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THE STABILIZATION UNIT FOR BONNEVILLE POWER ADMINISTRATION

by

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ABSTRACT

[illegible] Power Administration [illegible] the transmission system that joins the Pacific Northwest and southern California. A 30-MJ (8.4 mWh) Superconducting Magnet Energy Storage (SMES) unit with a [illegible]-MW converter can provide system damping for the frequency oscillations [illegible] scheduled to operate [illegible] 1981. Progress [illegible] the design [illegible] the [illegible] first type [illegible] and the design [illegible] and [illegible] the [illegible]

[illegible]

[illegible] Pacific Northwest and [illegible] part of the western Power System [illegible] Bonneville Power Administration (BPA) [illegible] the Pacific AC Intertie, [illegible] the Pacific HVDC Intertie. [illegible] have a thermal rating of 3100 MW, and the [illegible] the HVDC has a rating of 1440 MW.

The stability of the western Power System is affected by relative movement of the two projects by the 9.5-km-long Pacific AC Intertie. In fact, studies made before energization of the Pacific AC Intertie showed that negatively damped oscillations with a frequency of about 30 cpm were likely to occur. In 1974 negatively damped oscillations with a frequency of 27 cpm (0.45 Hz) were observed. The peak-peak oscillation on the Pacific AC Intertie was about 300 MW. Subsequent to these instabilities, the Bonneville Power Administration (BPA) installed equipment to modulate the power flow on the HVDC Intertie as a means of damping the oscillations. The maximum possible power modulation on the HVDC Intertie is 40 MW, about 3 percent of the HVDC power rating. The modulation of the HVDC Intertie has increased the stability limit of the Pacific AC Intertie from about 2100 MW to 2500 MW whenever the HVDC Intertie is operating. However, the HVDC Intertie does not operate continuously. The line availability is 89.5%, and the southern terminal was down for six months as a result of earthquake [illegible] representatives of BPA and the Los Alamos Scientific Laboratory [illegible] the feasibility of installing a [illegible] MJ [illegible] for the purpose of [illegible] system [illegible] similar to that now available through modulation of the Pacific HVDC Intertie. The design parameters of the unit to be installed at the Fitz Substation near Tacoma are summarized in Table [illegible]

Several technical descriptions of the project have appeared previously, [illegible] results for details. This report will concentrate primarily on the work done in [illegible] and on the current status of hardware procurement.

TABLE 1. Design Parameters of a 30-MJ System Stabilizing SMES Unit

Maximum power capability, MW	[illegible]
Operating frequency, Hz	[illegible]
Energy interchange, MJ	[illegible]
Maximum stored energy, MJ	[illegible]
Coil current at full charge, kA	[illegible]
Maximum coil terminal voltage, kV	[illegible]
Coil operating temperature, K	[illegible]
Coil lifetime, cycles	[illegible]
Heat load at 4.5 K, W	[illegible]
Coil diameter, m	[illegible]

Figure 1 is a schematic that shows the main components of a SMES system. The coil will be [illegible] figure-eight at 4.5 K and will have an open wound construction very similar to that employed in bubble chamber magnets. The unusual features of the coil are the very low heat generation allowed, despite the unusually short cycle time, and the very large number of operating cycles expected over its life. The conductor originally proposed for this application was a modification of the conductor used by Westinghouse* in a pulsed superconducting coil constructed for the Controlled Thermonuclear Reactor development program at LASL. The coil designer, General Atomic, has recently proposed a pancake coil design, which has necessitated a further conductor modification.

