BRUSHLESS ROTATING EXCITER CONVERSION TO MAIN FIELD STATIC EXCITER SYSTEM

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Abstract **- In the 1960s, many generator manufacturers began providing large scale brushless rotating exciters for use on a variety of turbine generator applications. The brushless exciters became increasingly popular in the 1970s through the present. Prior to brushless excited generators, rotating exciters were all rotating brush type which required brushes and commutators to rectify the voltage from ac to dc. Slip rings then apply the rectified dc voltage to the main field of the generator via the brushes, springs and holders.**

Today, in some applications, the brushless rotating exciter is being removed and a static exciter installed because of issues with the brushless exciter. This paper will discuss the retrofit process of a brushless rotating exciter to a static exciter main field system

Index Terms – Brushless Exciter, Static Exciter, Power System Stabilizer

I. INTRODUCTION

Prior to the brushless exciter, brushes and commutators were required to rectify ac to dc. The commutators would create a rectified dc that was delivered to the main field via the brushes/ holders riding the surface of the commutators. It was then cabled to another set of brushes/holders that were riding on the generator slip rings, one set for the F+ slip ring and one set for the F- slip ring. The brushes were subject to outside variables that could affect their operating integrity such as high temperature, moisture, oil contamination and lack of film. As the brushes became worn they would require replacement. See Figs. 1 and 2.

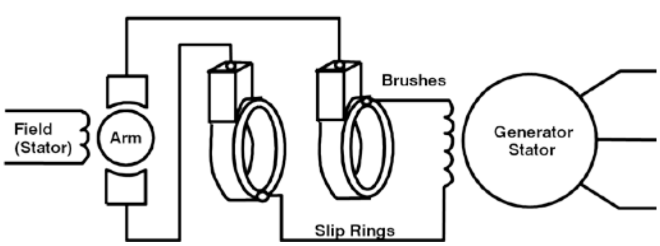

Fig. 1 Diagram of Rotary Excited, Brush-Type Generator

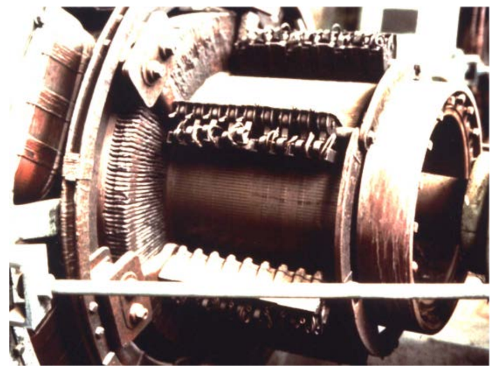

Fig. 2 Commutators for Rectifying Output

Brushless exciters were introduced with the availability of large ampere rated power semiconductors with high peak reverse voltage withstand capability. These power semiconductors would handle several hundred amperes of continuous rotor current and withstand large voltage induced transients from the generator rotor. Additionally, the power semiconductors could be parallel for fields rated for several thousands amperes. The semiconductors were connected in a three phase full wave bridge that would rectify the ac output to dc for the ac brushless excited generator. Commutators were no longer required which eliminated their associated maintenance of brushes. An additional benefit was a Permanent Magnet Generator (PMG) that could be mounted at the end of the shaft and used to supply operating power for the excitation system. The PMG could be single or three phase with typical operating frequencies up to 420 Hertz. See Fig. 3

