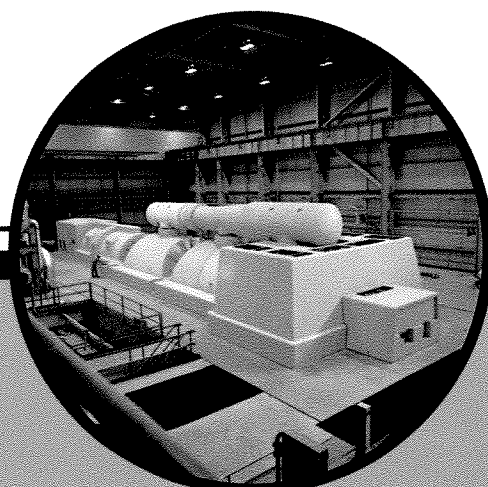
GER-3087

PERFORMANCE AND SERVICE EXPERIENCE WITH GENERREX* EXCITATION SYSTEMS FOR LARGE STEAM TURBINE-GENERATORS

N. H. Jones

General Electric Company
Schenectady, New York



Presented at

CIGRE

INTERNATIONAL CONFERENCE ON LARGE HIGH VOLTAGE ELECTRIC SYSTEMS

August 30-September 7, 1978
Paris, France

PERFORMANCE AND SERVICE EXPERIENCE WITH GENERREX* EXCITATION SYSTEMS FOR LARGE STEAM TURBINE-GENERATORS

N. H. Jones

SUMMARY

This paper presents a description of the uniquely new GENERREX excitation system now being applied to large steam turbine-generators. This system provides for a compact arrangement of equipment and, through the utilization of all static components, aims for high reliability and sustained generator availability. The system is essentially self-regulating with very high performance characteristics, enhancing generator and power system performance by contributing to dynamic and transient system stability. A discussion of the expected performance based on analysis, a description of the test results obtained both in the factory and in the field confirming the analysis, and a review of actual service experience with this unique system up to the present time are also included.

INTRODUCTION

The GENERREX excitation system is a high initial response system with its power source an integral part of the generator. The first commercial applications of this new system, with 3.5 per unit response ratio, are on the 377-MVA 3600-rpm generators for the Montana Power Company, Colstrip station, units 1 and 2. The first unit has been in commercial service since September 1975 and the second since May 1976, (Figure 1). The first generator and its excitation system were tested in the factory in April/May 1974, following a comprehensive program of careful component and system development; extensive tests were also conducted at the power station during a several-months period following startup and commercial service.

