time	Slower	Faster and more precise
Accuracy	Less accurate (wider regulation range)	More accurate (tighter regulation range)
Data Processing	Limited	Advanced - can process and analyze voltage fluctuations
Fault Troubleshooting	Basic (visual inspection, component testing)	Advanced - event and sequence logging with graphical data for easier fault identification
Communication	Limited (usually indicator lights)	More options - RS-232, USB, network connectivity
Additional Features	May have manual voltage adjustment	May offer programmable settings, overload protection, self-diagnostics

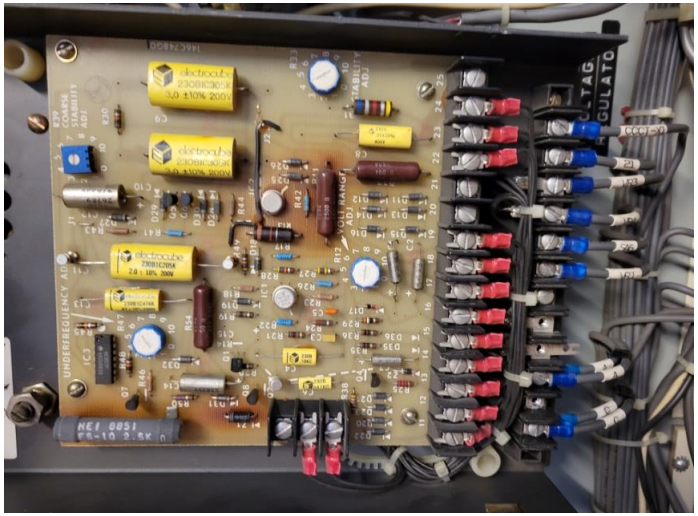
UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

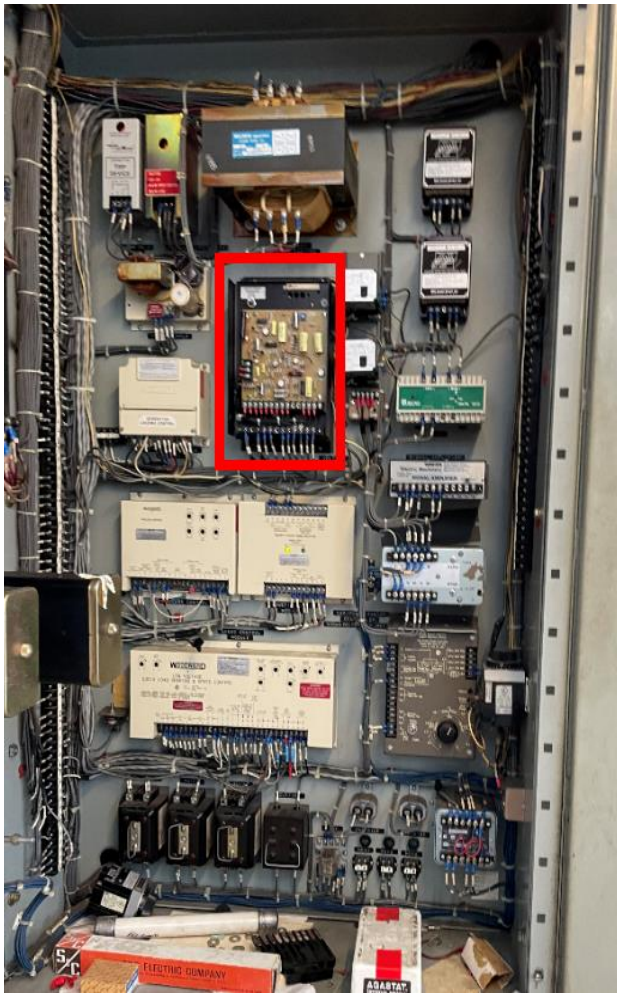
- Major University, with extensive facilities relying on continuous power, faced a critical generator forced outage. Initial investigations suggested an Analog Automatic Voltage Regulator (AVR) issue, specifically the aging EM VR40 series in service for over 20 years.