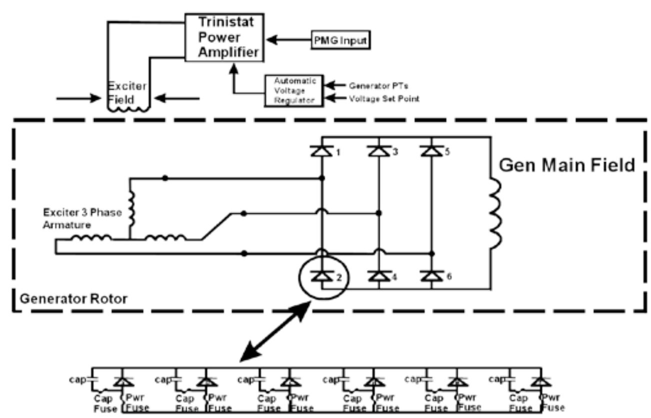

Fig. 3 Schematic of Brushless Rotating Exciter

The primary benefit of the brushless exciter was the elimination of maintenance associated with brushes, commutators, and slip rings. The turbine, generator, and brushless exciter have multiple bearings which require alignment in strategic locations to carry the mechanical loads. Like any rotating machine, the brushless exciter required regular maintenance such as exciter banding, diode module maintenance and monitoring of the machine vibration. Although the brushless exciter did not have brushes or slip rings to maintain, general maintenance is still required and issues such as excessive vibration could be a problem. See Figs 4 and 5 for general mechanical construction.

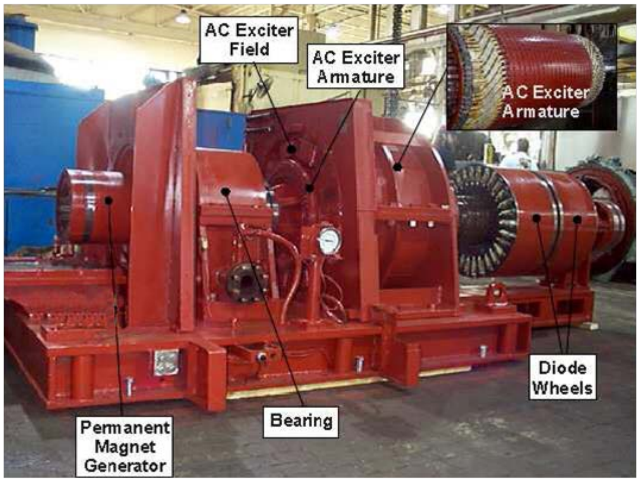

Fig. 4 AC Exciter & Diode Wheel

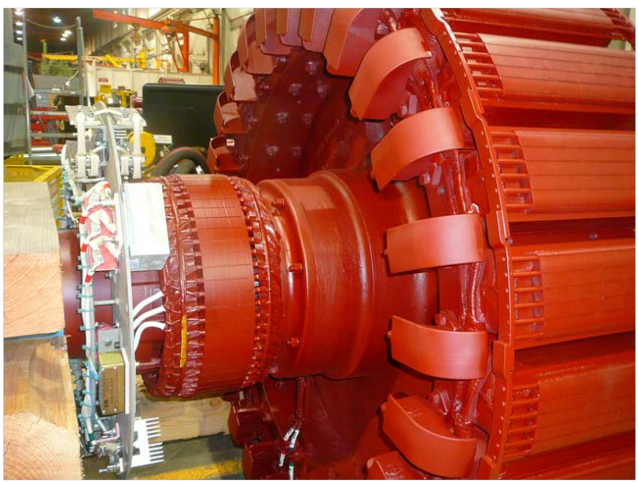

Fig. 5 Brushless Exciter Diode Wheel Assembly

II. THE STATIC EXCITER SYSTEM CONVERSION

For those applications where vibration and rising rotating exciter maintenance requirements have created concerns, the conversion of the brushless rotating exciter to a fully static exciter system has become a viable choice. The conversion to a static exciter system involves removing the brushless rotating exciter and adding a stub shaft to the end of the generator with new slip rings and brush riggings. See Fig. 6 & 7.

Fig. 6 Brushless Exciter Removed from End of Shaft

The new static exciter system upgrade involves a new power potential transformer to step down generator voltage or a station power source to appropriate voltages required by the power rectifier bridge. The power conversion rectifier bridge is designed for the main field requirements with an accompanying ac breaker for isolation and a new voltage regulator with manual control, excitation limiters, and a power system stabilizer where required. For additional reliability in critical generator applications, redundant channels for voltage control with N+1 redundancy of the power rectifier bridges is included. The issues with brushless exciter systems previously described have led to conversions to static exciter systems in some instants. Such was the case of a large MVA machine at a power plant located in North America. The power plant management team made the decision to replace the existing brushless exciter with a fully rated static exciter system. The integrator provided the engineering interface to create a solution for removing the brushless exciter and for engineering a new stub shaft to allow the required slip rings and brush riggings to apply the static exciter output into the generator rotor. For these retrofit systems, it is important to perform new balance shots of the machine to verify the proper alignment of the generator with the the new slip ring and brush assembly. See Fig. 7.