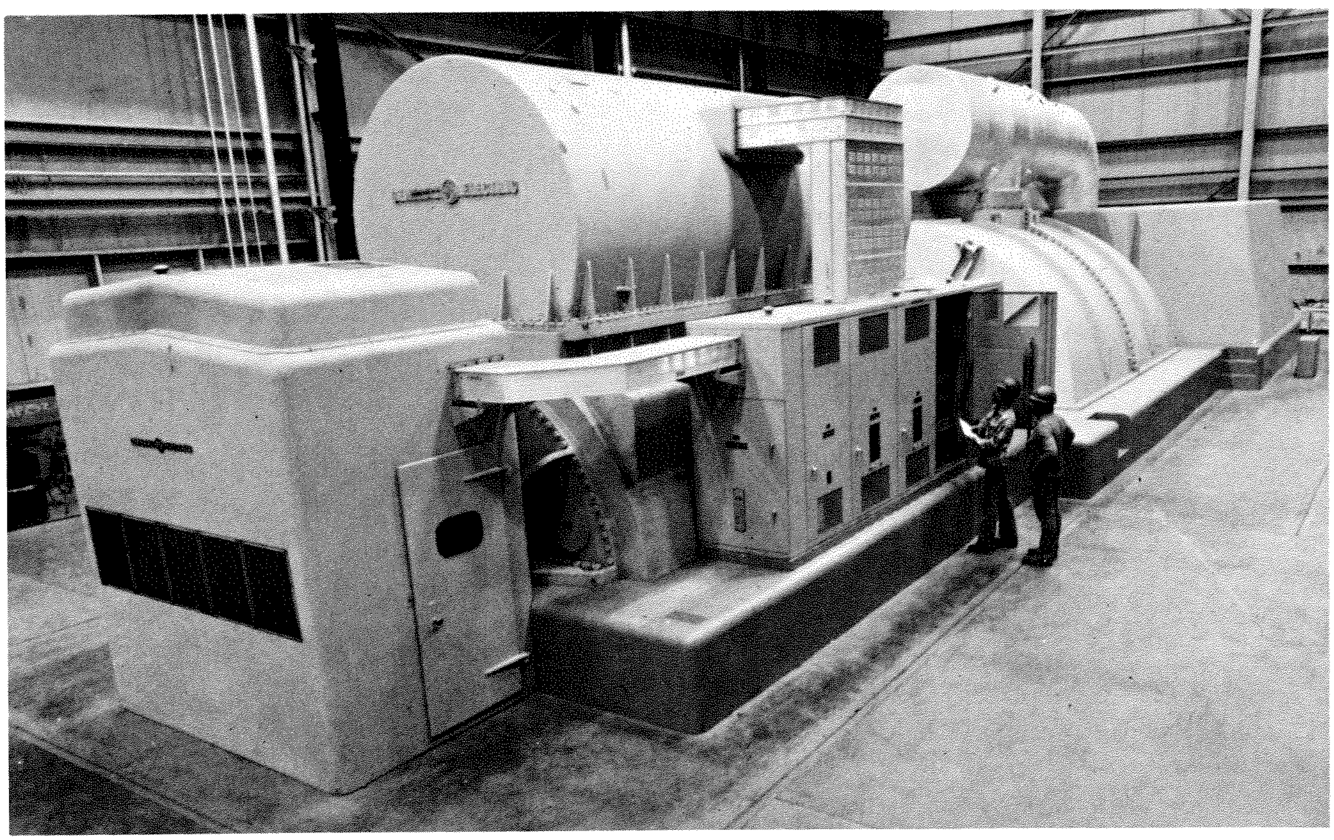


Figure 1. The Montana Power Company Colstrip Station 377-MVA generator with prototype GENERREX excitation system

*Trademark of the General Electric Company

DESCRIPTION OF SYSTEM

Excitation Power Source Components

The components of the exciter power source are located within the generator casing. The three single-phase excitation transformers, the three single-phase linear reactors, and the generator neutral are located on top of the generator, (Figure 3). Current transformers are also provided to maintain normal generator metering and relaying practices. These components are enclosed in a dome, and utilize the hydrogen ventilation circuits of the generator.

The excitation potential winding located above the stator winding slot wedges uses the cooling water system of the generator stator winding. This is a low-voltage, low-current winding with one conductor bar, "P" bar, per phase placed 120 mechanical degrees apart on the generator circumference, (Figure 4). To prevent damaging the "P" bars during rotor assembly, the "P" bars are not placed in the lower 60 degrees of the generator core.

A conservative approach is taken in the design of the excitation power source components since they constitute an integral part of the generator and function in a hydrogen atmosphere. The components are built with materials and manufacturing processes used in the main generator, and with which many years of experience have been accumulated. Temperature limits and insulation practices conform to generator design practice.

Power Rectifiers

The rectifier bridges, (Figure 5), basically comprise three-phase full-wave diode rectifier bridges. To regulate the generator field voltage, SCR's are connected in shunt across the diodes connected to the negative terminal of the field winding. This type of rectifier bridge is called a shunt thyristor bridge. Each electrical leg has two semiconductors in series to prevent loss of generator field excitation (should one short out) and to provide generous voltage-withstand capability during system disturbances.

Depending on the rating of the generator, several such bridges are contained in the exciter rectifier cubicle and connected in parallel. Each bridge is provided with a five-pole disconnect switch which permits electrical iso-

