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A Magazine for Electric Utilities Published by General Electric Co.
Electric Forum

THE GENERREX® EXCITATION SYSTEM

by Samuel R. Folger, Norman H. Jones and Robert L. Winchester

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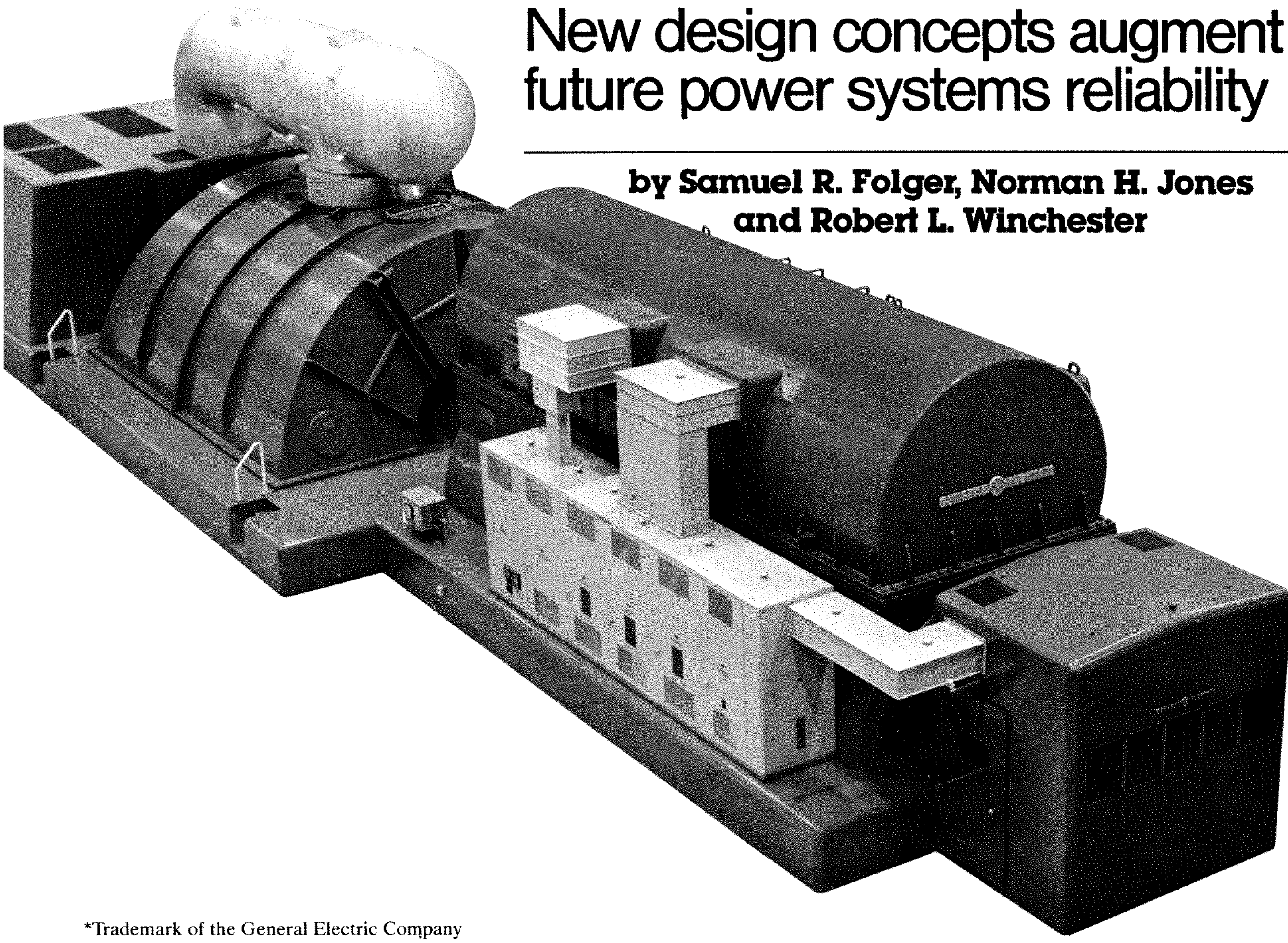
SCHENECTADY, N. Y. 12345