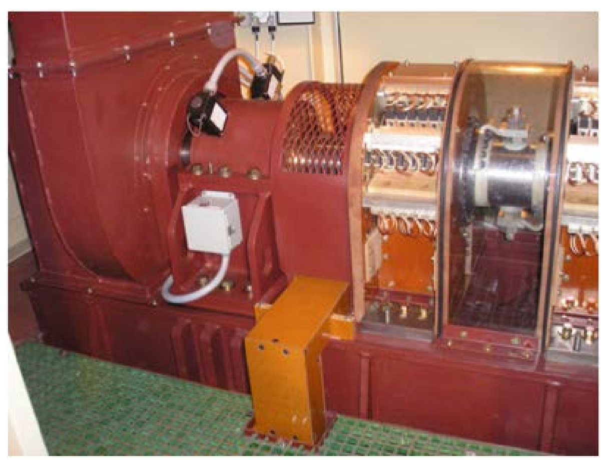

Fig. 7 New Slip Ring and Brushes

III. NEW HARDWARE REQUIREMENTS

The upgraded design involved interconnecting the new power potential transformer to the station bus to provide operating power for the static exciter along with the development of an interface for the transformer primary and required copper bus work to connect the generator rotor to the static exciter output. The new static exciter included a backup channel. In the event of an issue with the primary channel, control would automatically transfer to the backup controller that included the voltage regulator, excitation limiter, power system stabilizer, etc. With N+1 rectifier bridge paralleling, should a failure occur with a power semiconductor, the remaining paralleled bridges will continue carrying the load of the generator field. See Fig. 8.

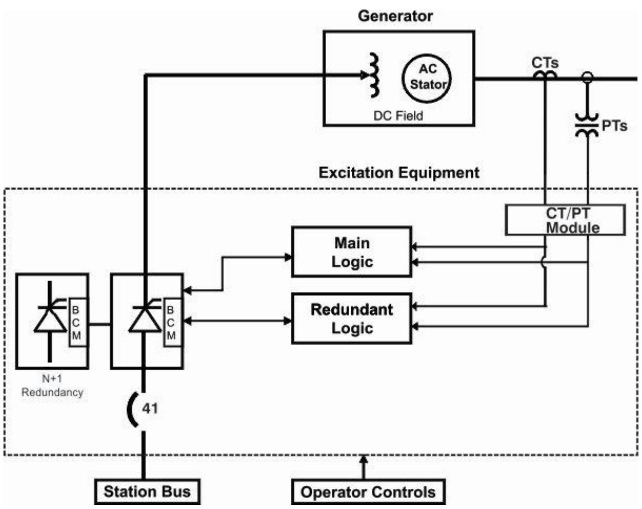

Fig. 8 Schematic of Static Exciter Dual Control Channel

Each controller included:

- .25% automatic voltage regulator
- Field current regulator and field voltage regulator
- Reactive droop compensation, crosscurrent compensation, and line drop compensation
- Power system stabilizer, Type 2: WECC Integral of Accelerating Power
- Limiters: minimum excitation, maximum excitation, (off-line, on-Line), volts/Hertz, overvoltage, var
- Loss of voltage sensing and transfer to manual control
- Autotracking for bumpless transfer to any standby operation mode and to the backup channel
- Generator voltage soft start
- Event Recorder, sequence of events, dynamic system analyzer (for performing WECC frequency response)
- Generator field temperature monitoring, continuous field ground monitoring (64F)

Power Rectifier Bridge Sections

- On-line drawout removable drawer construction, four (4) drawer bridges for continuous rating, plus one (1) for N+1 redundancy
- Temperature based "skip firing" active bridge sharing
- Fast de-excitation for field discharge
- High field forcing from no load rated field voltage
- AC field breaker disconnect for the power potential transformer secondary
- Field flash contactor and current limiting resistor for generator voltage buildup