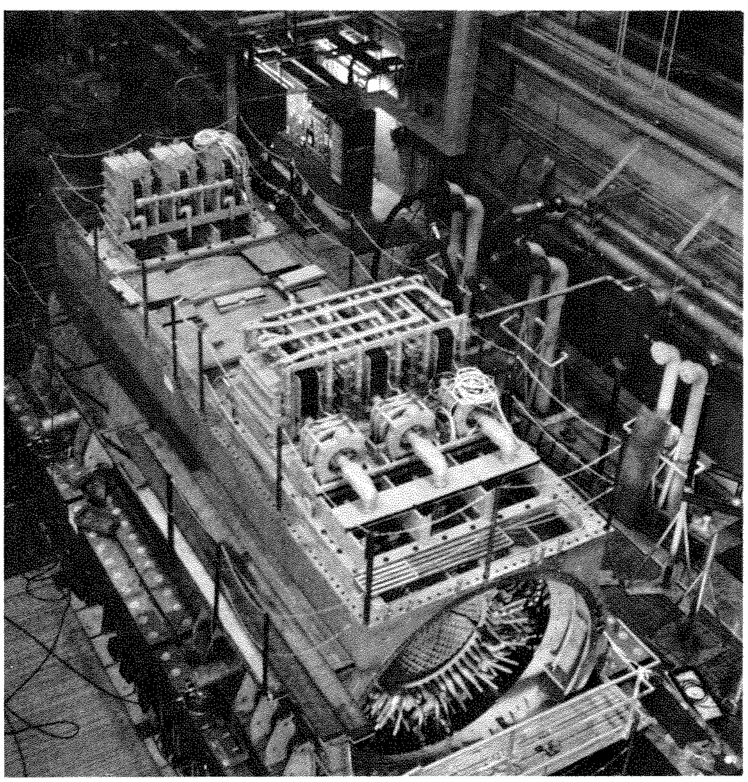


Figure 3. Top view of generator with excitation power source components assembled

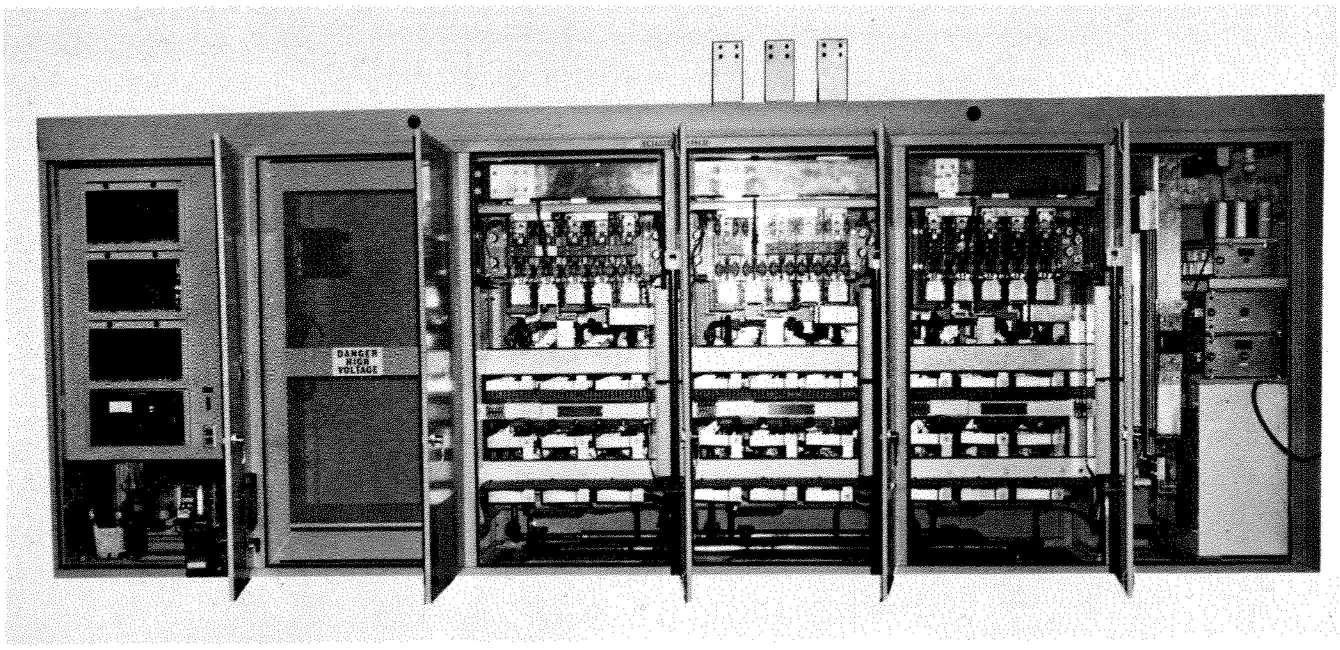


Figure 6. Rectifier cubicle

Basic design philosophy of the control system focuses on reliability with redundancy and conservative design and construction as prime considerations. The regulators utilize modern technology throughout. Construction is solid state with integrated circuits mounted with associated components on modular, plug-in, printed circuit boards. Solid state switching is almost exclusively employed in lieu of mechanical relaying.

Major components are mounted in a separate regulator cubicle normally located in a room with clean, controlled atmosphere. Redundant signal lines interconnect the exciter and regulator cubicles.

