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CONF 891009-1.3

LA-UR--89-3383

DE90 002391

10/10/89

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE DESIGN OF THE LOS ALAMOS GENERATOR INSTALLATION

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SUBMITTED TO presented to the IEEE 13th Symposium of Fusion Engineering,
Knoxville, TN, October 2-6, 1989

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FORM NO. 816-R
ST NO. 2070-1-1

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DESIGN OF THE LOS ALAMOS GENERATOR INSTALLATION†

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Abstract

A 1430 MVA synchronous generator from a cancelled nuclear power plant is being installed at Los Alamos to be used as the pulsed power generator for the Confinement Physics Research Facility. The generator is mounted on a spring foundation to avoid dynamic forces from being transmitted to the substructure and the ground. A 6 MW load-commutated inverter drive will accelerate the machine from standstill to the maximum operating speed of 1800 rpm and from 1260 rpm to 1800 rpm between load pulses. The generator cooling method is being changed from hydrogen to air cooling. A current limiting fuse, with a fuse clearing current of 80 kA, will protect the generator output against short circuit currents. Changes in the excitation system are described. A status report of the installation and an approximate schedule for completing the installation are presented. The paper also addresses results of special studies and tests undertaken to evaluate the condition of the generator and to predict the behavior of some critical mechanical generator components under pulsed loading conditions.

1. Introduction

In the summer of 1987 Los Alamos National Laboratory (LANL) acquired all components of a 1430 MVA steam turbine generator from the Tennessee Valley Authority (TVA). The components had been manufactured by the Brown Boveri Company, now ASEA Brown Boveri (ABB), in Baden, Switzerland, and shipped in 1981 and 1982 to the Hartsville, near Nashville, TN, plant site. The components were then stored in temporary buildings. The generator was designed to operate in a nuclear power plant as a steady state machine with 1430 MVA output power at 0.9 power factor. LANL intends to use the machine as a pulsed power source in the

Confinement Physics Research Facility, which initially will house a magnetically confined fusion experiment called ZTH. The generator must provide 200 to 250 MVA of peak pulsed power for the 1.7 MA plasma current. For a possible future upgrade of ZTH with the plasma current increased to 4 MA, the output is estimated to be between 1000 and 1200 MVA peak.

2. Generator Description

The total generator shaft train consists of a permanent magnet generator, a 315 mm slip ring bearing, the slip ring housing, the 630 mm non-drive end bearing, generator, 900 mm drive end bearing, intermediate shaft, 800 mm bearing, thrust bearing, turning gear with 400 mm bearing and the lube oil pump (Fig. 1). The total shaft train is 109' long and is mounted on a 112' x 40' inertia block. The main generator parameters are given in Table I.

TABLE I: Generator Parameters

Power rating	1430 MVA
Voltage	24 kV
Current	34.4 kA
Synchronous speed	1800 rpm
Lower speed limit	1260 rpm
Energy at 1800 rpm	1210 MJ
Extractable energy	800 MJ
Pulse repetition rate	10 min
Drive system rating	8000 hp
Stator weight	451 t
Rotor weight	234 t

† Work performed under the auspices of the US DOE.

Additional electrical parameters are summarized in Table II.

Fig. 1. Los Alamos generator installation

TABLE II: Electrical Parameters

Short circuit ratio	0.6
No load field current	2.8 kA
Rated field current	8.6 kA
Stator winding resistance	0.85 m Ω
Rotor winding resistance	74.4 m Ω
T'_{do}	7.5 s
T''_{do}	0.044 s
T'''_d	0.031 s
x_d	1.9
x'_d	0.435
x''_d	0.31

The friction losses at 1800 rpm are estimated to be 2.7 MW and the windage losses 1.9 MW. The total lube oil inventory is 34,000 gallons.