Communications:

- RS 485 and Ethernet over Modbus

Power Potential Transformer:

- Three (3) phase overcurrent protection with CTs for each phase of the power potential transformer secondary. See Fig. 9.
- Station power connected
- Transformer over temperature alarm

Fig. 9. Power Potential Transformer

The equipment was defined and major components, including the static exciter, power potential transformer, stub shaft, etc., were planned to coordinate with the project team's outage timeline and recommissioning schedule. See Fig. 10.

Fig. 10. New Static Exciter with
Power Rectifier Drawers, with local HMI for Metering and Alarm Information

IV. COMMISSIONING THE NEW STATIC EXCITER SYSTEM

After installation, the preliminary checkout of the new equipment control interface and balance shots of the turbine generator were planned prior to startup.

The commissioning of the new static excitation system included:

- Generator open circuit voltage regulator step test
- Excitation limiter performance off-line and on-line
- Tracking performance between the voltage regulator and manual control modes as well as between the backup digital controllers
- Dynamic under excitation limiter reactive step test,

The power system stabilizer related test included:

- Generator open circuit saturation
- Generator voltage regulator frequency response
- Load rejection test to determine the reactance of the generator and inertia of the machine
- Step test to validate the power system stabilizer performance
- Final report in accordance with WECC requirements created by the turnkey provider

Built-in testing tools included with the static excitation system provided the means to conduct testing quickly to minimize machine down time. During the re-commissioning of the power plant, numerous tests were performed and recorded to validate the new excitation system with the generator upgrade as described above. Figure 11 highlights the generator voltage buildup, a controlled voltage buildup limiting the rate of rise with no voltage overshoot. The new excitation system starts up in field current regulator mode and then automatically transfers to automatic voltage regulation.

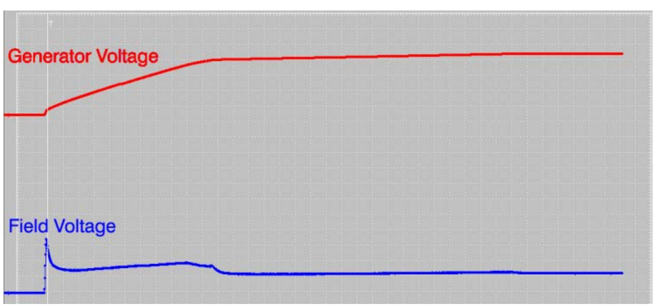

Fig. 11: Generator Voltage Buildup

To test the dynamics of the automatic voltage regulator, generator open circuit voltage step tests were performed to determine the generator voltage stability and speed of voltage response. In Figure 12, a 2% voltage step change is introduced, resulting in a voltage response time of 90ms and achieving a square way voltage response and no voltage overshoot.

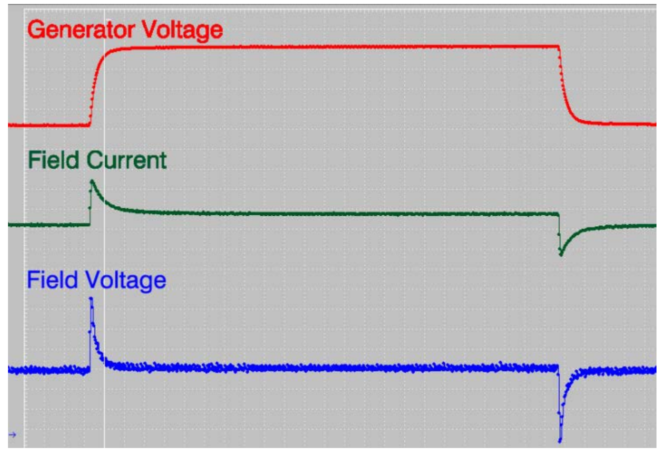

Fig. 12: Generator Open Circuit 2% Voltage Step Test

Once the primary AVR gains were validated, a more dramatic 5% open circuit voltage step change was introduced, recording 0.1 second generator voltage response time with no voltage overshoot. See Figure 13.