De-excitation

Because of the essential nature of the function on all generator excitation systems, two methods of de-excitation are utilized, one static and one mechanical. The static de-excitation circuit triggers all SCR's in each phase simultaneously and continuously to short circuit the rectifier input voltage, reducing it essentially to zero. The field current will decay to zero at a rate determined by the appropriate time constant of the field.

The mechanical method consists of a fast acting generator field shorting breaker. Both the static and mechanical de-excitation methods operate simultaneously.

Generator field breakers are available for those applications where it is desirable to insert a field discharge resistor in the field circuit to reduce the time constant associated with de-excitation.

Collector

The generator field collector and the brushholder rigging assembly are located in a walk-in housing, (Figure 1). Collector-ring ventilation is provided through fans and filters, and removable-type brush magazines allow easy maintenance. For 3600-rpm units a steady bearing is provided within the housing, at the end of the turbine-generator shaft.

OPERATION AND PERFORMANCE

Operator Interface

A unique and comprehensive three-part interface between the excitation system and station operators is introduced. First, a compact, factory-wired excitation system control station complete with a mimic bus is provided for mounting in the station control room. Second, a comprehensive system of alarms is provided for proper annunciation of excitation system status. Third, a meter current limit protects the shunt thyristor bridge from excessive overexcitation. The generator field maximum excitation limit protects the generator field from overheating in accordance with its short-time thermal capability, but – through the use of alternate control circuits – avoids unnecessary unit trips.

- The underexcited reactive ampere limit acts to prevent the generator excitation from being reduced to a level which would result in loss of synchronism or cause excessive end heating in the generator stator.

Analytical Simulation

An accurate analytical model with the generator, excitation system, and all control system inputs is required to insure desired overall power system performance. The ability to predict the performance of the turbine-generator and GENERREX system under severe disturbances has been developed and verified by tests in the factory and at the power station on the prototype unit for the Montana Power Company.

The detailed model of the GENERREX system is based on the physical characteristics of the components of the system. Dynamic models have been developed for the various components incorporating the time varying characteristics as well as nonlinear characteristics necessary to determine the system performance. Model parameters are obtained from design computations and have been verified by measurements of the physical components. A functional block diagram of the system is shown in Figure 8.

For large scale power system studies, a less rigorous computer model than described above is definitely advantageous. A simplified model embodying the essential elements necessary to predict performance extending to frequencies of 3 Hz has been developed and is available for general usage. The major elements of the large scale computer model are: (1) the voltage regulator dc gain and stabilization network, (2) the excitation power source, combining voltage and current sources, and the saturation level of the transformers, (3) the regulation effect due to the flow of field current.

Power System Performance

The performance features of the GENERREX excitation system which are of major significance are the high excitation system response ratio, the fast initial voltage response, the short excitation system time delays, the ceiling voltage under severe conditions, and the expected performance with power system stabilizers to provide generator and system damping. These features provide benefits to both transient stability first swing reduction and to damping of subsequent swings.

The degree of these benefits may be appraised in Figure 9 from the computer-simulated performance of the Colstrip 1 unit for a three-phase fault close to the station, which was cleared in six cycles. The system impedance as viewed from the generator terminals changed from 0.32 per unit to 0.52 per unit (on the unit MVA base), representing the opening of the faulted line section. A series of computer runs was

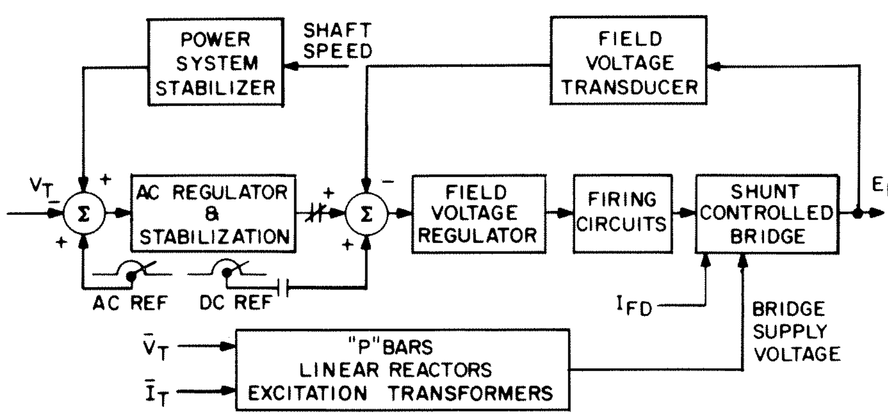


Figure 8. GENERREX excitation system – functional block diagram

Tests in the Factory

A complete series of tests was conducted with the generator open-circuited and again with the generator connected short circuit. Included were thermal measurements of all excitation system components, current and voltage of the excitation system components including harmonic content measurements, saturation tests on components such as the excitation transformers to confirm ceiling voltage capability, gas flow, and vibration measurements. A total of 250 instrumentation readings were monitored for the excitation system portion of the tests alone to check temperatures, pressures, gas flow, vibration, and system output variables.