GENERAL ELECTRIC

THE GENERREX* EXCITATION SYSTEM

New design concepts augment future power systems reliability

by Samuel R. Folger, Norman H. Jones and Robert L. Winchester



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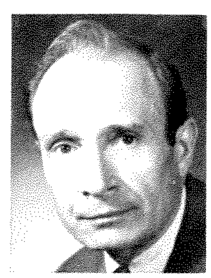

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Providing dc power to a field winding is the expected function of a generator excitation system, but it is considerably more challenging to provide the intricacy of excitation control needed by a modern large steam turbine-generator. When a power system is troubled suddenly, extreme demands may be placed upon the generator and its excitation system must respond rapidly, making changes in the voltage that drives current through the field winding. Excitation system design is defined by this performance level, as well as factors of reliability, maintainability, and the impact of equipment location on overall station cost.

SYSTEM DESIGN

Through the years, most large electric utility generators have utilized shaft-driven exciters. For a long time, they were the familiar commutator-type dc machines. These were succeeded by various forms of shaft-connected rotating ac machines whose output was rectified by solid-state power rectifiers. Although this equipment has served the industry well, it occupies valuable floor space, and most of the maintenance and operating problems are in the rotating machine. Also, the exciter shaft and its coupling are sensitive to potentially damaging torques which can be imposed by system induced shaft torsional vibrations.

The GENERREX excitation system utilizes a fully static power source: all the excitation power is taken from windings in the generator, and the shaft-connected exciter is gone. The system is fully contained, and the machine designer is responsible for locating all major equipment. The GENERREX-CPS (Compound Power Source) system, a high performance design, meets demanding power system performance requirements. In this system, the exciter power source is compound, utilizing both potential and current sources in producing excitation power. Therefore, it avoids a characteristic of the bus fed system where the ac source voltage (which is taken directly from the mahine terminals or station auxiliary bus) sags severely during a fault when maximum excitation output is needed. The GENERREX-PPS (Potential Power Source) system, a standard performance design, meets many power system performance requirements utilizing a potential source.

The GENERREX excitation system is a high initial response system providing rapid generator field voltage change in response to power system needs. These changes are achieved through the use of thyristors in the power rectifier complement. The GENERREX system spans the full range of ratings suitable to electric utility application—with voltage response ratios up to and including 3.5 per unit and higher.

Power Source

In the GENERREX-CPS system, Figure 1, the outputs of a voltage source and a current source are combined in an excitation transformer system, providing three-phase ac output.

The voltage source is a three-phase water-cooled excitation winding located in the generator stator winding slots above the slot wedges. Its voltage is proportional to the generator air-gap flux and provides all of the generator field excitation under no-load conditions.

The current source consists of the three neutral leads of the generator stator winding passing through the windows of the excitation transformers' cores. This source provides the additional field excitation needed under load conditions. It also provides excitation power during system faults when the system voltage and the machine air-gap flux are at depressed levels. Thus, the current source provides the compounding effect.

In the GENERREX-PPS system, Figure 2, the three-phase water-cooled excitation winding is the ac power source. In addition, a three-phase excitation transformer is utilized.

Rectification and Controls

Ac power from the excitation transformer output is converted to dc power for application to the generator field by