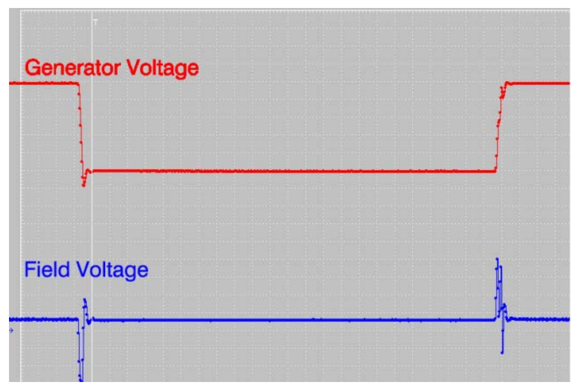

Fig. 13: Generator Open Circuit 5% Voltage Step

The new static excitation system included a power system stabilizer for system stability. Here, the machine reactances, machine time constant and generator inertia were determined to validate the provided machine data. A generator frequency response was conducted with the new static exciter voltage regulator to determine the appropriate time constants for the power system stabilizer. Figure 14 shows an on-line 2% voltage step test with the machine operating at high load. The disturbance initiates a response from the power system stabilizer to quickly dampen the power system disturbance. In Figure 14, the power swing dampens within 700ms.

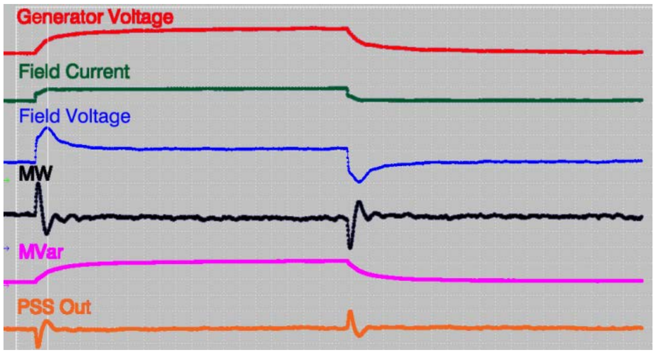

Fig. 14: Full Load 2% Voltage Step with Power System Stabilizer Enabled

Under excited voltage step test validates the minimum excitation limiter to ensure accurate and stable performance in the under excited region of the machine when the system is disturbed. The minimum excitation limiter shown in Figure 15 illustrates a very stable controller that responds within .5 seconds to the step change.

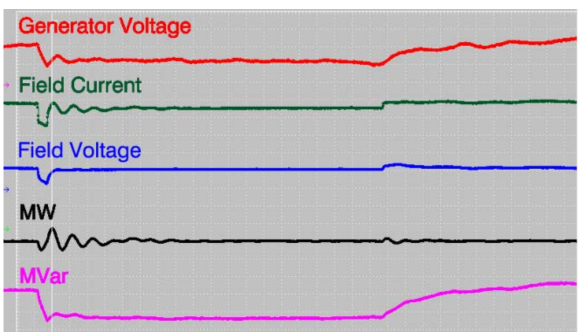

Fig. 15: Underexcited Performance Step Test

V. Conclusions

The conversion of the brushless exciter to a static exciter is a solution for power plants where maintenance and vibration has become a problem for the brushless excited generator system. The static exciter system upgrade provides a long term solution with the additional benefits of performance and improved operating efficiency that has lower watt losses.

VI. References

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VII. Authors' Information

Richard C. Schaefer, a Senior IEEE Member for 16 years, holds an AS degree in Engineering Technology. He is Senior Application Specialist in Excitation Systems for Basler Electric Company. Since 1975, Rich has been responsible for excitation product development, product application, and the commissioning of many plants. He has authored technical papers for numerous conferences including IEEE Power Engineering Society, IEEE IAS Pulp and Paper, EPRI, and IEEE Transactions on Energy Conversion and IEEE Transactions on Industry Applications publications. He has been involved with power plants for longer than 25 years.

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