Most of the other components of the unit are well within the state of the art. The converter, a transistorized version of the [illegible] used on high-voltage direct-current transmission lines, is under construction. The control system for regulating the power flow between the ac system and the SMES system has been developed and demonstrated in the laboratory. The refrigerator is a standard unit. The power, similar to one that has operated successfully for a period of several years, must be made of a nonmagnetic material [illegible] heat [illegible]

[illegible]

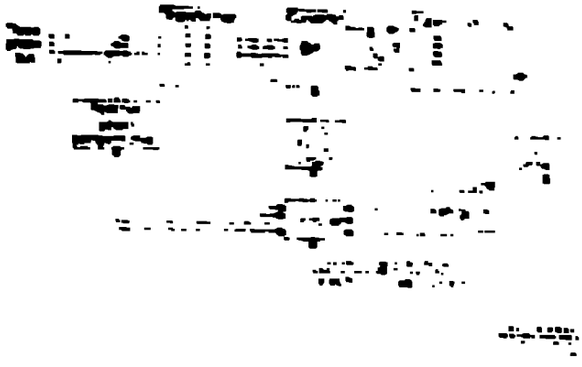

Fig. 1 Components of a superconducting magnetic energy storage system

SITE SELECTION

The SMES unit will be located at the Fife Substation of the BPA transmission system, which is situated in an industrial area several miles east of Tacoma, WA. The coil will be located in a flat area, 300 ft x 300 ft, in the center of the substation. The site should avoid complaints about noise, esthetics, or magnetic field effects. A liquid-nitrogen supplier is located within a few miles. The site has limited water, so that a closed-loop system must be used to supply cooling water for the refrigerator components.

The only problem with the substation is that it is manned only 8 hours per day. This has led to an anticipated requirement for automated control of the entire system, which will [illegible] the hardware cost of the system. There are sites available at stations which are manned around the clock. Any SMES system which operates commercially will certainly need a high degree of automation, however, and there is no reason not to solve the problem at this time.

CONDUCTOR DEVELOPMENT

The cable design for the SMES coil, as shown in Fig. 2, has been modified somewhat from that described in previous presentations [illegible] results of the ongoing program of a [illegible] tests, mechanical tests, and [illegible] the designer, General Atomic. General [illegible] The [illegible] components [illegible] stiffness [illegible] through a disk. In the [illegible] stiffness [illegible] stiffeners present, appears necessary, [illegible] performance and a saving of [illegible] costs. Insulation must be added to the [illegible] substable, as shown, to limit ac losses. For the pancake design proposed by GA, the stiffener strip in longer forms an integral element of the coil. The [illegible] strip of kapton or Mylar® that serves to prevent fretting of the interior cable surfaces. It is expected that the modified conductor will be far easier to wind than the original conductor.

Most of the development work which has gone into the original conductor concept is directly applicable to the modified conductor. Samples of original conductor are undergoing the entire series of qualification tests so that the original concept will be available for use if necessary.

*Westinghouse trademark

Fig. 2. Low-loss cryostable cable for 30-MJ coils

ELECTRICAL TESTING PROGRAM

Stability tests on a mock-up conductor array using second subcable with Kapton insulated first subcable show that the original conductor concept is stable at 800 A and 9 T. Tests will be done in samples of [illegible] cable as they become available, although it is expected that the modified cable will be stable at an even higher current than the original conductor.

A test of electrical resistivity at 20 K is used as a quality control procedure during cable fabrication. It has been found that the first subcable must be annealed at 600°F for 2 hours to recover the original low electrical resistivity of the stabilizing copper. This procedure does not affect the superconductor. Forming the second subcable and final conductor results in only a further 10% increase in the resistivity.

Ac losses have been measured as a function of frequency and cable geometry to define the separate contributions due to superconductor hysteresis, coupling currents, and copper eddy currents. With soldered first subcable the losses are approximately equal to those calculated in the original 30-MJ system proposal. With nonsoldered cable, the contact resistance between the copper wires is sufficient to reduce the coupling and eddy current losses by a factor of ten, with no detectable effect on conductor stability. Further, the contact resistance between first subcables is large enough that they need not be insulated before the second subcables are formed. Leaving the first subcables bare reduces cost, increases stability, and solves a number of problems related to current sharing between insulated strands in a cable. The present design calls for each of the 10 second subcables to have a separate power lead from the liquid helium bath to a common, room-temperature, bussbar. The lead resistance forces each second subcable to carry the same current, while the uninsulated first subcables within each second subcable automatically share the current. It is