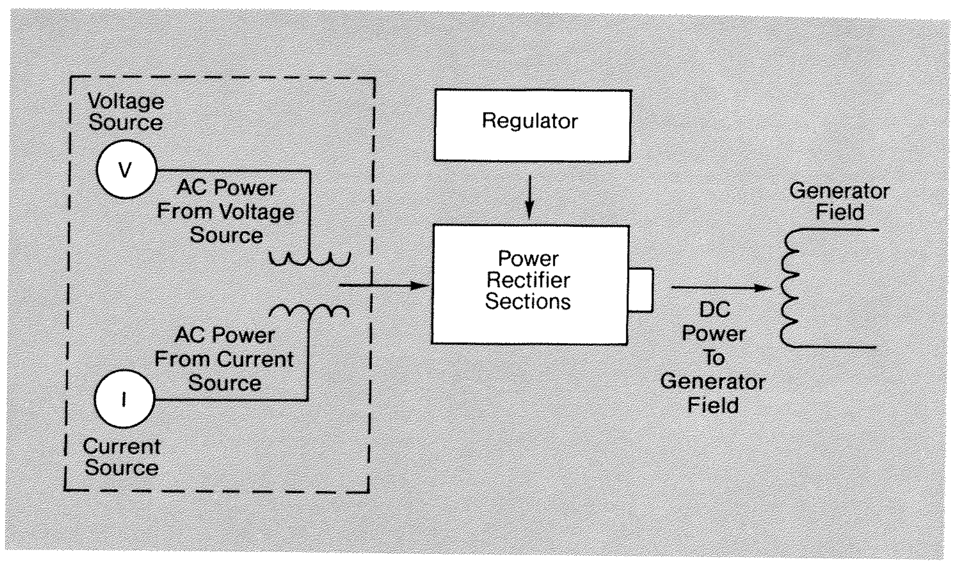


Figure 1—GENERREX-CPS excitation system, with a 2.0, 3.5 response ratio and higher, spans the full range of ratings suitable to electric utility application.

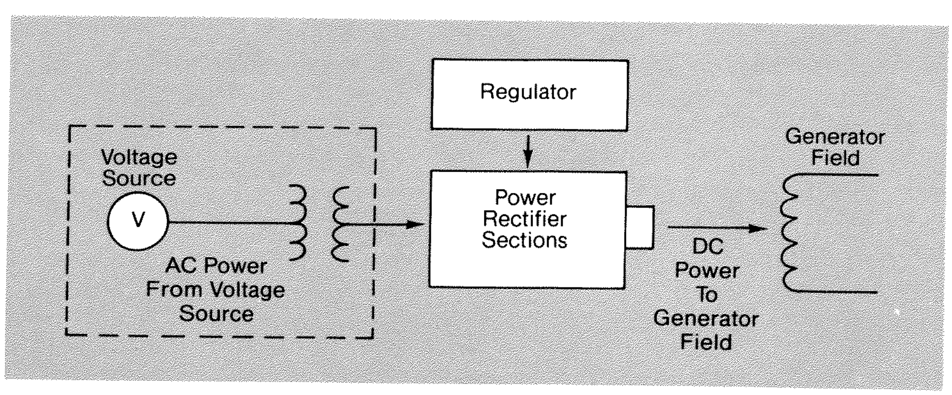


Figure 2—GENERREX-PPS excitation system with a 0.5 response ratio utilizes a potential power source, a three-phase water-cooled excitation winding.

a three-phase, full-wave rectifier assembly mounted alongside the generator, and containing silicon diodes and silicon controlled rectifiers (SCR's). Generator field-excitation is closely regulated by the voltage regulator through control of the trigger circuits to SCR's in the rectifier bridges.

All GENERREX excitation controls provide voltage regulation, appropriate control functions, and operator interface. The GENERREX system also includes several protective functions which either prevent undesirable generator operation, or provide proper detection logic, alarming, and tripping in the event of undesirable generator operation.

PERFORMANCE

Excitation system performance is fully tested when the network operation is disturbed by faults resulting in transmission outages pushing the network to its steady-state or transient stability limits.

Steady-State Stability

Steady-state power transfer is limited by voltage level and by the reactance that power must flow through. However, the maximum transfer from a generator through a transmission system is not limited to the manual control value. It can be larger if the generator is controlled by a properly adjusted, fast acting excitation system with adequate damping. Damping is provided by a power system stabilizer (PSS) tuned to the connected transmission system. The GENERREX system, with virtually no inherent delays, has been designed to obtain maximum stability margins.

Transient Stability

Electrical faults on the network and the power transients that follow them place unusual demands on the generator. Excessive line currents exist before circuit breakers can remove the faulted line section, as well as during periods of subsequent swings. These demagnetize the generator and depress terminal voltage. The GENERREX-CPS excitation system with high initial response acts quickly to restore system voltage, which maximizes the power transfer or synchronizing capability of the transmission system during this crucial period, as shown in Figure 3.