3. Generator Building and Equipment Layout

The generator building is 200' long and 60' wide and has two floors, the operating floor and the basement floor. Except for the generator shaft train, all other components, including the lube oil tanks, batteries, drive and excitation system converters, are in the basement. Electrical equipment is located close to the generator terminals. Personnel safety and ease of machine maintenance were the primary considerations in determining the equipment layout. A 32' x 12' control room will be installed in the northeast corner on the operating floor. Figure 2 shows a cross section of the building. A 25 t overhead crane will be installed in the building. The crane capacity was chosen so that a routine maintenance of the generator could be performed. The heaviest piece to be lifted by the crane for removing the rotor is the 23 t bottom half of the 630 mm bearing pedestal. The building is long enough to house the rotor when it is removed from the stator. The building is being erected and should be completed in October, 1989.

Fig. 2. Cross section of the generator building.

A small switchyard is located on the east side of the generator building. It includes the station service, the drive and excitation transformers and 13.4 kV switchgear. The incoming power to the switchyard is provided by three 1,000 mcm, 13.4 kV cables.

4. Foundation

The generator is being installed at Los Alamos on a mesa which also houses several nearby laser experiments. A concern that the pulsed generator load would result in soil vibrations and ultimately would have a negative effect on laser alignment was expressed. To minimize the problem, the generator uses a spring mounted foundation. Sixty springs, thirty on each side, resting on the 4' thick base concrete block, are installed under the inertia block. Figure 3 shows a cross section of the 22" high spring assembly. The lower part of the spring assembly consists of four leg supports, which allow an adjustment in height. Four Belleville-type spring washers in a spring box provide the spring action. The inertia block (4,800 t) and the generator (1,200 t) have been raised 1.5" by hydraulic jacks in combination with the spring support adjustments and the springs adjusted to assure leveling of the inertia block.

Fig. 3. Spring assembly.

5. Feasibility Study

Before a contract was signed with TVA, LANL hired the generator manufacturer to evaluate whether the given machine could electrically and mechanically operate reliably under repetitive pulsed loading conditions for a given 4 MA pulsed load profile. The investigations showed that electrically the machine was more than adequate. No excessive temperatures would occur in the windings, and the excitation system rating and machine impedances would provide the expected load pulse. The two most critical areas of the rotor, the teeth and the retaining rings, could be expected not to show low cycle fatigue material cracking due to the cyclic loading caused by 30% speed variations. With a 2800 MJ flywheel added, the shaft of the machine could show low cycle fatigue cracking caused by torsional shaft oscillations, provided the shaft train would be subject to large and almost instantaneous real power changes (1200 to 1200 MW). The feasibility study also pointed out that further mechanical stress studies were necessary to evaluate whether the number of start/stop cycles should be limited. This would require the machine to be kept at 1260 rpm at night and allow shut downs only over weekends. In a follow up cyclic stress study the rotor retaining rings, end windings, main fans, slip ring fans, and rotor body were investigated to determine if those elements would slip during deceleration during the pulse and if relevant fixing elements could become overloaded. The calculations showed that the machine can

be safely operated for at least 100,000 speed changes from 1800 to 1260 rpm and for at least 1700 start/stop cycles and that the safety against slipping is high. However, the generator manufacturer recommended inspection of the machine at different time intervals, initially more often and later less frequently.

6. Testing

After LANL acquired the generator and before the stator and rotor were shipped to Los Alamos, LANL had the generator manufacturer test the rotor and stator to evaluate the integrity of the machine after several years in storage. After a visual inspection for obvious damage, several electrical tests were performed in May, 1987. These tests included dielectric tests and an ac high pot test for the stator at 42 kV rms for 1 minute. The stator winding insulation withstood the test. Test results were compared with those taken during factory acceptance testing and no degradation of the insulation was detected. In September, 1989, with the stator on the foundation in Los Alamos and the rotor installed in the stator, the tests were repeated. The ac high pot test was planned to be run at slightly reduced voltage (39 kV rms). However, because of insufficient power for the test equipment, an equivalent dc high pot test at 66 kV dc, as recommended by the ANSI standard, was performed. Two stator phases passed the test, while the third phase failed after 56 seconds of applied voltage. The failure location was quickly detected in the end winding section of the drive end side at the phase separation and was repaired. The failed phase was tested again and passed the high pot test at 63 kV dc for 1 minute. Megger readings before and after the high pot test showed the same results, thus it can be assumed that the winding was repaired properly. The rotor was megger tested in 1987 at Hartsville and in 1989 at Los Alamos and showed high insulation resistance.

