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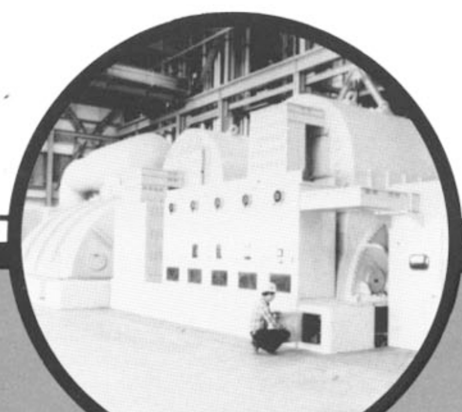

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ABSTRACT

The GENERREX-PPS or Potential Power Source excitation system has been developed in response to utility interest in high reliability, maintainability, and simple, compact arrangement of excitation components, while supplying a base level of excitation system performance. This paper describes the basic elements and design features of the GENERREX-PPS excitation components, factory, and field performance tests conducted on the generator and power system, and a review of actual GENERREX* system service experience.

INTRODUCTION

Historically, the majority of excitation systems has been supplied with a "nominal response"(2) of 0.5 per unit, and at the present time there is significant interest and application for this level of performance. GENERREX-PPS is designed to provide this performance level. This unique concept utilizes a static power source integral with the generator. This feature eliminates rotating exciter components, thus reducing space requirements, simplifying generator maintainability, and achieving high reliability. Thyristors provide direct, high-speed control of generator field voltage. Figure 1 is a three-phase schematic diagram of the GENERREX-PPS excitation system. The internal potential power source consists of an auxiliary winding, called "P" bars, placed at the top of the stator winding slots where its power is derived from the air gap flux of the generator. Excitation power is transformed in a three-phase transformer located in close proximity to the generator. The transformer output is converted from ac to dc power for generator field excitation in a three-phase rectifier bridge, also located close to the generator. An ac and a dc voltage regulator and additional protective circuitry control the application of triggering pulses to the thyristors. The neutral end of the excitation potential winding circuit is completed in a protection cabinet, which includes a three-phase power vacuum breaker for generator de-excitation, "P" circuit grounding equipment, and current limiting fuses for fault protection.