TABLE 2. Conductor Specifications for 30-MJ Coil

A.	Superconductor Composite Core	
	Area of NbTi, mm²	4.85 × 1.7²
	Filament diameter, cm	6.5
	Number of filaments	1464
	Strand diameter, mm	0.511
	Cu to NbTi ratio	2.94:1
	Twist pitch, mm	5.[illegible]
B.	First Subcable (Six copper wires cabled about one core)	
	Uncompacted diameter, mm	1.39
	Overall Cu to NbTi ratio	26.7:1
C.	Second Subcable (Insulated)	
	Six first subcables around a copper core	
	Diameter, mm	4.59
D.	Finished Conductor	
	Ten second subcables around a Kapton strip	
	Strip dimension, mm	18 × 2.25
	Conductor dimension, mm	23 × 9.[illegible]

possible to use short lengths of superconductor cold-welded together, and even a complete break in the superconductor can be tolerated.

Acceptance tests have been performed on 64 samples of superconducting composite core wire, drawn from 90% of the wire order. All samples met the specified current carrying performance of 110 A at 4.2 K, 3 T and 1×10^{-12} Ω-cm. The average performance was 20% higher.

MECHANICAL TESTING PROGRAM

The behavior of the conductor for transverse compression is nonlinear. The apparent modulus of elasticity in the expected 30-MJ load range is 10 000 to 20 000 psi. This low modulus is apparently caused by the conductor taking the load by elastic bending of the numerous short arches in the wires and subcables that remain in the cable after fabrication. Mechanical hysteresis, if any, will be within design limits. The low modulus causes no unusual problems in coil design, although it does produce larger absolute values of conductor displacement than previously anticipated.

Magnetomechanical forces will cause individual first subcables to deflect radially outward in the space between the support teeth. For the worst case of unsoldered, fully-annealed first subcables, there may be some plastic deformation in the highest field region, with a small but negligible effect on the electrical resistivity. [illegible] loading will be in the elastic region [illegible].

Three types of fatigue tests are being [illegible] in the [illegible] of the National Bureau of Standards (NBS), Boulder, has recently completed work on his contract to measure how [illegible] affect the electrical resistivity of the copper stabilizer in the BPA conductor. He used samples of soldered and unsoldered first subcable with various initial resistivity ratios representing differing degrees of hardness. A cyclic strain amplitude of 0.25%, which is several times the design amplitude in the 30-MJ coil, is necessary to see any effect. At 10^5 cycles the resistivity change is less than 5% in all cases, including a dead-soft, unsoldered cable. A plot of [illegible] verses log N is linear, permitting extrapolation to higher N.

Also at NBS, mockup coil sections at 4 K are subjected to compressive cyclic loads in excess of those predicted for the 30-MJ operation, for up to 10^6 cycles. So far, a section of the original conductor-coil configuration has withstood 10^6 cycles between 1000 and 1500 psi with no degradation of the interstrand insulation or of the fiber-glass/epoxy structure. A similar test is underway at the University of Wisconsin, using a slightly different sample configuration. This test will accumulate 10^7 cycles at 77 K.

COIL DESIGN AND CONSTRUCTION

Four responses were received to the RFQ for design and construction of the 30-MJ superconducting coil, which would include procurement of the conductor. Phase I of the contract has been awarded to General Atomic Company of San Diego, CA. The result of Phase I will be an engineering design, including working drawings, material specifications, and quality control plans. Phase II can also be awarded to GA at the option of LASL.

DEWAR

A preliminary inquiry to locate manufacturers who are interested in fabricating the large fiber-reinforced-plastic dewar elicited five positive responses. Conceptual drawings have been prepared for two different design options. In the first, the dewar is simply a large cylindrical tank with dished ends, designed according to the ASME code for pressure-vacuum vessels. To save helium, a second, evacuated, chamber would be placed inside the bore of the coil. In the second option, the dewar is toroidal, with a roughly rectangular cross section and a flat lid. In both cases, there must be liquid nitrogen cooled shields in the vacuum spaces and in the helium gas space above the coil and superinsulation in the vacuum spaces. The superinsulation must be arranged not to form a conductor ring encircling the coil. At least one vendor has successfully fabricated the second type of dewar, 10 feet in diameter and 3 feet deep. Currently, the two sets of drawings are being circulated among the vendors for comments, following which modifications and more specific designs will be made and a formal RFQ will be issued.