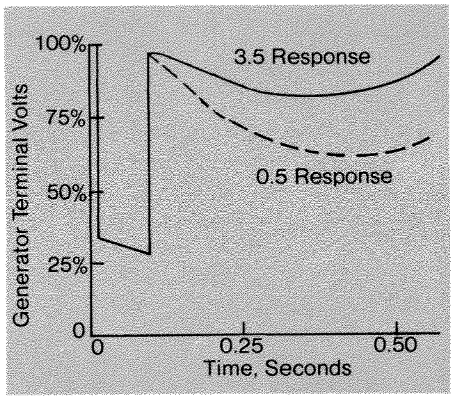


Figure 3—Generator voltage restoration following the clearing of a line fault is enhanced by a 3.5 response ratio of a GENERREX system.

As the response of an excitation system is properly controlled and increased by a PSS, it will provide greater stability margins or, as shown in Figure 4, it will maintain the same margins for transmission systems of lower capacity (higher impedance).

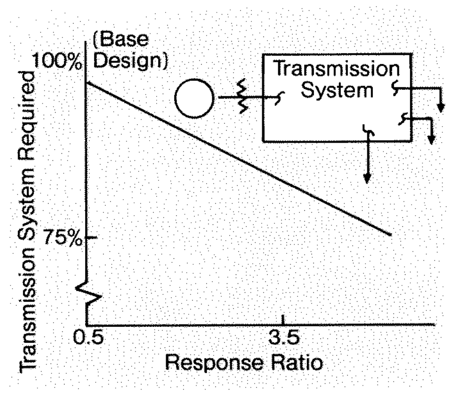


Figure 4—Transmission system requirements can be reduced by application of high response ratio excitation systems.

Response Ratio

Two excitation system characteristics important in evaluating effectiveness in maintaining transient stability are voltage response and ceiling voltage. A measurement of their combined effect is the response ratio which expresses the average rate (in per unit based on rated output volts per second) at which exciter voltage can be increased, starting from rated voltage, over the first one-half second.

Many excitation systems are designed for a minimum response ratio of 0.5 under no-load conditions. With the transmission limitations found frequently on today's networks, there is a need for higher performance systems. For that reason, the GENERREX system is designed for response ratios from 0.5 up to 3.5, and even higher if required. Performance is always specified with the generator operating at full load and under realistic system fault conditions.

High Initial Response

High initial response is defined as reaching 95% of exciter ceiling voltage in 0.1 seconds. This makes the achievement of response ratios above 2.0 practical under load conditions. Required ceiling voltage of the high initial response GENERREX-CPS system is much less than that required by other excitation systems with the same response ratio. Since the time duration when ceiling voltage may be safely applied is shorter with higher ceiling voltages, which must be limited to maintain adequate field insulation margins, there is a decided advantage in the high initial response GENERREX-CPS system.

A high initial response system provides an additional benefit during unit under-excited operation—at high, unity, or even leading power factor with field voltage and current well below rated even with the unit at full load. During a disturbance, a much larger increase in exciter voltage is required to get to ceiling. The high initial response exciter will appreciably outperform another system with the same response ratio but without high initial response, as shown in Figure 5.

FUTURE SYSTEM REQUIREMENTS

A generating unit purchased today will

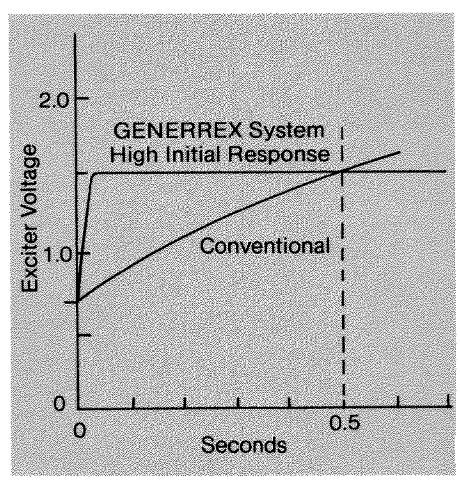


Figure 5—Excitation system performance from unity power factor shows benefits of a high initial response GENERREX system.

go into service in the late 1980s. By the year 2000, the unit will be only 10 to 15 years into its operating life. Its performance design should be appropriate to systems of the future as well as today. Future power systems are likely to have the following characteristics:

- More remote plants—environmental constraints may seriously limit the number of plants which can be built close to some large load areas, resulting in longer transmission lines.
- Increasing difficulties in obtaining transmission rights-of-way—rights-of-way will be crowded with high capacity EHV circuits. Loss of circuits during system disturbances can result in major reductions in power transfer capability.
- More costly line construction—could result in less system transmission reserve.
- More economy interchange as a result of fuel imbalances in cost and supply—may result in greater stability exposure between systems with energy being transferred over longer distances, particularly during light system loads.
- Reduced reserve margins—will result in more emergency interchange and increased stability problems.
- Higher machine reactances and lower inertias—will create a push for higher ratings from given amounts of material, which may result in increased stability problems.