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- "The User replaced the AVR, after failing the test suspecting wear and tear, but the generator continued to fail with high voltage issues upon excitation. Our team was contacted for remote support to diagnose and resolve the persistent problem."





UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

- We provided support to the Facility to address the generator forced outage. Our approach included remote diagnostics and on-site investigation, leading to successful resolution

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

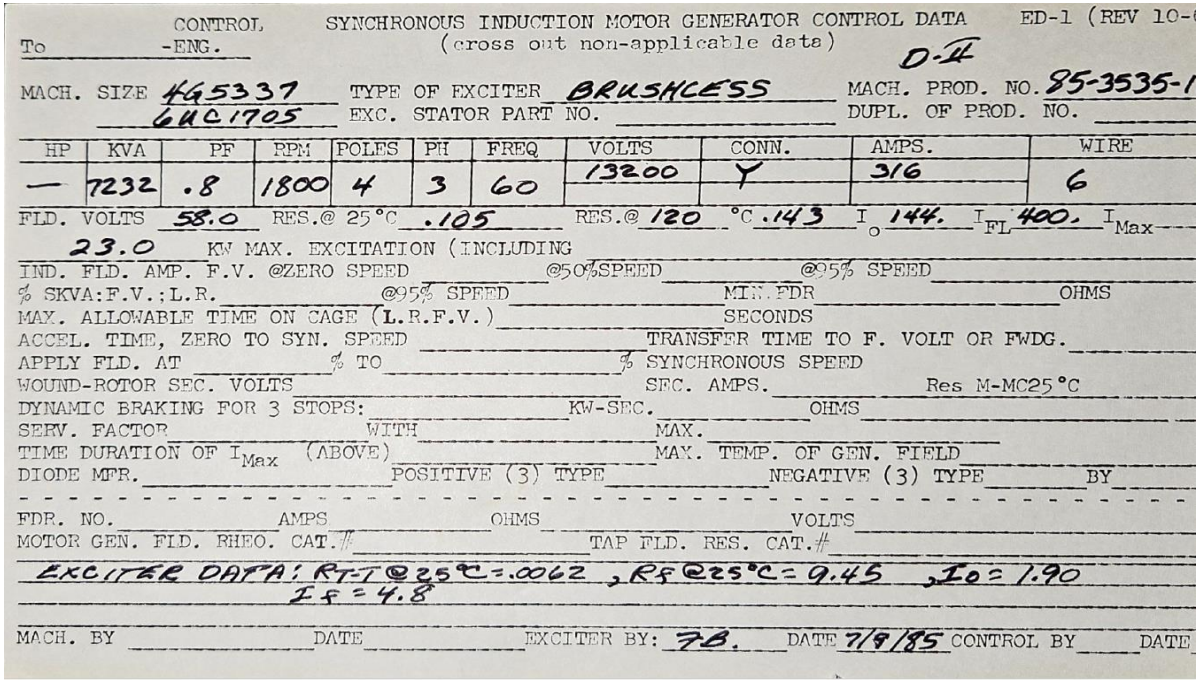
INITIAL FINDINGS AND ACTIONS TAKEN

- "We provided initial remote support, suggesting a comprehensive test plan. Initial findings indicated normal 125 VAC from PMG wires feeding the regulator operating power but an unexpected 92 VAC between F+ & F- at rated speed, leading to further investigation."

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- "With remote diagnostics proving insufficient, our field service team was deployed for an in-depth on-site investigation. This included extensive testing of the generator's main components and subsystems."



CONTROL SYNCHRONOUS INDUCTION MOTOR GENERATOR CONTROL DATA ED-1 (REV 10-
To -ENG. (cross out non-applicable data) D-H

MACH. SIZE HG5337 TYPE OF EXCITER BRUSHLESS MACH. PROD. NO. 85-3535-1
6UC1705 EXC. STATOR PART NO. DUPL. OF PROD. NO.