Besides the electrical tests, mechanical tests were performed on the retaining rings. The high strength non-magnetic retaining rings were removed from the rotor in August, 1989, before the rotor was installed into the stator, and inspected. These rings are made of 18Mn5Cr steel and are subject to corrosion pitting and stress corrosion cracking caused mainly by moisture. The inspection consisted of a visual and fluorescent dye penetrant examination of all surfaces. Both rings tested well and showed very little corrosion pitting. If the rings had failed the test, purchase of new rings made of non stress corrosion susceptible 18Mn18Cr steel would have become necessary.

7. Hydrogen to Air Modification

The machine was originally designed to operate under 75 psi hydrogen pressure. Because of the low thermal loading of the machine during pulsed loads, simplicity in operation with air cooling and avoiding a tedious licensing procedure, LANL asked the generator manufacturer to investigate the possibility of running the machine in air. The manufacturer's investigation into this question revealed that the machine can be operated with air cooling, provided the machine is energized to 24 kV only during the pulse and certain modifications are made. Heaters and an air dryer are being installed in the machine which heat and dry the air when the cold temperature is below 77° F and the machine runs below 50 rpm. Shaft seals, using pressurized air out of the diffusers of the main fans, are installed on both sides of the stator casing in order to provide controlled air flow through the specially installed air filters. The air modification has increased the windage losses by 300 kW at 1800 rpm compared to the 75 psi hydrogen operation.

8. Intermediate Shaft

Provision is made in the foundation to install a 2800 MJ flywheel in the future. The space in the shaft train for the flywheel is now bridged by an intermediate shaft. The bearings which will support the flywheel are the original 900 mm generator and 800 mm low pressure turbine bearings. LANL purchased from TVA the shaft ends of the original low pressure turbine, had the ends cut off the turbine and welded together to form a 32 t, 5600 mm long intermediate shaft.

9. Excitation System

The static excitation system consists of the original three-phase, 10 MVA, 24 kV/0.792 kV, wye-delta, oil filled transformer, feeding four parallel connected six-pulse thyristor bridges. Each bridge has a no load voltage of 1050 V and a rated current of 3800 A. The thyristors are water cooled. Originally, the excitation transformer was designed to be connected to the 24 kV generator terminals. For pulsed operation it is desirable to take the excitation power from the utility system and therefore the excitation transformer was connected to the 13.4 kV utility system. The circuit of the transformer secondary winding was changed to a wye connection, resulting in approximately the same exciter no load voltage as designed originally. The exciter provides a field current of about 600 A during the drive mode operation of the machine and 2800 A for 24 kV no load voltage. During the pulse the field current can be raised up to 5000 A by the voltage regulator without exceeding the transformer rating. Because of the low exciter losses during no load mode operation compared to the 8600 A for steady state operation, the cooling water is only being circulated through the rectifiers without the use of the external heat exchanger.

10. Drive System

An 8000 hp, solid-state, load-commutated inverter (LCI) drive has been purchased, which will accelerate the machine as a motor. The drive system consists of a 7.1 MVA, oil filled, six-phase converter transformer, a twelve pulse rectifier, a 4 mH dc link reactor and a six-pulse inverter. The rectifier and inverter are ethylene glycol cooled. The maximum output voltage of the inverter is 4 kV. Because the low generator impedance would have caused excessive fault currents in the inverter, a three phase 0.4 mH current limiting reactor was installed between the generator terminals and the inverter. Figure 4 shows the circuit of the LCI drive. The LCI drive was sized to accelerate the rotor from 1260 rpm to 1800 rpm in 9 minutes. To accelerate the machine from the 8.8 rpm turning gear speed to 1800 rpm will take about 25 minutes. The drive can be operated down to speeds of 180 rpm in the regenerative braking mode.

11. Current Limiting Fuse

The generator will be protected against short circuit currents by a current limiting fuse (CLF). LANL has contacted current limiting fuse manufacturers and identified several companies with sufficient expertise to build a fuse for our application. The fuse will trip currents in excess of 40 kA. The peak let through current is expected to be 80 kA, which is about one fourth of the peak short circuit current. The advantage of a CLF over a conventional circuit breaker is that the generator output bus can be designed electrically and mechanically for the lower current. Line reactors to limit the short circuit current can be eliminated, thus providing a stiffer power source.