These pressures are already causing increased problems in maintaining margins for both steady-state and transient stability. In recent years, there has been evidence of response from system designers:

- More series compensation of lines
- Widespread use of independent pole switching
- Almost universal use of load shedding
- System islanding schemes
- A revival in synchronous condenser usage
- Development of high-speed static VAR control
- Lower generator step-up transformer reactances
- Faster relaying, breaker, and backup clearing times.

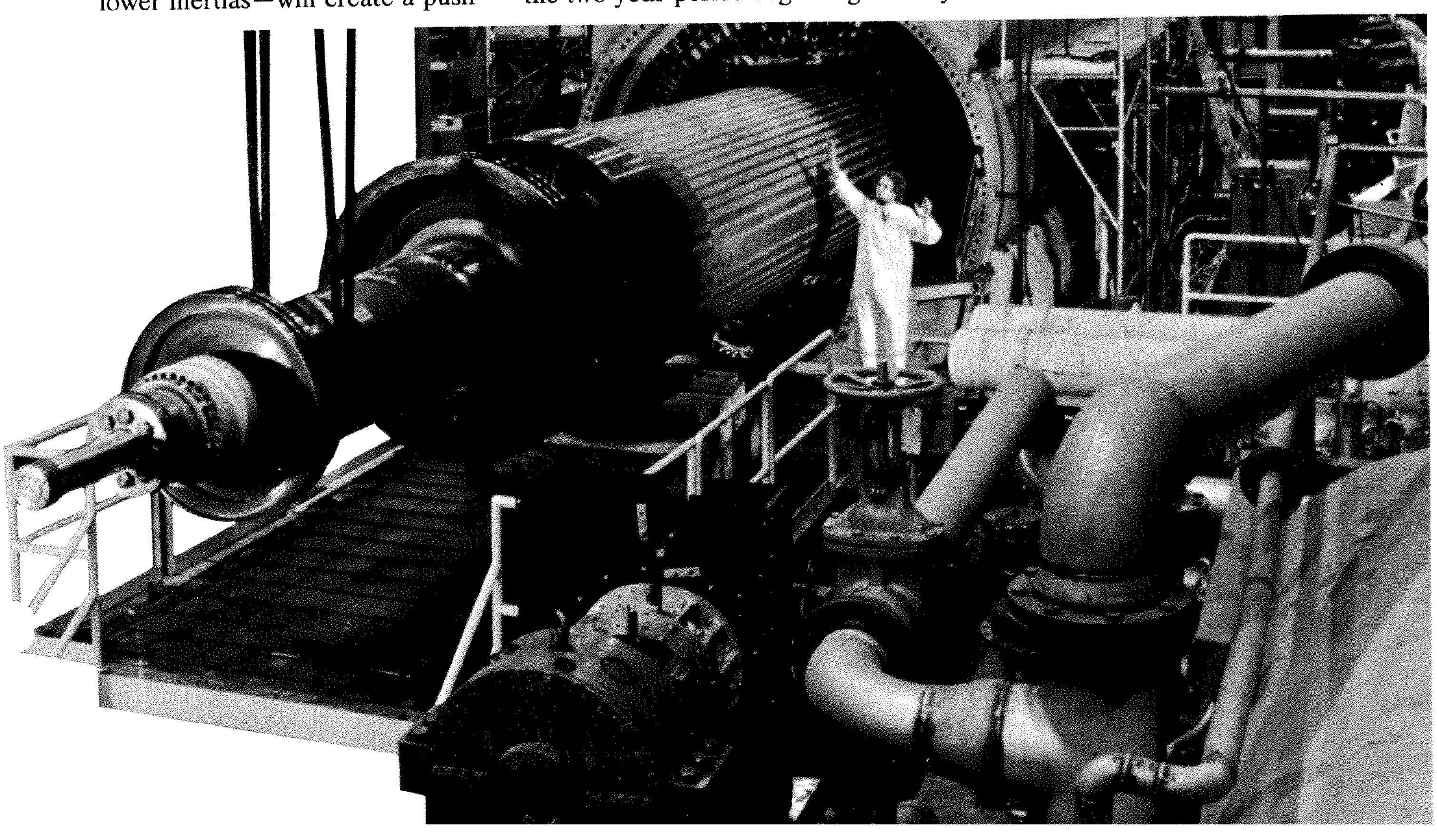
System designers are also expecting the turbine-generator to carry more of the burden of supporting system stability. Since it may be very difficult, if not impossible, to increase the response ratio of an excitation system already in service, many station designers are now specifying high performance systems at the time of purchase. For example, in the two-year period beginning January 1, 1966, less than 10% of the large steam turbine-generators built by the General Electric Company were specified for response ratios above 0.5. However, for units shipping during the two years beginning January 1, 1978, response ratios in excess of 0.5 are found on 22% of the machines.