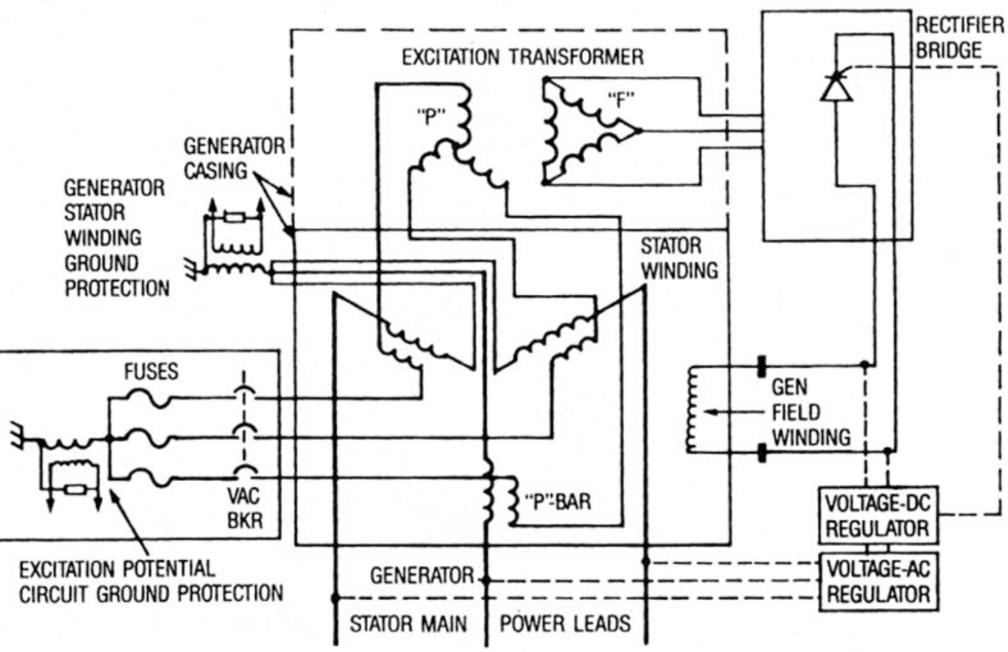

Figure 1. GENERREX-PPS three-phase schematic diagram

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DESCRIPTION OF SYSTEM

Excitation Power Source Components

The excitation power source ("P" bars) is a low-voltage, low-current three-phase winding with one conductor bar per phase placed in three selected stator winding slots in the generator core. The conductors are located 120 mechanical degrees apart on the generator circumference. Two such bars are illustrated in Figure 2. Depending on the generator rating and stator winding cooling method, deionized water or hydrogen may be used for "P" bar cooling. Since the winding is an integral part of the generator, temperature limits, insulating materials, and conductor supports all conform to established generator design practice. The "P" bars are connected to a two-winding three-phase transformer. The transformer has been located alongside the generator in the lower MVA ratings range and on top for larger units. Depending on generator excitation requirements and the particular application, alternative transformer construction and cooling methods are used. In the majority of applications, the transformer has been located inside the generator casing and has been cooled with hydrogen gas. It can also be located external to the generator and cooled with either deionized water or air. In each case the close, compact arrangement of the system and the use of proven technology is maintained. An example of the generator frame construction associated with a top-mounted hydrogen-cooled transformer design is shown in Figure 3. This is a 460 MVA, 3600 rpm generator with a GENERREX excitation system.

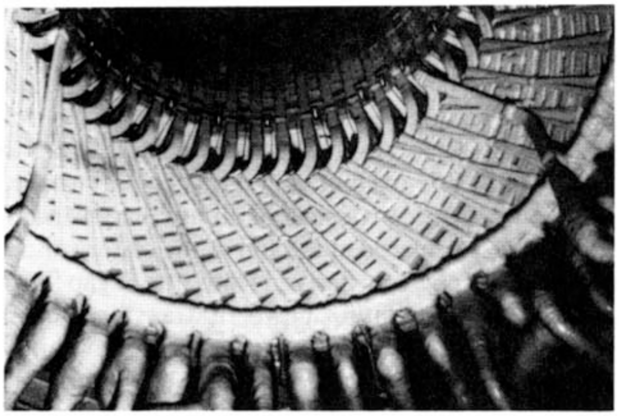

Figure 2. End winding view of generator showing two of three assembled "P" bars

Power Rectifiers

The system utilizes a three-phase full-wave rectifier bridge. To regulate field voltage, the bridge