HP	KVA	PF	RPM	POLES	PH	FREQ	VOLTS	CONN.	AMPS.	WIRE
—	7232	.8	1800	4	3	60	13200	Y	316	6

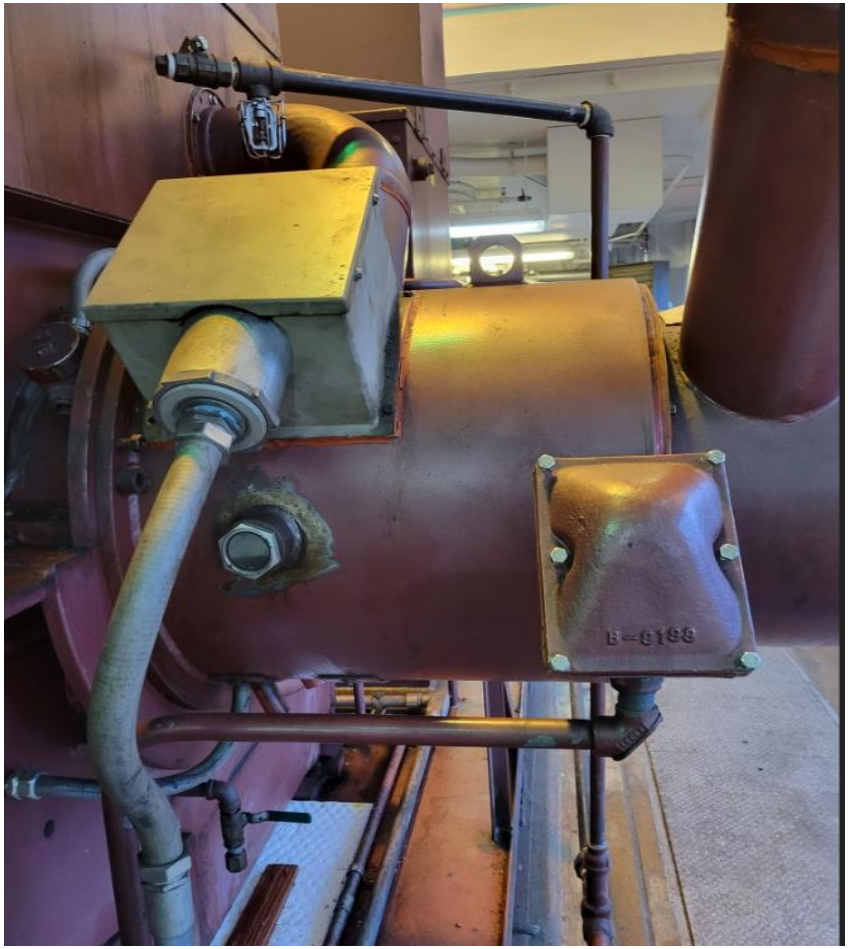
FLD. VOLTS 58.0 RES.@ 25°C .105 RES.@ 120 °C .143 I_o 144. I_{FL} 400. I_{Max}
23.0 KW MAX. EXCITATION (INCLUDING
IND. FLD. AMP. F.V. @ZERO SPEED @50%SPEED @95% SPEED
% SKVA:F.V.;L.R. @95% SPEED MIN. FDR OHMS
MAX. ALLOWABLE TIME ON CAGE (L.R.F.V.) SECONDS
ACCEL. TIME, ZERO TO SYN. SPEED TRANSFER TIME TO F. VOLT OR FWDG.
APPLY FLD. AT % TO % SYNCHRONOUS SPEED
WOUND-ROTOR SEC. VOLTS SEC. AMPS. Res M-MC25°C
DYNAMIC BRAKING FOR 3 STOPS: KW-SEC. OHMS
SERV. FACTOR WITH MAX.
TIME DURATION OF I_{Max} (ABOVE) MAX. TEMP. OF GEN. FIELD
DIODE MFR. POSITIVE (3) TYPE NEGATIVE (3) TYPE BY

FDR. NO. AMPS OHMS VOLTS
MOTOR GEN. FLD. RHEO. CAT.# TAP FLD. RES. CAT.#
EXCITER DATA: RT-I @25°C=.0062 , RF @25°C=9.45 , Io=1.90
If=4.8
MACH. BY DATE EXCITER BY: T.B. DATE 7/9/85 CONTROL BY DATE