This trend is expected to continue as a relatively low cost way of further increasing stability margins on machines which will be in the middle of their careers early in the next century.

SERVICE EXPERIENCE

Field Tests

During the fall and winter of 1975/76, a comprehensive test program was conducted at the Montana Power Company's Colstrip No. 1, 377 MVA generator and prototype GENERREX excitation system. This program included heat runs on the generator, and GENERREX system components over the full load range demonstrated conservative thermal design practices. Performance and stability tests included time and frequency response tests of the generator and excitation system and dynamic stability tests under both ac and dc regulator control. The excitation control system demonstrated high performance and stable operation during all of these tests; response was fast and stable for both small and large signal disturbances.

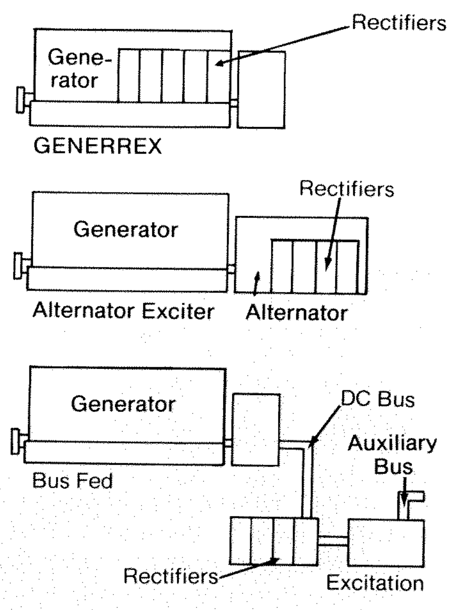


In addition, excellent correlation was obtained with calculations.

Operating Experience

Five GENERREX systems were in service at the start of 1980. A prototype system has been operating since 1975 on the Montana Power Company's Colstrip No. 1 generator. A second system was placed in service in 1976 on the duplicate Colstrip No. 2 unit. The third went into service in 1978 on the 402 MVA unit at Black Hills/Pacific Power and Light Company's Wyodak Station. The fourth and fifth systems went online in 1979 on the 496 MVA unit at Colorado-Ute Power Association's Craig Station, and the 457 MVA unit at the Coronado Station of the Salt River Project.

All five units were initially synchronized without major problems, and have performed in accordance with all design criteria. At this writing, there has been only one forced outage due to the GENERREX systems—a water leak at a rectifier hose fitting which was corrected promptly by replacement of an "O" ring.



Prior to development of the GENERREX system, there were two choices for excitation power sources: the alternator exciter —successor to the dc commutator exciter— mounted on a main shaft extension, or the bus fed excitation transformer. On large units the transformer is connected to the unit auxiliaries bus, thus affecting the required capability of the auxiliary system. Additional equipment includes an ac supply breaker and a high current dc bus.

The GENERREX system eliminates the physical drawbacks of these two systems; the shaft connected alternator of the first and the station arrangement complications of the second.