ELECTRICAL SYSTEM

A schematic of the electrical system is shown in Fig. 3. The SMES magnet [illegible] a 13.[illegible] kV three-phase line [illegible]

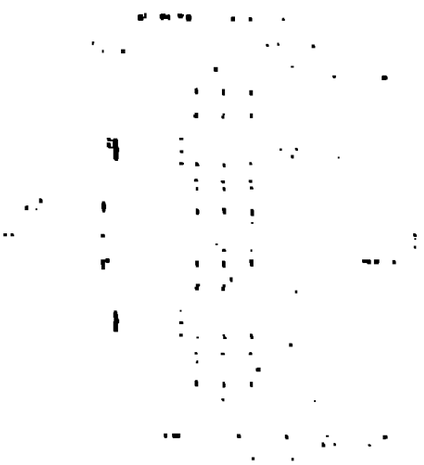

Fig. 3. Electrical system for SMES [illegible] system stabilizer

transformer and a solid-state converter. The 2.6 kV, 5.0 kA converter consists of two 6-pulse Graetz bridges, which are connected in series. The current in each leg of each bridge is carried by 8 parallel connected 3200 V, 800 A Westinghouse thyristors. A contract for the converter was let to Robicon Corp., Pittsburgh, PA, and was subsequently extended for modifications to include integrating the energy dump circuit. The final design review has been held, detailed drawings approved and, fabrication begun. Scheduled delivery date is November 30, 1979. The 108 SCR's for the converter were purchased at the end of FY 78 from Westinghouse Electric Corp. An additional order has been placed for 48 SCR's for the energy dump circuit and for spares.

Considerable effort on the part of the LASL staff went into the design of the energy dump circuits. By placing an ac breaker in series with the converter, rather than in parallel, it is possible to discharge the coil at a higher voltage and therefore in a shorter time. The entire electrical system is arranged so the 30-MJ coil can be protected under any conceivable failure mode. The 5-kA dc vacuum interrupter is formed by a parallel combination of the three contacts of a commercially available three-phase ac vacuum breaker and a converter pulse circuit. The remaining components of the energy-dump circuit are presently being fabricated by various vendors.

Bids have been received and are being evaluated for the 5-MVA converter transformer. It is expected that the contract will be let very shortly, with delivery scheduled for the end of FY 80.

The four firing circuits shown in Fig. 3 are built into the converter. The control circuitry, which forms the logic interface with the BPA network, will be designed and built by LASL. Experiments with a prototype circuit have been [illegible] successfully.

Present plans call for all the electrical system components to be delivered to Los Alamos except for the transformer, which will be delivered to Tacoma, WA. Power at Los Alamos will be supplied by an existing 3.25-MVA rectiformer. The control circuit will be integrated into the system and the computer controlled operation will be tested.

CRYOGENIC SYSTEM

Figure 4 shows a block diagram of the cryogenic system, with the components arranged for the Tacoma site. All the components are mounted on trailers, so that the entire system is portable. In particular, the system will be assembled at Los Alamos in mid FY 80, which will permit an extensive testing of the automatic operation and which should limit the amount of plumbing that needs to be done at Tacoma.

The refrigerator is a CTI Cryogenics model 2800 with Sulzer gas bearing turbines, three variable flow compressors, and liquid nitrogen precooling. The refrigerator will produce 75 ℓ/hr of liquid helium or 320 W of refrigeration at 4.2 K, or any linear combination of the two. The refrigerator has been tested and meets the conservatively estimated BPA load of 15 ℓ/hr and 150 W with two compressors running.