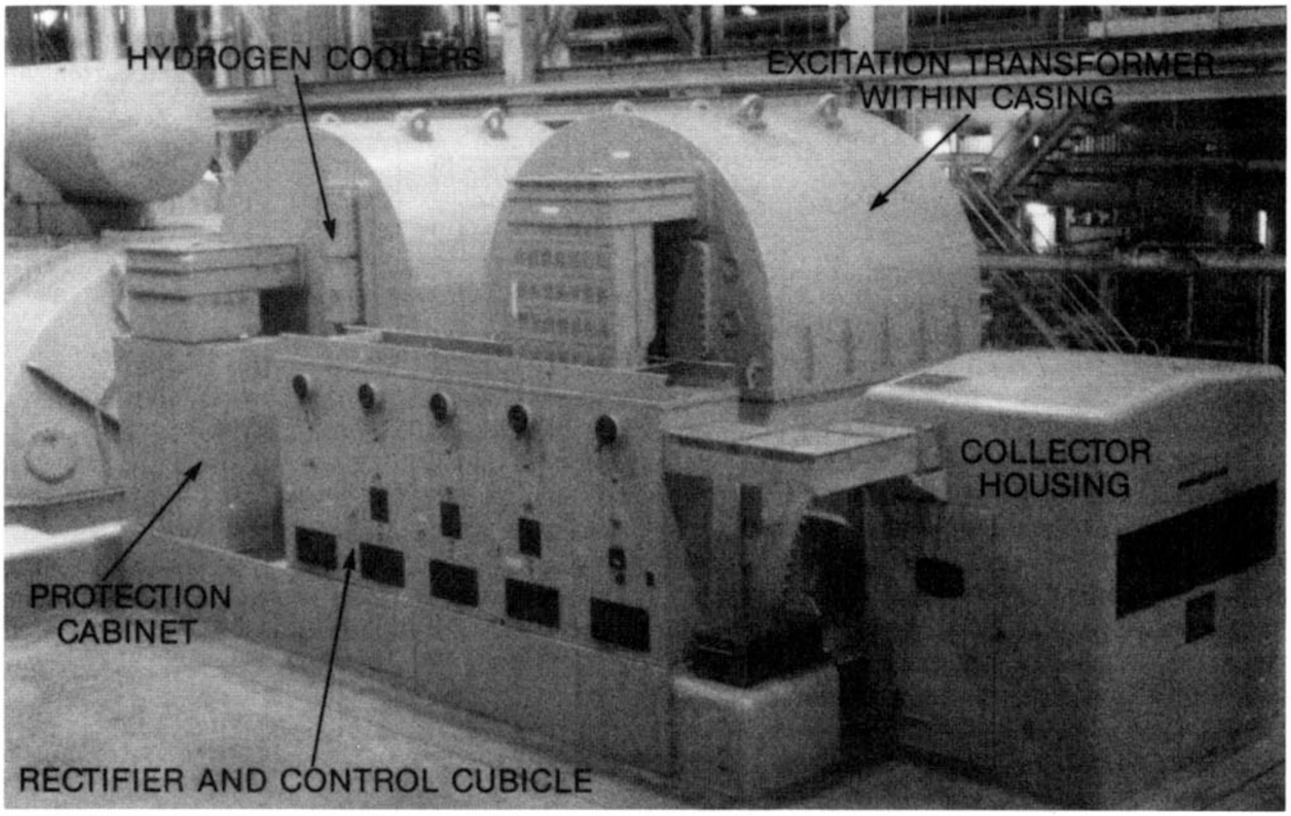

Figure 3. 460 MVA generator with GENERREX-PPS excitation system

contains thyristors or silicon-controlled rectifiers. Depending on the rating of the generator, several such bridges are contained in the exciter rectifier cubicle and connected in parallel. Each parallel section is provided with a five-pole disconnect switch that permits electrical isolation for maintenance under load. The system is designed so that with one rectifier bridge removed from service, full generator steady-state and transient current requirements can be accommodated. The rectifiers are of the unit-cell type. They are cooled by air or by circulating water through heat sinks. The method of cooling is dictated by the excitation requirements of the generator and the availability of deionized water. Light-emitting diodes that monitor the status of all semiconductors are mounted on the door of each rectifier bridge section. Both diodes and thyristors have demonstrated excellent reliability on General Electric excitation systems. Based on actual field records, spanning 19 years on over 300 steam turbine-generator exciters, there are 28,000 diodes in service and only five known failures during operation. Specifically, on GENERREX and other static systems, there are 5000 diodes and 2500 thyristors in service with not one recorded failure during operation.

Controls and Operator Interface

Excitation system control circuitry consists of two basic regulators: an ac and a dc regulator. The regulators utilize integrated circuits mounted with associated components on modular, plugin printed circuit boards. Solid-state switching is used extensively, providing greater reliability than mechanical devices. Photocouplers provide electrical isolation from plant wiring. The GENERREX system provides a comprehensive interface between the excitation system and either station operators or plant computer automatic startup sequencing systems. A compact, factory-wired excitation system control station complete with a mimic bus can be provided for mounting in the station control room. Control system alarms are easily identified because of the modular design of the circuitry. Abnormalities in power supplies and transducers, and protection circuit operation are annunciated as "exciter cubicle alarm" or "regulator cubicle alarm" according to the cubicle from which the alarm originated. The panel provides for the application or removal of excitation, for adjusting the desired regulator set-point, and the transfer between regulators.