Dynamic performance tests on the GENERREX excitation system served two main objectives. The first was to demonstrate that the control components and circuits would perform as predicted. The second was to obtain test data which could be used to validate the dynamic simulation model. The responses of the excitation system and the open-circuited generator to step changes in the reference voltage were obtained. The magnitude of the step change was varied to observe the effect on nonlinearities in the system. Large step changes were applied to observe the effects of the various system limits and nonlinearities. This testing procedure was executed with the excitation system in both ac and dc control modes. Changes were made in system control parameters, gains and time constants, to observe the sensitivity of the system performance to these changes and also to aid in the dynamic model verification process.

In addition to the transient response tests, the relative magnitude and phase shift between various points in the system were obtained over a wide range of frequencies. Both closed and open loop frequency response data were obtained for the overall voltage regulation loop. These frequency response data served as a valuable complement to the time response data in validation of the computer model.

Figure 10 illustrates a key test result – the change in exciter output voltage and the change in generator terminal voltage, with the generator under no load conditions, following a signal applied at the voltage regulator input calling for a five percent increase in generator terminal voltage. The change in the voltage applied to the generator field illustrates the fast performance of the shunt thyristor bridge system. Correlation between tested and simulated performance is illustrated for generator field voltage, field current, and terminal voltage.

A second set of very extensive factory tests was conducted in the summer of 1976 to confirm the application of a 3.0 response ratio GENERREX excitation system to a 496-MVA, 3600-rpm generator. A program of similar tests is scheduled as the planned application of the GENERREX excitation system is extended to larger ratings and to generators with different characteristics – i.e.,

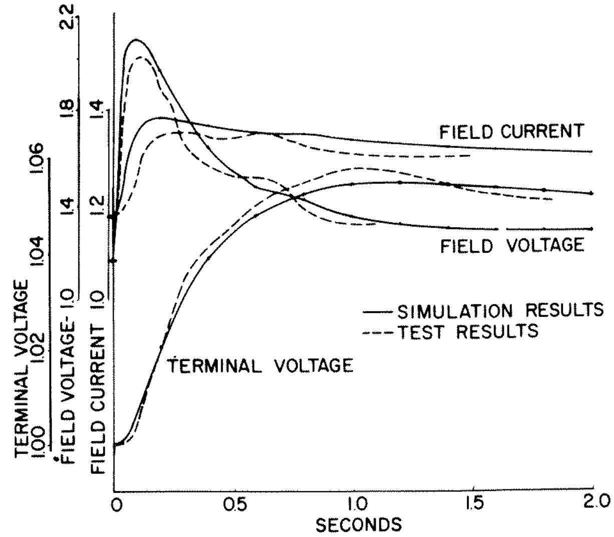


Figure 10. Factory test and computer simulated results for a five percent step-change in terminal voltage reference

speed, stator frame construction, etc. Table I shows the tests now identified and exemplifies the careful planning and thorough development work which have characterized the measured introduction of the innovative GENERREX excitation system.

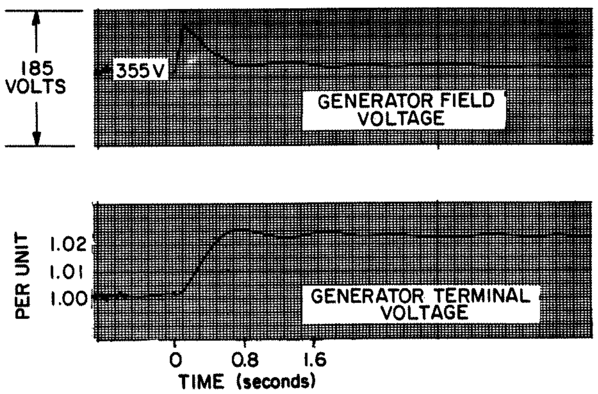
TABLE I. GENERATOR AND GENERREX EXCITATION SYSTEM TESTS IN THE FACTORY

Test No.	Date	Generator Rating	Exciter Rating
1	1974[1]	377-MVA 3600-rpm	1435-kw 3.5 response ratio
2	1976[1]	496-MVA 3600-rpm	1640-kw 3.0 response ratio
3	1978[2]	690-MVA 3600-rpm	2510-kw 3.5 response ratio
4	1978[2]	1559-MVA 1800-rpm	3335-kw 0.5 response ratio