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

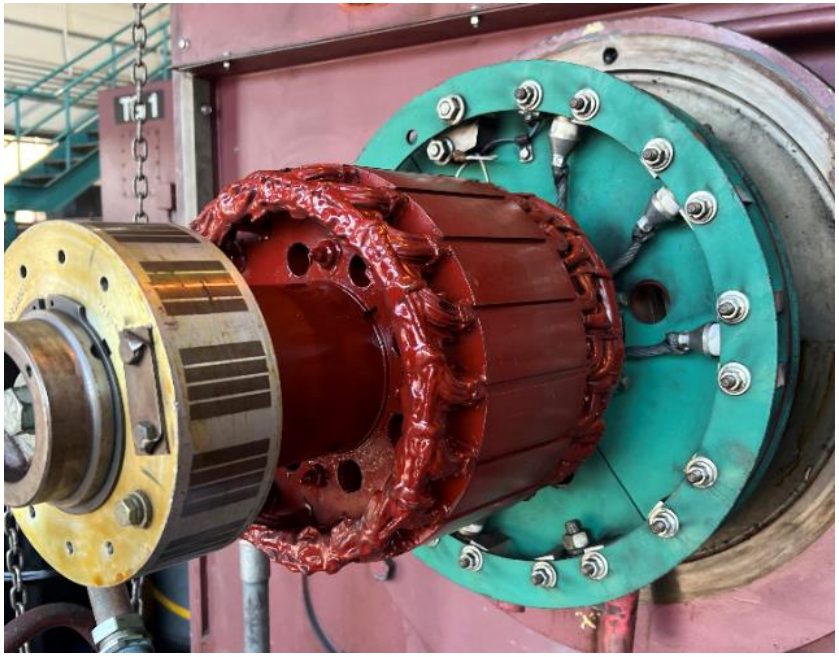
- "Our team conducted detailed checks on the main stator, rotor, and brushless exciter components. Initial findings showed these parts to be in good condition, prompting further focus on other potential issues."



UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

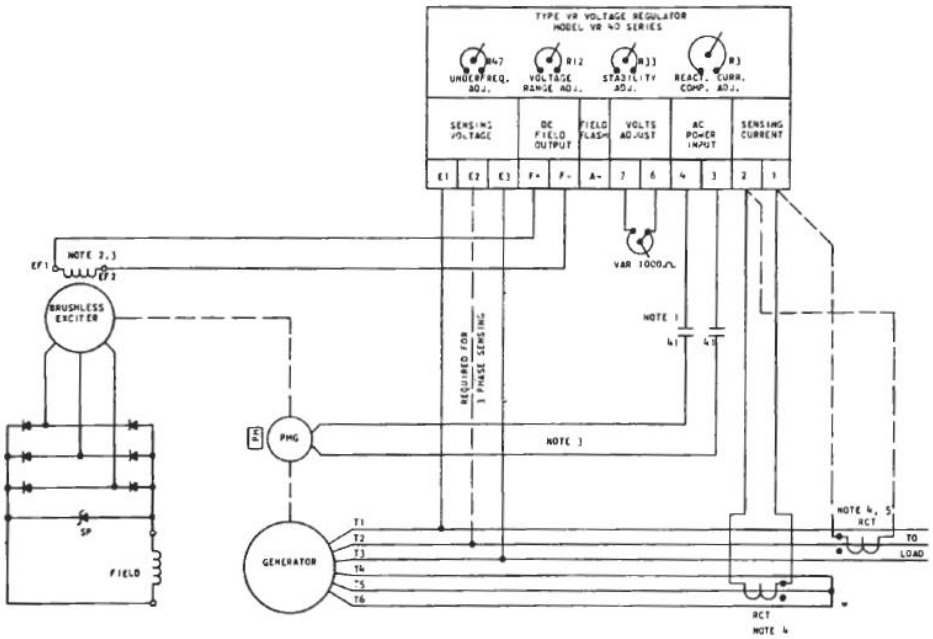
- “During testing of the diode wheel components, we discovered two shorted diodes and damaged surge suppressors. These components had likely never been tested before, contributing to the generator's issues."



UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- "Even after replacing the shorted diodes, the generator still exhibited higher than expected AC voltage across F+ & F- at rated speed. This led to additional advanced diagnostics to uncover the root cause."



UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- "We employed a Gauss meter to check for magnetization in the brushless exciter rotor/stator.
- The test revealed over 160 G of flux, significantly higher than expected, indicating this as the cause of the voltage build-up.“
- Expected value was less than 100 G.

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

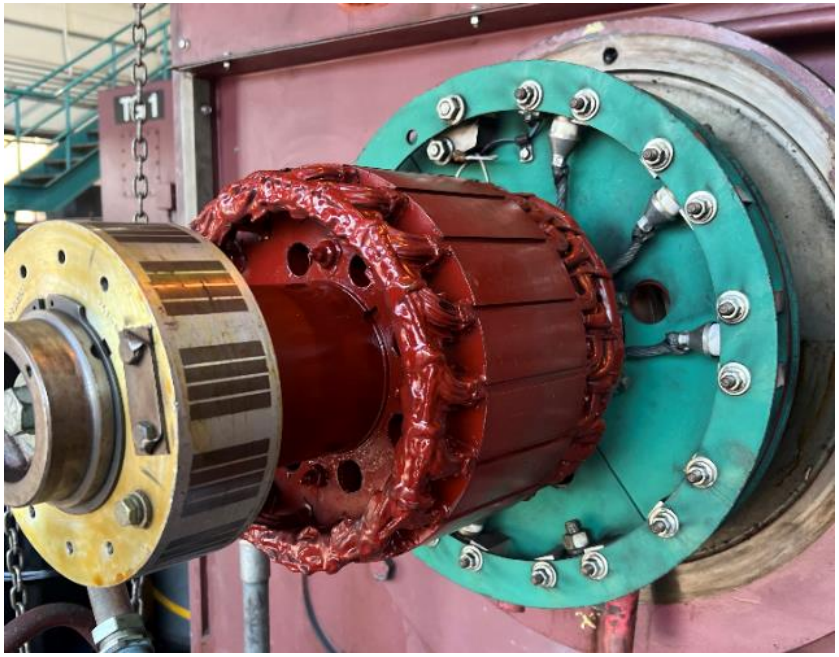
INITIAL FINDINGS AND ACTIONS TAKEN

- "Using the Vanguard Instrument TRM-403, we successfully demagnetized the windings. Post-demagnetization tests showed a reduction in flux to 14 G, resolving the abnormal voltage build-up issue.“
- You can simply demagnetize the windings by Passing an AC current through the windings and gradually reduce the amplitude of the AC current to zero. This method slowly reduces the magnetic field to eliminate residual magnetism.

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- “It was determined that the shorted diodes caused a short circuit of the brushless exciter preventing any AC from passing through. Additionally the strong rotor magnet of the PMG was close enough to magnetized the brushless exciter rotor. These two factors combined cause the problem



UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- "To ensure proper AVR response, we conducted simulation tests using the Doble 6150. The tests confirmed satisfactory performance, validating that the AVR would function correctly when reinstalled."

UNIQUE FAILURE, TROUBLE SHOOTING AND RESOLUTION OF AVR PROBLEM

INITIAL FINDINGS AND ACTIONS TAKEN

- “Final results - After all adjustments and tests, the generator operated smoothly with only 1.4 VAC between F+ & F- at rated speed. Excitation applied resulted in stable voltage build-up, marking the successful resolution of the issue."

USER PATH FORWARD

- The User decided to upgrade to a digital excitation control system to take advantage of enhanced monitoring and data logging capabilities. This upgrade allows for real-time performance tracking and comprehensive data analysis, significantly reducing generator downtime through proactive maintenance and faster troubleshooting, ensuring higher reliability and efficiency.

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