Collectors

The generator field collector and brushholder rigging assembly are located in a walkin housing, shown in Figure 3. Collector-ring ventilation is provided by shaft-mounted fans and housing filters, while removable-type brush magazines allow easy maintenance. The magazine type brushholders have produced an outstanding performance record since their introduction in 1964. They have been used on over 360 large steam turbine-generator units, accumulating over 3600 unit years of operation, with only 3 known forced outages. Without exception, these outages resulted from failure to follow recommended maintenance procedures.

POWER SYSTEM PERFORMANCE

The performance of the excitation system will affect both transient and steady-state stability of turbine-generator units. The performance parameter universally recognized as quantifying the effect on transient stability is the overall excitation system nominal response. Recent industry standards[2] emphasize the importance of evaluating performance under conditions imposed by power system faults. For potential source excitation systems, the drop in supply voltage during the critical time period following a severe power system disturbance must be taken into account. The condition causing an average depression of generator terminal voltage to 70%, for the half-second definition period, was selected as the nominal design criterion for the GENERREX-PPS excitation system. This value coordinates well with the design of power plant auxiliaries. Auxiliary drive motors are commonly specified to have 200% pullout torque at rated voltage, which allows brief operation at 70% without stall and widespread loss of essential drives. During the course of GENERREX component design, extensive power system analyses were made to verify adequate performance for a broad range of system applications. Figure 4 describes the variation in performance as a function of voltage disturbance severity. It was observed that remotely located generating units with higher impedance transmission ties

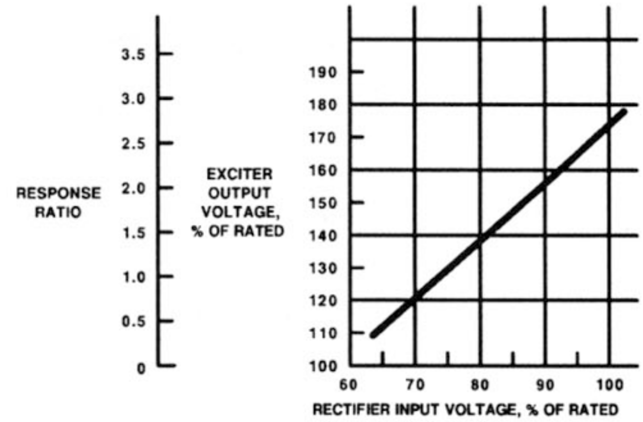

Figure 4. Characteristics of potential-source excitation system

required shorter fault clearing times, but had less voltage depression before stability was lost. In such demanding applications, potential source exciters, such as GENERREX-PPS, actually perform better than rotating exciters having the same nominal response. Furthermore, for rated turbine power output, as the initial generator operating point moves away from rated power factor, the potential source exciter transient performance is also superior. When generating units must maintain stability under severe conditions with delayed fault clearing because of breaker failure, other stability aids should be considered. Turbine valve control, referred to as "fast" or "early" valve actuation, can prove especially cost-efficient, and cost-effective.[3]

FACTORY AND FIELD TESTS

An extensive test program, conducted in the factory and at power stations, has verified the performance of the GENERREX system under various operating modes. Table 1 shows the ongoing test program that has contributed to the successful development and sustained reliability of the system. Tests No. 6, 7, 8, and 10 were conducted on GENERREX-PPS exciters. The generator and exciter identified in Test No. 10 are approximate design duplicates of those being designed for People's Republic of China, Shijiazhuang station. In a typical factory test, the steady-state performance of the GENERREX excitation system is evaluated while the generator is operated open-circuit to 120% of rated generator terminal voltage. Included in this testing are thermal measurements of all excitation system components, current and voltage of the excitation system circuits including waveshape harmonic content, saturation tests on the excitation transformer to confirm ceiling voltage capability, coolant flow, and vibration measurements. Dynamic performance tests are performed on the system to demonstrate that the control components and circuits would function as predicted. The components are also evaluated through a series of sudden short-circuit tests. Test results confirmed the capability of the excitation system to reliably supply the required steady-state field power. Power source component temperatures and vibration levels, corresponding to rated duty operation, were found to be well within an acceptable range. A resistive-capacitive filter circuit, placed across the ac input to the rectifiers to reduce the leading edge spike on the field voltage waveshape, was demonstrated to be effective in reducing the spike to only 10 to 15% of the peak field voltage. Current distribution among all parallel rectifier bridge sections had less than 10% deviation from the average. The Power/Vac breaker was thoroughly tested. Tests included successfully deexciting while operating at the breaker steady-state and transient sudden short-circuit rating. The current limiting fuses in the potential winding circuit were subjected to a controlled fault condition and demonstrated clear capability to safely and reliably interrupt currents attainable under a worse case fault scenario. Field tests have been conducted on generators equipped with the GENERREX excitation system at