The refrigerator trailer, fabricated by Aluminum Body Corp., Los Angeles, CA, has been shipped to CTI and installation is proceeding. Still outstanding is an RFQ for refrigerator modifications to allow long-term unattended operation and automatic remote control.

The liquid nitrogen trailer was obtained as excess equipment and will be reconditioned at Los Alamos.

A minimum inventory of 108 000 SCFM of helium is required to operate the system. It is assumed that there will be intervals during which the refrigeration plant will not be running when the gas will be recovered and stored. The gas recovery subsystem consists of any one of the refrigerator compressors, three Corblin 2500 psi compressors, a 100 W heater in the coil dewar, and a high pressure tube trailer. One Corblin will handle the gas flow resulting from the normal heat load on the dewar, which evaporates the liquid helium in 86 hours. The heater and additional Corblin compressors permit the dewar to be emptied in one day, if desired.

The Corblin compressors were obtained from excess property and are currently being serviced. A suitable trailer to contain them exists at Los Alamos. Bids were received for the tube trailer but acceptance has been deferred to allow for a search of excess property lists for this item. If all the compressors run simultaneously, they require 60 gpm of cooling water, which is too much for once-through cooling. An evaporative cooling tower has been located at Los Alamos which appears suitable for this application. A flat-bed trailer to hold the cooling tower has also been located as excess property.

CONCLUSION

The 30-MJ SMES transmission line stabilization project is proceeding with the critical items on schedule. Verification testing has been performed on one version of the original conductor. Much of this testing also applies to a modified conductor that promises to perform even better and which will be easier to fabricate. The refrigerator and converter systems will be completed early in FY 80 and tested at LASL.

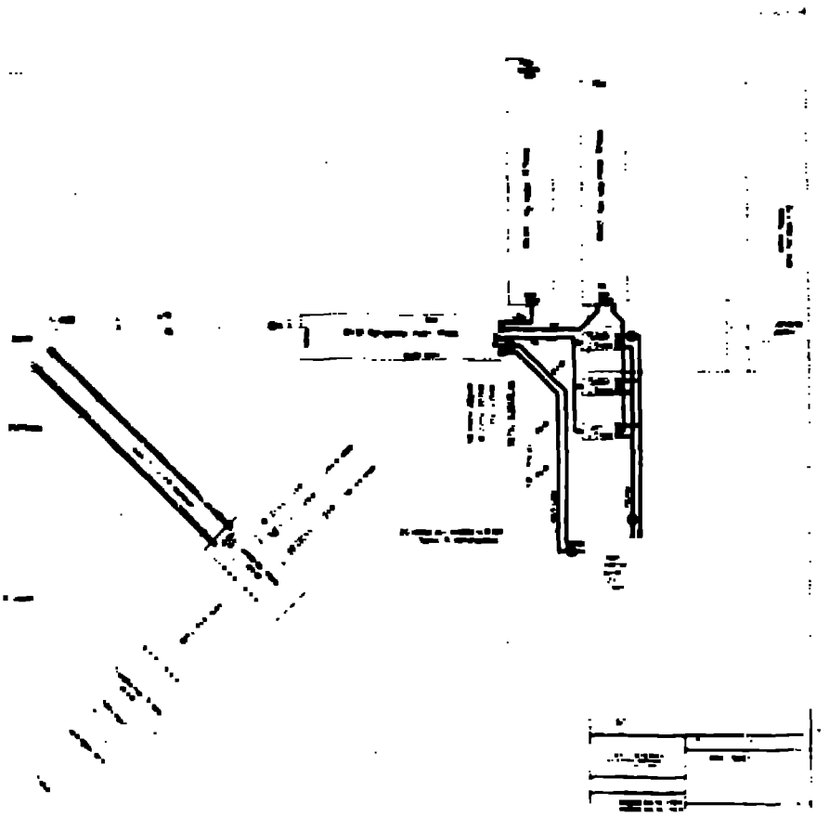

Fig. 4. Layout of SMES at Fite Substation, Tacoma, WA.

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