The first three units have undergone their first annual inspections which included removal of the generator fields and inspection of GENERREX excitation system components. On two of the units, evidence of vibration was observed on one of the potential circuit leads comprising the electrical connection from the generator stator into the dome area. Additional stiffening and support members were provided and vibration testing conducted to confirm that mechanical resonant frequencies had been shifted substantially above the frequency of electrical force stimulus. No other problems of any consequence were observed.

EXCITATION COMPONENTS

Excitation Power Source

Components of the exciter power source are located within the generator casing. The excitation transformer system is enclosed in a dome on top of the generator, and utilizes the generator hydrogen cooling circuits. The excitation potential winding located in the stator winding slots above the slot wedges uses the cooling water system of the generator stator winding. This is a low-voltage, low-current winding with one conductor bar per phase placed 120 mechanical degrees apart from the next on the generator circumference.

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 many years of accumulated experience. Temperature limits and insulation design conform to generator standards.

Power Rectifiers

The rectifiers consist of three-phase full-wave bridge assemblies containing both diodes and SCR's. Depending on the generator rating, several such bridges are contained in the exciter rectifier cubicle and connected in parallel. Each bridge is provided with a disconnect switch which permits electrical isolation for maintenance under load. The system is designed so full generator steady-state and transient current requirements can be met with one rectifier bridge removed from service.

Collector

The generator field collector and brushholder rigging assembly are located in a walk-in housing. Filtered air for the collector-ring ventilation is provided by a shaft-driven fan, and removable-type brush magazines allow easy maintenance. For two-pole units, a steady bearing is provided within the housing, at the end of the turbine-generator shaft.

Regulation and Control

The GENERREX excitation system control consists of two basic regulators. The dc regulator provides a means for dc field voltage regulation when the ac regulator is not in service. The ac regulator performs the basic duty of controlling generator terminal voltage. Static voltage regulators of advanced solid-state modular design incorporate maximum redundancy with provisions for on-line maintenance and trouble shooting.

Operator Interface

A unique and comprehensive three-

Benefits from Eliminating the Direct-Connected Exciter

- The shorter overall generator length produces savings in installation, building space, and foundation costs.
- Increased generator reliability can be expected since more than 50% of the downtime in a modern excitation system is chargeable to the rotating exciter.
- Improved generator accessibility should reduce the downtime of generator outages. For example, elimination of the rotating exciter can save three days in a maintenance cycle when generator rotor removal and reinstallation are involved.
- Reduction in the number of masses comprising the turbine-generator unit reduces the potential for subsynchronous shaft torsional resonance problems when series compensation is used in the transmission system.

part interface between the excitation system and station operators is introduced in these new systems. First, a compact, factory-wired excitation system control station, complete with a mimic bus, is provided for mounting in the station control room. This station gives the operator essential information regarding the excitation system's operating status. Second, a comprehensive alarm system is provided for proper annunciation of excitation system status. Third, printed circuit board test points and a meter panel are applied in both the exciter and control cubicles to facilitate monitoring of critical points in the circuitry.

De-excitation

Two methods of de-excitation are utilized to rapidly reduce generator current for permanent faults close to the generator, one static and one mechanical. The static de-excitation circuit reduces field voltage to zero by controlling the SCR trigger signal. The mechanical method uses a fast acting breaker in the main field circuit. Both static and mechanical de-excitation methods operate simultaneously.

Generator Protection

As previously discussed, the system includes several protection functions:

- The volts/hertz regulator prevents the ac regulator reference signal from rising above a level which would result in an undesirable generator volts/hertz condition during operation in ac regulator mode.
- An independently acting volts/hertz relay is provided as additional protection to guard against excessive volts/hertz operation.
- Maximum excitation limit circuitry provides two functions:
  - A field current limit protects the power rectifiers from excessive over-excitation.
  - A 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 generator excitation from being reduced to a level which would result in loss of synchronism or cause excessive end heating in the generator stator.

SUMMARY

An excitation system par excellence must respond rapidly to constantly changing demands which can upset a power system's transient and steady-state stability.

A very high level of performance is achieved in the GENERREX excitation system utilizing fully static power source, rectifiers, and control. In addition the GENERREX system improves turbine-generator reliability and maintainability while lowering overall station costs. □

Photo courtesy Colorado-Ute Electric Association, Inc.

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