Table 1

GENERATOR AND GENERREX SYSTEM TESTS IN THE FACTORY AND FIELD

TEST #	GENERATOR RATING	EXCITER RATING	FACTORY TEST	FIELD TEST
1	377-MVA 3600-RPM	1435-KW	1974	1975
2	496-MVA 3600-RPM	1640-KW	1976	
3	690-MVA 3600-RPM	2510-KW	1978	
4	1559-MVA 1800-RPM	3335-KW	1979	
5	1350-MVA 1800-RPM	3105-KW	1980	
6	460-MVA 3600-RPM	1570-KW	1981	1985
7	722-MVA 3600-RPM	2205-KW	1982	
8	755-MVA 3600-RPM	2845-KW	1984	
9	991-MVA 3600-RPM	3195-KW	1984	1986
10	511-MVA 3600-RPM	1740-KW		1987

high generator load levels. These tests verified that design objectives had been satisfied. The minimal time delays associated with control and firing of the thyristors were demonstrated. The application of Power System Stabilizers was shown to be effective in damping power system oscillations.

SERVICE EXPERIENCE

The initial GENERREX excitation system was placed in service in September 1975. This first GENERREX system has operated flawlessly since its synchronization. In eleven years there has not been one forced outage on the exciter or collector. Many of the exciters have been subjected to thorough inspection during routine maintenance outages, and no problems of consequence have yet been observed. Eighteen units are in service with GENERREX, while another seven are due to synchronize by the end of 1987, including four more GENERREX-PPS systems. Exciter reliability data collected through 1984 indicate that the ALTERREX* (an alternator-exciter with stationary diodes) forced outage rate is only about half the rate of rotating rectifier exciters produced by other manufacturers. Table 2 shows a summary of the GENERREX system reliability and experience record in comparison with the ALTERREX system. The clear advantage of the fully static GENERREX system over any exciter with rotating components can be seen.

Table 2

EXCITATION SYSTEM RELIABILITY
MARCH 1986

	GENERREX	ALTERREX
FIRST UNIT IS SERVICE / NUMBER IN SERVICE	1975 / 18	1966 / 273
TOTAL UNIT-YEARS OF OPERATION	87.9	2697
AVERAGE FORCED OUTAGE RATE (HOURS / UNIT / YEAR)		
AVERAGE FOR ALL YEARS (OVERALL)	2.9	5.8
AVERAGE FOR ALL YEARS (ROTATING PARTS ONLY)	---	4.4
1982-1985 OVERALL FOUR YEAR AVERAGE	0.25	3.8

CONCLUSION

When compared to rotating exciters, static excitation systems with collectors have provided sustained improved reliability and cost efficiency, while at the same time supplying the base level of excitation system performance. Furthermore, the fully static GENERREX excitation system, utilizing a power source integral with the generator, provides to the utility the additional benefits of a close, compact arrangement of generator and excitation components.

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[2] IEEE Standard 421, "Standard Criteria and Definitions for Excitation Systems for Synchronous Machines," revised 1985.

[3] T.D. Younkins, J.H. Chow, A.S. Brower, J. Kure-Jensen, J.B. Wagner, "Fast Valving with Reheat and Straight Condensing Steam Turbines," presented at IEEE Power Engineering Society Winter Meeting, Feb. 2-7, 1986, New York.

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