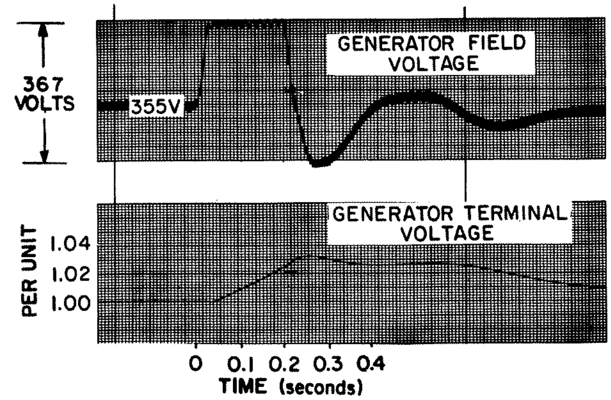
1 – complete
2 – scheduled

Field Tests

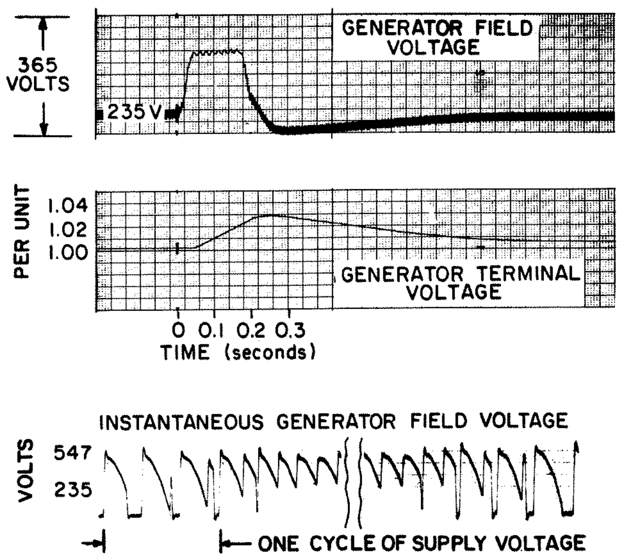
During the fall and winter of 1975/1976, a comprehensive test program was conducted on the Montana Power Company Colstrip 1 unit with the prototype GENERREX excitation system at the power plant site. The field tests



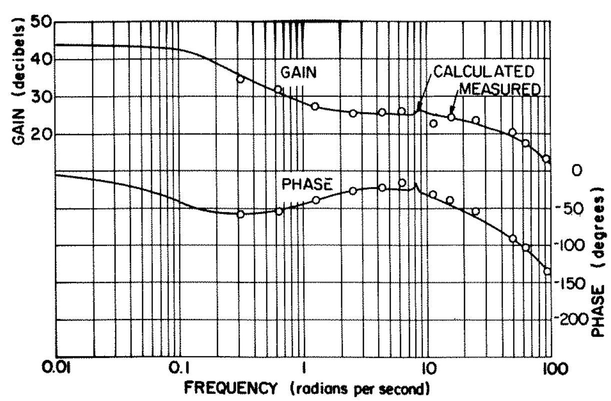
a. Two percent step of reference. Full load. No PSS



c. 15 percent step of reference. Full load. PSS in service



b. 15 percent step of reference. Half load. No PSS



d. Excitation system frequency response – generator terminal voltage error signal to field voltage (full load)

Figure 12. Station test results for the Montana Power Company Colstrip 1 generator with prototype GENERREX excitation system. All with ac regulator control

- The new system has a fully static power source, unit cell rectifiers, and an advanced solid-state modular control system with innovative control and protection concepts and major advancements in operator control interface.
- It provides for a compact station arrangement, shorter overall unit length, easier access to the main generator for maintenance and rotor removal, and includes the function of the generator neutral enclosure.

These features have been verified by design, manufacture, factory and field tests, and service experience on a prototype unit. Detailed appraisal of the results indicates excellent performance of the new system.