12. Installation Status and Schedule

A contract for installing the generator was placed with the generator manufacturer and the installation of the generator began in April, 1989. The foundation was prepared for the stator, rotor and bearings to be installed. The sole plates were glued with epoxy onto the concrete, the base plates and anchors set, and the bearing pedestals, thrust bearing, turning gear and shaft driven oil pump

Fig. 4. Drive system circuit.

installed.

The rotor and stator were transported to the site in June 1989 and placed onto the foundation [1]. A modification in the stator end windings to achieve additional mechanical strength was done in July and August and the rotor retaining rings were tested. The placing of all auxiliary equipment, such as the drive and excitation system took place in July. The lube oil piping installation started in August and should be completed by the end of October.

Insertion of the rotor into the stator was a rather time consuming process, since no 250 t overhead crane is available in the generator building. LANL had designed and contracted for building a simple 250 t bridge crane, which can be erected at both the drive and the non-drive end of the generator. This crane has a 10" vertical lift capability, provided by four stationary jacks, and can travel axially 15'. No lateral movement is possible. The rotor was inserted using this gantry crane and two trolleys equipped with hydraulics for movement in an axial direction and running on rails placed on the non-drive end side of the generator. Also a slide block, attached to the drive end side of the rotor, and a sliding plate, placed in the shaft bore, were used.

The bridge crane was first placed on the non-drive end side of the generator, where the rotor was located on the two trolleys to be inserted. First the bridge crane lifted the rotor, the trolley nearest to the stator was removed, the other one placed under the slip ring coupling, and the rotor moved into the stator bore until the slide block could be set on the sliding plate. Then by using the hydraulics on the trolley the rotor was pushed through the stator bore until the slide block nearly reached the drive end of the stator core and the neck of the drive end coupling of the rotor was accessible to the bridge crane. The bridge crane was then moved to the drive end side of the generator. Now by using the bridge crane and the hydraulics of the trolley, the rotor was moved further until the coupling flange could be set on the auxiliary bearing pad within the drive end bearing

pedestal.

Finally the bridge crane had to be moved back to the non-drive end side of the generator to remove the remaining trolley and to set the non-drive end of the rotor on a provisional support mounted to the lower half of the end cover. Insertion of the rotor took place in September, 1989.

The schedule calls for final alignment of the machine, installation of the jacking oil pumps, temporary oil supply to the jacking oil pumps and the auxiliary turning gear ready for operation by the end of October, 1989.

Work has started on the electrical power wiring of all components, from the substation to the electrical loads, such as excitation system, drive system, motor control center, motors, etc. The control, instrumentation, and protection (CIP) system is being designed and hardware purchased. The generator manufacturer is to provide the design and the hardware for the electrical protection of the generator and the CIP design and sensor hardware for the generator lube oil system, auxiliary and regular turning gear, air cooling system and the shaft train. Los Alamos will provide the hardware for these portions of the CIP system, implement the logic and the CIP design and hardware for the drive system, water cooling and battery system. While the electrical power wiring will be provided by the installation contractor, LANL personnel will install the CIP wiring. Commissioning of the generator is expected to take place by early summer 1990.

13. Summary

A 1430 MVA synchronous generator is being installed at Los Alamos to be used as the pulsed power generator for the Confinement Physics Research Facility. Studies have shown that the machine can be operated under pulsed loading conditions. Electrical and mechanical tests have proven that the machine is in good condition after years in storage. All major components of the generator shaft train and of the auxiliary systems have been installed. Commissioning of the generator is scheduled for the early summer of 1990.

14. References

1. H. J. Boenig, J. D. Rogers, G. R. McLelland, C. T. Pelts, "Transportation of a 451 ton Generator Stator and a 234 ton Generator From Hartsville, TN, to Los Alamos, NM," presented at the 13th IEEE Symposium on Fusion Engineering, Knoxville, TN, October 1989.